

Pollution Prevention in Metal Painting and Coating Operations:

A Manual for Technical Assistance Providers

NEWMOA

THE NORTHEAST WASTE MANAGEMENT OPERATORS ASSOCIATION



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A Manual for
Pollution Prevention
Technical Assistance Providers

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Alexander Ross, RadTech
Mike Simek, Rutgers
Rodger Talbert, Chemical Coaters Association International
David Liebl, Solid and Hazardous Waste Education Center
Kathy Blake, New Hampshire Department of Environmental Services

Project Staff/Contributors

Terri Goldberg, NEWMOA P2 Program Manager—Editor/Manager
Lisa Regenstein, NEWMOA P2 Project Manager—Research/Writer
Jennifer Shearman, NEWMOA Technical Staff—Research/Writer
Beth Anderson, EPA—EPA Project Manager
Laurie Case, WMRC—Layout and Desktop Publishing

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Northeast Waste Management Officials' Association

The Northeast Waste Management Officials' Association (NEWMOA) is a non-profit, nonpartisan, interstate governmental association. The membership is composed of state environmental agency directors of the hazardous waste, solid waste, waste site cleanup and pollution prevention programs in Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.

NEWMOA's mission is to help states articulate, promote, and implement economically sound regional programs for the enhancement of environmental protection. The group fulfills this mission by providing a variety of support services that facilitate communication and cooperation among member states and between the states and EPA, and promote the efficient sharing of state and federal program resources.

NEWMOA was established by the governors of the New England states as an official interstate regional organization, in accordance with Section 1005 of the Resource Conservation and Recovery Act (RCRA). The organization was formally recognized by the U.S. Environmental Protection Agency (EPA) in 1986. It is funded by state membership dues and EPA grants.

NEWMOA established the Northeast States Pollution Prevention Roundtable (NE P2 Roundtable) in 1989 to enhance the capabilities of member state environmental officials to implement effective source reduction programs. The NE P2 Roundtable's program involves the following components: (1) managing a regional roundtable of state pollution prevention programs; (2) publishing a newsletter; (3) managing a resource center of books, reports, case studies, fact sheets, notices of upcoming meetings and conferences, and a list of P2 experts; (4) organizing training; and (5) conducting research and publishing reports and other documents. The resource center provides pollution prevention information to state and local government officials, the public, industry, and others. Funding for the NE P2 Roundtable is provided by the NEWMOA member states and the U.S. EPA. For more information contact: Terri Goldberg, NEWMOA, 129 Portland Street, 6th floor, Boston, MA 02114, (617) 367-8558 x302 (Phone); (617) 367-0449 (Fax); newmoa@aol.com (e-mail).

About This Manual

The Northeast Waste Management Officials' Association (NEWMOA) designed this manual to provide environmental assistance staff with a basic reference on the metal coatings process. The purpose of the manual is to enable assistance providers to rely on a single publication to jump start their research on pollution prevention for companies with which they are working. The manual is explicitly designed to be useful to assistance professionals with experience working with metal coating operations and those who have never before encountered this process. The U.S. Environmental Protection Agency Pollution Prevention Division funded this manual as a model of a comprehensive packet of pollution prevention (P2) information on a single industry.

The Northeast Waste Management Officials' Association designed this manual to provide information on P2 methods for paints and coatings processes. Specifically, the manual focuses on P2 methods for reducing volatile organic compounds (VOCs) emitted during the coating of metal substrates. This manual stresses the use of low-VOC paints and coatings (i.e., high-solids, waterborne and powder coatings that contain lower solvent concentrations than conventional paints) as well as techniques that can increase transfer efficiency (i.e., the percentage of paints actually put on the part compared to the amount of paint used/sprayed). Methods for reducing the amount of solvents used during other stages of the coatings process, particularly surface preparation and equipment cleaning, also figure prominently.

NEWMOA collaborates with state and local environmental assistance programs in the Northeast; these programs have requested this manual to help them provide more efficient and effective help to the numerous companies with metal coating operations. Assistance providers have reported frustration with having to search databases for materials only to obtain a list of citations and case studies that they have to spend considerable time finding in order to provide information to their client companies. In addition, these officials rarely have the opportunity to check the accuracy of the information they find in databases to determine whether the material is still current. To avoid duplicating efforts and to ensure that the information companies receive is up-to-date and accurate, NEWMOA developed this manual as a model "synthesized" information packet that includes an exhaustive compilation and synthesis of existing materials on P2 for the metal coatings process.

To compile this manual, NEWMOA reviewed many books, articles, fact sheets, reports and guides on P2 for metal coatings operations. NEWMOA staff also sent a draft of the manual to more than 15 expert reviewers for their comments and suggestions. The result is an up-to-date compilation of information on P2 options for metal coatings. However, pollution prevention is a rapidly changing field, and all users should check with the various centers identified in Appendix A to determine whether any new information is available.

Overview of Manual

This manual is broken down into nine chapters as described below. Supporting case studies, tables, figures and appendices are also provided.

- ◆ Chapter 1 provides background information on paints and coatings, including a discussion of the coatings process and wastes generated.
- ◆ Chapter 2 presents an overview of federal regulations that affect coatings processes.
- ◆ Chapter 3 provides specific information on the role of technical assistance providers in promoting pollution prevention.
- ◆ Chapter 4 is an overview of pollution prevention options for surface preparation, coatings application/curing and equipment cleaning.
- ◆ Chapter 5 discusses surface preparation methods with an emphasis on reducing solvent use.

- ◆ Chapter 6 presents alternatives to solvent-borne coatings, including high-solids, waterborne and powder coatings.
- ◆ Chapter 7 provides an overview of application techniques (i.e., spray painting and other methods) along with a discussion of transfer efficiency.
- ◆ Chapter 8 presents information on curing methods.
- ◆ Chapter 9 discusses alternatives to traditional equipment cleaning methods.
- ◆ Appendix A presents information resources for coatings.
- ◆ Appendix B presents information on how to calculate VOC/HAP emissions.
- ◆ Appendix C provides information on conducting an economic analysis of paint costs.
- ◆ Appendix D presents purchasing guidelines for HVLP spray guns.
- ◆ Appendix E presents information on coatings testing.
- ◆ Appendix F provides a glossary of terms pertaining to the coatings process.
- ◆ Appendix G provides information on calculating transfer efficiency.

Audience

NEWMOA designed this manual for individuals who are involved in providing technical assistance to firms seeking information on P2 for paint and coating processes. NEWMOA believes that the information in this manual also would be useful for environmental inspectors and permit writers who are involved in regulatory compliance activities. Comments and suggestions from manual users on content and format are welcomed. Please take a moment and complete the evaluation form included with this document to help us with future versions of this manual and related manuals, or call NEWMOA at (617) 367-8558 to speak with us directly.

Using This Manual

This manual is designed to serve as a complete reference on P2 methods for paint and coating processes, however, it alone should not be used to advise companies on the selection of a particular coating system. The selection of a coating system depends on a number of application-specific factors, including the type of surface to be coated as well as the required performance characteristics of the coating. Companies that decide to adopt an alternative system should do so only after consultation with the appropriate coating and equipment vendors, and careful in-house analyses of the costs and benefits as well as technical feasibility of the alternative system.

Disclaimer

The views expressed in this report do not necessarily reflect those of NEWMOA, NEWMOA member states, Waste Management and Research Center (WMRC), or U.S. EPA. Mention of any company, process, or product name should not be considered an endorsement by NEWMOA, NEWMCA member states, WMRC, or U.S. EPA.

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Background

Simply stated—pollution prevention makes good business sense. Faced with the increasing costs and liabilities associated with end-of-pipe pollution control practices, many companies are turning to pollution prevention as a cleaner, safer and more cost-effective alternative.

EPA defines pollution prevention as any practice which reduces or eliminates the amount or toxicity of pollutants entering the waste stream or the environment prior to recycling, treatment or disposal. Pollution prevention includes such techniques as modification or redesign of processes; reformulation or redesign of products; product substitution; raw materials substitution; and improved maintenance, housekeeping and operating practices (EPAj, p. v).

Designed for technical assistance providers, this manual focuses on pollution prevention techniques for reducing emissions of volatile organic compounds (VOCs) from paint and coating processes, including reducing the amount of solvents used in coating formulations as well as in surface preparation and equipment cleaning. Most of the information contained in this manual relates to the coating of metal substrates used to manufacture metal containers, automobiles, machinery (including computers), metal furniture, appliances and other consumer goods.

This chapter presents the definitions of key terms, discusses uses for paints and coatings and provides general information on paint composition and coatings processes. It also provides examples of typical coating systems and discusses the sources of wastes in the coatings process, including the specific pollution problems that are the focus of this manual.

Definition of Terms

The following terms are used throughout the manual. These terms are often used to mean a variety of things. To clarify the use of the terms in

this document, we have provided the following definitions.

Coating: This term refers only to organic or polymer coatings and their associated application techniques. In other words, although metal plating does perform the function of a coating (e.g., it improves appearance, corrosion resistance, abrasion resistance, and electrical or optical properties), this manual does not cover metal plating (i.e., zinc, aluminum, etc.) or related processes (i.e., electroplating, conversion coating, sputtering, ion plating, and plasma spraying). Detailed information on P2 options for metal plating can be found in NEWMOA's manual *Pollution Prevention for the Metal Finishing Industry*.

Solvent: This term generally refers to hydrocarbon-based or organic solvents only; that is, solvents made from petroleum that contain the chemical elements hydrogen and carbon. In other words, although water is a solvent in terms of function (i.e., it is a liquid capable of dissolving another substance), the use of the term solvent in this manual, for the most part, does not apply to water or other non-carbon compounds.

Uses for Paints and Coatings

Paint is a generic term typically used to identify a wide range of surface coating products, including conventional solvent-borne formulations, varnishes, enamels, lacquers and water-based systems. Normally, painting is a process where a liquid consisting of several components, when applied, dries to a thin plastic film. Traditionally, major constituents of these paints are solvents. However, non-liquid paints such as powder coatings and high solids paints have also been developed. These newer materials have led to the use of the term coating instead of the term paint. In general, the function of all paints and coatings is to provide an aesthetically pleasing colored and/

or glossy surface, as well as to help metal and other substrates withstand exposure to both their environment and everyday wear and tear (TURIB, p. 1).

Paints and coatings can be categorized according to their use into three major groups:

- ◆ Architectural coatings include all shelf goods and stock type coatings that are formulated for normal environmental conditions and general applications on new and existing structures. These coatings include interior and exterior house paints and stains, as well as undercoaters, sealers and primers.
- ◆ Product coatings are paints sold to and used by original equipment manufacturers (OEM). Paint consumers in this sector include producers of wood furniture and fixtures, metal containers, automobiles, machinery, metal furniture, metal coil, appliances and other consumer goods.
- ◆ Special purpose coatings are used in automobile and machinery refinishing, high-performance maintenance, bridge maintenance, traffic paint, aerosol applications and other similar operations (TURIB, p. 1).

Coatings Sales

In 1995, sales by paints and coatings manufacturers were \$15.9 billion. Architectural coatings accounted for 38% of total surface coating shipments, product coatings for 33%, and special purpose coatings for 19%. Miscellaneous paint products made up 9% of the sales (NPCA). Most of the architectural coatings sold are water-based (73%), while the overriding majority of product and special purpose coatings were still conventional solvent-borne systems (TURIB, p. 1).

The intent of this manual is to provide information on pollution prevention opportunities for users of product coatings. Because product coatings are used by a wide variety of industries, it is difficult to accurately quantify these users. In addition, the use of product coatings occurs not only in OEM settings, but also in contract job shops. The pollution prevention opportunities identified in this

manual are not industry specific, but rather they include general options available to a variety of firms that coat metal substrates. Therefore, many of the P2 opportunities identified in this manual can be applied to users of architectural and special-purpose coatings as well.

Paint Composition

The major components of solvent-borne paints and coatings are solvents, binders, pigments, and additives. In paint, the combination of the binder and solvent is referred to as the paint "vehicle." Pigment and additives are dispersed within the vehicle (IHWRI, p. 2). The amount of each constituent varies with the particular paint, but solvents traditionally make up about 60% of the total formulation. Typical solvents include toluene, xylene, MEK, and MIBK. Binders account for 30%, pigments for 7 to 8%, and additives for 2 to 3% (KSBEAP, p. 4). Environmental issues surrounding paints usually center around solvents and heavy metals used in the pigments. Binders and other additives can also affect the toxicity of the paint depending on the specific characteristics of the paint. For more information on paint composition, refer to chapter 6.

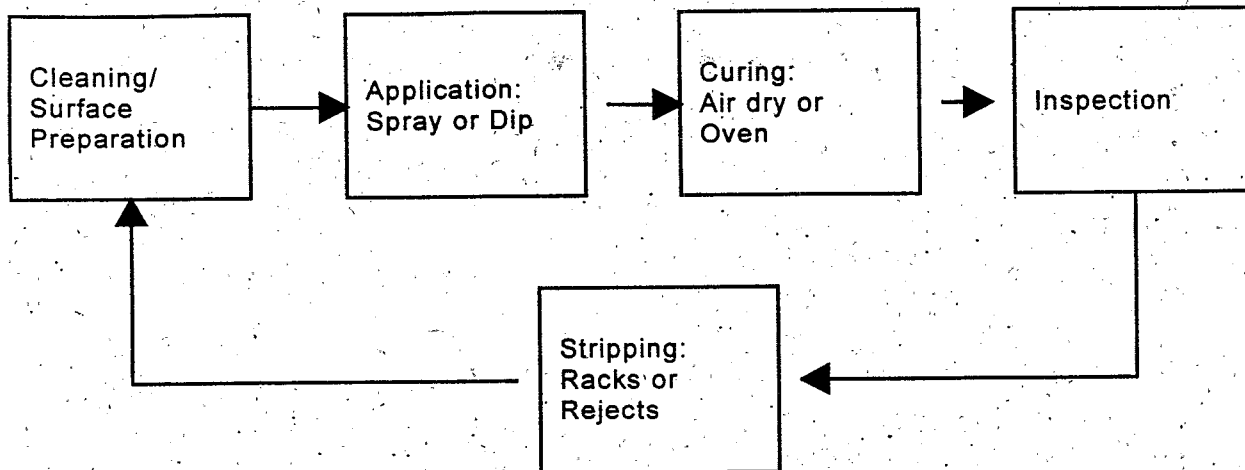
Description of Coatings Processes

The coating of metal substrates can be broken up into three major steps: surface preparation, a two-step paint application/curing process and equipment cleaning. These steps are presented in figure 1.

Surface Preparation

Although each of these steps can affect the performance of the final finish, proper surface preparation is essential in ensuring the success of a particular coating. In fact, as high as 80% or more of all coating adhesion failures can be directly attributed to improper surface preparation (Binks, p. 1).

In surface preparation, a variety of methods are used to remove soils or other imperfections from substrates, creating a surface that bonds well with

Figure 1. Overview of the Coating Process

the coating. The most common form of debris are oils and/or greases that originate from mechanical processing or oils and greases that are deliberately applied for temporary storage or shipping (Kuhn, p. 25). Other contaminants commonly include oxidation, rust, corrosion, heat scale, tarnish, and smut (SME, p. 27-1). In some cases, old paint must also be removed prior to the application of a new paint coat (MnTAP, p. 2). Traditionally, halogenated solvents have been used as cleaning and stripping agents to remove these substances.

As part of surface preparation, a conversion coating might be applied to improve adhesion, corrosion resistance, and thermal compatibility. The processes used most often for the application of conversion coatings on metal are phosphating (using iron or zinc) and chromating. Anodizing (i.e., the electrochemical deposition of an oxide coating) is sometimes used on aluminum surfaces (KSBEAP, p. 2-3).

In the phosphating process, acid attacks the metal surface, forming a microcrystalline layer that improves the surface for paint application. Zinc phosphate coatings are predominately used for metal substrates (Doren et al., p. 131). Combining cleaning and phosphating in a single solution is possible; however this is not the case with zinc phosphating (KSBEAP, p. 2-3). For more information on conversion coatings consult, *Pollution Prevention for Metal Finishing: A Manual for Pollution Prevention Technical Assistance*

Providers, published by the Northeast Waste Management Officials' Association.

Coatings Application

Following surface preparation, paints and coatings are applied to substrates using a variety of methods, including:

- ◆ Dip coating, in which parts are dipped into tanks of paint and the excess paint is allowed to drain off;
- ◆ Roller, in which paint is rolled onto a flat part;
- ◆ Curtain coating, flow coating;
- ◆ Electrodeposition, in which a part is coated by making it anodic or cathodic in a bath that is generally an aqueous emulsion of the coating; and
- ◆ Various spray processes, in which paint is sprayed from a gun onto a part.

Coatings are usually applied in a number of coats, starting with a prime coat followed by subsequent coats (basecoats and topcoats) and a finishing coat (clearcoats). Given the different types of coatings necessary to ensure adequate protection and performance, coatings should always be considered as a system.

Curing

Once a paint has been applied, a curing process takes place that converts the coating into a hard, tough, and adherent film. Coatings cure by

chemical reaction or polymerization of the resins (i.e., crosslinking). Mechanisms for initiating curing generally include ambient temperature oxidation, chemical reaction with another component (two-component coating systems) or baking in an oven. Radiation is an additional curing mechanism (IHWRIIC, p. 11).

Equipment Cleaning

The final stage of any coating operation is the cleaning of equipment, such as spray guns and hoses. This generally involves flushing solvent through the coating system (Freeman, p. 483-484).

Examples of Typical Systems

Although the basic process remains the same, the particular coating system, coating formulation and application method used, can vary considerably from industry to industry. In the automotive industry, for example, approximately 80% of all painting starts with an electrocoat primer, usually applied by electrodeposition. Visible indoor areas of automobile bodies receive a topcoat, usually of the same color as the overall body topcoat. In addition, the underside of the hood and inside of the engine compartment usually receive a topcoat of black alkyd or acrylic paint which is sprayed on; therefore, they carry a two-coat system. Outside surfaces of the body receive a sandable surface coat, which is either fully or partially sprayed and is applied on either the wet or incompletely baked electrocoat. Next, the color topcoat, usually an acrylic resin, is sprayed on and baked. In many cases, a clearcoat is sprayed over the color coat to provide "depth" (SME, p. 29-4-6).

The appliance industry, however, uses high-solids paints to spray coat surfaces. These paints are hardened with a crosslinking agent called melamine. Some assembled appliance cabinets receive a 7-stage zinc phosphate metal preparation and are then prime coated inside and out by electrodeposition. The cabinets can also be spray primed with a thermosetting epoxy-resin-based paint, followed by a topcoat of acrylic melamine paint, which is sprayed on. Other appliances carry

a powder coat, which is sprayed directly over the metal preparation, plus a decorative acrylic melamine coat (SME, p. 29-4-6).

Steel furniture for indoor use generally receives a 3- to 5-stage iron phosphate metal preparation, plus a dip, spray, or electrodeposited prime coat. The topcoat is usually an alkyd or acrylic. Steel outdoor furniture and steel doors usually receive a 7- or 9-stage zinc phosphate treatment, plus a prime coat of epoxy-based spray paint or an electrocoat. The topcoats may be alkyds or polyesters, and are sometimes modified with silicone. In some cases, powder coats are applied over the iron phosphate preparation (SME, p. 29-7).

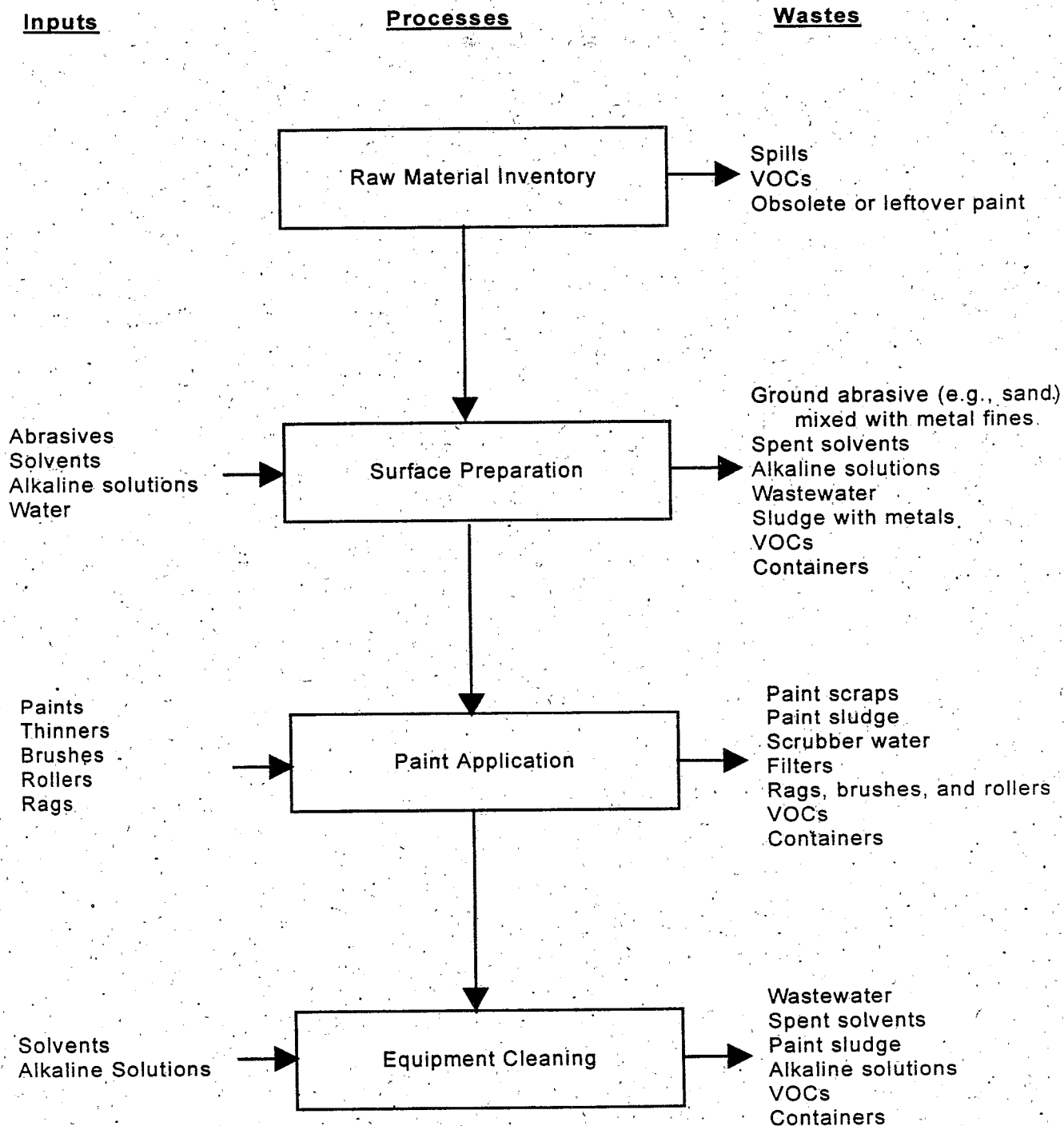
Sources of Wastes

Traditionally, each step in the coating process generates waste and emissions. Figure 2 presents a process flow diagram that outlines the sources and types of pollutants. Wastes occur in solid, liquid, and gaseous forms and can include the following:

- ◆ Scrubber water, paint sludge and filters from air pollution control equipment
- ◆ Spent solvents, aqueous cleaners, wastewater and paint sludge from equipment cleaning
- ◆ Aqueous waste and spent solvents from surface pretreatment
- ◆ VOC emissions during paint application, curing and drying
- ◆ Empty raw material containers
- ◆ Obsolete or unwanted paint (IHWRIIC, p. 38)

Inefficient paint transfer can be the largest source of waste and VOC emissions from paint and coating processes. Paint used but not applied to the surface being coated (e.g., paint overspray) generally becomes waste. A spray booth can be used to remove the overspray as it is generated (IHWRIIC, p. 38). However, the type of booth selected can also affect the volume and type of paint waste generated (MnTAP, p. 4). See chapter 4 for more information on spray booths and their effect on waste generation.

Evaporation of organic solvents is an important source of air emissions. During coating application, solvents that are present in conventional

Figure 2. Coating Process and Waste Generation (IHWRI, p. 34)

paint formulations evaporate and release VOCs into the air (IHWRI, p. 38). Emissions occur during initial coating, as well as each time a surface is recoated during the life of the object or structure (EPAK). In addition, solvents used to thin paint, to clean equipment, and to prepare

surfaces for coating can be sources of VOCs (IHWRI, p. 38).

Specific estimates of the amount of solvents released during coating application are difficult to make as use is spread across numerous industry

groups. However, EPA has developed air emission factors for solvent losses from paint and coating applications. EPA estimates that all toluene and 87% of the xylene isomers used in paints and coatings are emitted to the atmosphere when the emissions are uncontrolled. No emission factors are available for MEK and MIBK used in paints and coatings, but it can be assumed that, like toluene and xylene, virtually all these solvents are eventually released to the atmosphere (EPA, p. 157-158).

Cleaning of equipment is a third major source of waste generation. Generally, all paint-application equipment must be cleaned after each use to prevent dry paint residue and avoid contaminating batch processes. In addition, brushes and rollers must be cleaned after each use to remain pliable (IHWRIC, p. 38).

Summary

The primary focus of this manual is on P2 methods for reducing pollutants generated during coatings application and on reducing emissions of VOCs in particular. VOCs can pose risks to human health and the environment. These problems have prompted the federal government and a number of states to promulgate regulations to control releases of solvent emissions and wastes from paint and coating processes. For an overview of applicable regulations, see chapter 2.

Pollution prevention is an effective method for reducing emissions of VOCs and other wastes, and therefore, for reducing a firm's regulatory compliance burden. General information on promoting pollution prevention can be found in chapter 3. An overview of specific P2 options for coatings processes is discussed in chapter 4, with detailed technical information provided in chapters 5-9. See table 7 at the end of chapter 4 for a complete list of P2 options.

2 Regulatory Overview

The use of solvents in coating formulations and in other areas of the coating process poses a number of risks to human health and the environment. To reduce the risks resulting from exposure to these substances, the federal government and individual states have regulated the generation and management of wastes from paint and coating operations. Applicable regulations depend on the environmental medium to which the waste is released (e.g., air, land, or water) and the regulatory status of the generator (IHWRI, p. 10).

A discussion of individual state laws is beyond the scope of this document. However, this chapter provides an overview of the major federal statutes that affect coating processes, including the Clean Air Act (CAA) and the Clean Air Act Amendments of 1990 (CAAA), which regulate air releases; the Resource and Conservation Recovery Act (RCRA), which regulates hazardous wastes; and the Clean Water Act (CWA), which regulates wastewaters. For an overview of the regulatory status under the CAAA and RCRA for particular solvents used in paint and coating operations, see table 1. Technical assistance

Table 1. Common Solvents, Federal Regulatory Status (IHWRI, p. 5)

Solvent	RCRA Hazardous	Air Toxics Program ^a
Aliphatic Hydrocarbons Mineral Spirits	Yes	Maybe ^b
Aromatic Hydrocarbons Toluene Xylene	Yes Yes	Yes Yes
Esters Ethyl Acetate Butyl Acetate	Yes Yes	No No
Ketones Acetone Methyl Isobutyl Ketone Methyl Ethyl Ketone	Yes Yes Yes	No ^c Yes Yes
Glycol Ethers Monoethyl Ether	No	No
Alcohols Ethyl Alcohol Butyl Alcohol	Yes Yes	No No

^a Under the 1990 Clean Air Act Amendments.

^b Depends on the composition of the mineral spirits; some cheaper blends may contain aromatic solvents such as benzene.

^c Acetone has recently been delisted from the CAAA's Title III list of VOCs. However, technical assistance providers should not promote the use of acetone to achieve environmental compliance. Material substitution using acetone does not constitute a pollution prevention option.

providers should check with their state regulatory programs to see if their state has imposed requirements stricter than those developed under the federal programs. Coating operations might also be affected by a number of other federal and state regulations. Many of these regulations are industry specific rather than process specific.

Clean Air Act

The Clean Air Act and the Clean Air Act Amendments of 1990 consist of 11 chapters or titles that require EPA to establish national standards for ambient air quality and to work with states to implement, maintain, and enforce these standards. Of these titles, none have attracted more attention from industry than the Title III air toxics program, which brought many previously unregulated companies and processes under legislative control (Freeman, p. 34).

Under Title III, EPA created a list of 189 hazardous air pollutants (HAPs) of which 149 also are VOCs. Surface coating operations of all kinds are major users of these compounds. Commonly used compounds include toluene, xylene, MEK and MIBK. VOCs not regulated under the air toxics program might be regulated under Title I provisions for ozone non-attainment areas (Falcone, p. 35). Details of these titles are provided below.

Air Releases from Coatings Processes

- ◆ VOCs, which contribute to ozone pollution
- ◆ Heavy metal dust from pigments
- ◆ Atomized paint from spray applications
(IHWRIC, p. 10)

Air Toxics

Under Title III, facilities that emit HAPs are grouped into categories with similar operating processes, including the process of surface coating. Individual sources within a category are considered "major" if they emit or have the "potential to emit" 10 or more tons per year of any HAP on the list or 25 or more tons per year of a combination of HAPs. EPA defines "potential to emit" as the amount of emissions that a facility could release if it operated at maximum capacity 24 hours per day, 365 days per year.

Under Title III, major sources are subject to maximum achievable control technology (MACT) standards. MACT standards specify the maximum degree of reduction in the emission of HAPs that must be met through the use of traditional control technologies as well as through pollution prevention techniques. EPA has listed 16 surface coating processes as source categories subject to MACT standards, although not all of these surface coating processes apply to the coating of metal substrates. MACT standards are to be promulgated according to the schedule in table 2. Existing sources generally will have up to 3 years from the effective date of the standards to comply.

Ozone

Under Title I, EPA established national ambient air quality standards (NAAQS) to limit levels of "criteria pollutants," including carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide. The federal government has developed control technique guidelines (CTGs) which deal with a number of sources of air pollution in nonattainment areas (i.e., geographic areas that did not meet the NAAQS). These guidelines require the use of reasonably available control technologies (RACT).

For surface coating sources, the federal CTGs generally define RACT in terms of the VOC content limits of a coating; that is RACT is the mass of VOC per unit volume of coating (minus water) as applied (ready for application). In some cases, however, RACT is defined in terms of the percentage emission reduction achieved with addition control devices, equipment specifications, record keeping, reporting requirements, and exemption levels (EPAf, p. 2-1). While limits are based on specific industry groups and applications, the VOC limit of 340 g/l (2.8lb/gal) can be considered an unofficial national standard (Freeman, p. 486). For more specific information on EPA guidelines for VOCs in coatings, see table 3.

Other Requirements

Under Title V, the permitting provision of the CAAA, all major sources must apply for operating permits. Accurate information on source pollutants and emission quantities must be gathered before application submittal (Falcone, p. 35). Information about calculating VOC and HAP emissions from

Table 2. Scheduled Date for MACT Standards for Surface Coating (EPAm, p. 1-5)

Source Categories	Scheduled Date for Emissions Standards
Aerospace Industries	10/8/96
Auto and Light Duty Truck (Surface Coating)	11/15/00
Flat Wood Paneling (Surface Coating)	11/15/00
Large Appliances (Surface Coating)	11/15/00
Magnetic Tapes (Surface Coating)	11/15/94 (final rule issued 12/15/96; compliance 2 or 3 years)
Manufacture of Paints, Coatings, and Adhesives	11/15/00
Metal Can (Surface Coating)	11/15/00
Metal Coil (Surface Coating)	11/15/00
Metal Furniture (Surface Coating)	11/15/00
Miscellaneous Metal Parts and Products (Surface Coating)	11/15/00
Paper and Other Webs (Surface Coating)	11/15/00
Plastic Parts and Products (Surface Coating)	11/15/00
Printing, Coating, and Dyeing of Fabrics	11/15/00
Printing/Publishing (Surface Coating)	11/15/94 (final rule 5/30/96; compliance 3 years)
Shipbuilding and Ship Repair (Surface Coating)	11/15/94 (final rule issued 12/15/95; compliance 1 year)
Wood Furniture (Surface Coating)	9/7/95 (final rule issued 2/9/96; compliance 11/21/97)

NOTE: Work is beginning on the development of the 2000 regulations. Meetings were held in April of 1997 and workgroups are organizing to further develop the regulations.

coatings processes can be found in appendix B. State and local governments oversee, manage, and enforce much of the permitting program and many of the other requirements of the CAAA. For more information pertaining to the CAA, see 40 CFR Parts 50-99.

Resource Conservation and Recovery Act

Under the Resource Conservation and Recovery Act Subtitle C, EPA has established a "cradle-to-grave" system governing hazardous waste. Most RCRA requirements are not industry specific but apply to any company that transports, treats, stores, or disposes of hazardous waste. Wastes

generated during the application of paints and coatings might be considered hazardous because of the presence of solvents or toxic metals (IHWRI, p. 10).

RCRA Wastes from Coating Processes

- ◆ Organic solvents commonly used in paint formulations
- ◆ Waste paint containing heavy metals
- ◆ Materials used for surface preparation and equipment cleaning (IHWRI, p. 12)

Waste Characterization

A waste is considered hazardous if it is included on one of the four EPA lists of hazardous wastes; if it displays one or more of the characteristics of

Table 3. EPA Guidelines for Maximum VOC Content of Coatings (SWR, p. 46)

Process	Limitation (pounds per gallon)
Can Coating ♦ Sheet basecoat and overvarnish; two-piece can exterior ♦ Two-, three-piece can interior body spray; two-piece can exterior end ♦ Side-seam seal ♦ End sealing compound	2.0; 2.8 3.6; 4.2 5.5 3.7
Coil Coating	2.6
Fabric Coating	2.9
Vinyl	3.8
Paper	2.9
Auto and Light-Duty Truck ♦ Prime ♦ Topcoat ♦ Repair	1.9 2.8 3.0
Metal Furniture	3.0
Magnet Wire	1.7
Large Appliance	2.8
Miscellaneous Metal Parts	0.4-4.4
Wood Paneling ♦ Printed interior ♦ Natural finish hardwood ♦ Class II hardwood	1.7 3.2 2.7

hazardous waste (ignitability, corrosivity, reactivity or toxicity); or if it is a mixture that contains a listed hazardous waste.

- ♦ Listed wastes include acutely hazardous commercial chemical products and toxic commercial chemical products, designated with the code "P" or "U," respectively; hazardous wastes from specific industries/sources, designated with the code "K"; or hazardous wastes from nonspecific sources, designated with the code "F".

F wastes are of particular interest to paint and coating operations because they are generic wastes commonly produced during coating

application. Examples from this list include spent solvents used in cleaning and used paint thinners such as xylene and toluene (IWRCb, p. 15).

- ♦ Characteristic wastes include those that are ignitable, corrosive, reactive or toxic. Ignitable wastes have a flashpoint of less than 140°F and are easily combustible or flammable. Corrosive wastes have a pH of 2 or less, or of 12.5 or greater and can dissolve metals or other materials. Reactive wastes are unstable, or undergo rapid or violent chemical reaction with water or other materials. Toxic wastes contain concentrations of heavy metals, certain solvents, or pesticides in excess of correspond-

ing regulatory parameters determined by the Toxicity Characteristic Leaching Procedure (TCLP). Characteristic wastes are designated with the EPA hazardous waste code "D." See table 4 for more information on hazardous wastes generated from coatings operations.

Generator Status

To determine what a facility must do to comply with RCRA requirements, the facility must first determine its generator status. Generator status is based on the amount of waste generated on a monthly basis. The following criteria determine the quantity of waste that is regulated by RCRA:

- 1) material remaining in a production process is not counted as waste until it is no longer being used in that process.
- 2) waste discharged directly and legally to a POTW in compliance with CWA pretreatment standards is not counted toward RCRA generation total.
- 3) any material that is characteristic or listed as a hazardous waste, and is accumulating after its removal from the process before being sent off site for treatment, storage, or disposal, is counted toward RCRA Subtitle C generation total.

Facilities that generate hazardous waste are subject to certain waste accumulation, manifesting, and record keeping standards based on the amount of waste generated. RCRA specifies three categories of waste generators. The following outlines the basic guidelines for generator status; be aware, however, that state guidelines may vary.

- ◆ Conditionally exempt small quantity generators (CESQGs) generate less than 220 pounds of hazardous waste, or 2.2 pounds of acute hazardous waste (K wastes), per calendar month. CESQGs cannot accumulate more than 2,200 pounds of nonacute hazardous waste (or 1 kilogram of acute hazardous waste).
- ◆ Small quantity generators (SQGs) generate 220 to 2,200 pounds of hazardous waste per calendar month. SQGs cannot accumulate

more than 13,200 pounds. Storage time is restricted to 180 days.

- ◆ Large quantity generators (LQGs) generate more than 2,200 pounds of hazardous waste per calendar month. Storage time is restricted to 90 days.

Each state has varying degrees of regulation for the three generator classes. At a minimum, however, EPA requires each class to comply with the following requirements:

Large Quantity Generators

- ◆ Notify the US EPA or state and obtain an EPA ID number from the state regulatory agency
- ◆ Store waste for no more than 90 days
- ◆ Comply with container standards and tank rules
- ◆ Prepare and retain a written contingency plan
- ◆ Prepare and retain a written training plan which includes information on the annual training of employees
- ◆ Prepare a written waste minimization plan
- ◆ Dispose of hazardous materials only at a RCRA permitted site
- ◆ Only use transporters with EPA ID numbers
- ◆ Use proper Department of Transportation (DOT) packaging and labeling
- ◆ Use the full Uniform Hazardous Waste Manifest
- ◆ Place a 24-hour emergency number on all manifests
- ◆ Report serious spills or fires to the National Response Center
- ◆ Obtain a DOT registration number for shipments over 5,000 pounds
- ◆ Keep all records for 3 years
- ◆ Make sure that any treatment or recycling done onsite is permitted
- ◆ Report missing shipments in writing
- ◆ Submit biennial reports of hazardous waste activities, including waste minimization

Small Quantity Generators

- ◆ Notify the US EPA or state and obtain an EPA ID number from the state regulatory agency
- ◆ Store waste for no more than 180 days (270 days if the waste is shipped more than 200 miles)

- ◆ Comply with container standards and tank rules
- ◆ Dispose of hazardous materials only at a RCRA permitted site
- ◆ Only use transporters with EPA ID numbers
- ◆ Use proper Department of Transportation (DOT) packaging and labeling
- ◆ Use the full Uniform Hazardous Waste Manifest
- ◆ Place a 24-hour emergency number on all manifests
- ◆ Post emergency response telephone numbers near telephones
- ◆ Provide informal employee training
- ◆ Make sure that any treatment or recycling done onsite is permitted
- ◆ Report missing shipments in writing
- ◆ Keep all records for 3 years

Conditionally Exempt Small Quantity Generators

- ◆ Avoid accumulating more than 1,000 kilograms (2,200 pounds) of hazardous waste onsite at any one time
- ◆ Send waste to a facility that is at least approved to manage municipal or industrial solid waste

Toxics Release Inventory Reporting

Some coating facilities may have to publicly report many of the chemicals they use under the federal Toxic Release Inventory (TRI) reporting requirement. Facilities report information on a TRI data form (Form R) for each toxic chemical that is used over the threshold amount. Basic information that is reported in a Form R includes the following:

- ◆ Facility identification
- ◆ Parent company information
- ◆ Certification by corporate official
- ◆ SIC code
- ◆ Chemical activity and use information
- ◆ Chemical release and transfers
- ◆ Off-site transfer information
- ◆ On-site waste treatment
- ◆ Source reduction and recycling activities

The releases and transfers reported on a Form R include the following:

- ◆ Emissions of gases or particulates to the air
- ◆ Wastewater discharges into rivers, streams, and other bodies of water
- ◆ Releases to land onsite including landfill, surface impoundment, land treatment, or other mode of land disposal
- ◆ Disposal of wastes in underground injection wells
- ◆ Transfers of wastewater to POTWs
- ◆ Transfers of wastes to other off-site facilities for treatment, storage, and disposal

A facility must fill out Form R if it meets the following criteria:

- ◆ The facility is included in SIC codes 20 to 39
- ◆ The facility has 10 or more full-time employees
- ◆ The facility manufactures, processes, or "otherwise uses" any listed material in quantities equal to or greater than the established threshold for the calendar year

The manufacturing and processing thresholds have dropped over the reporting years from 75,000 pounds in 1987 to 25,000 pounds in 1989. For a chemical "otherwise used," the threshold amount is 10,000 pounds. Technical assistance providers can use TRI data to develop an aggregate picture of the releases and transfers from a facility.

Clean Water Act

The primary objective of the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act (CWA), is to restore and maintain the chemical, physical and biological integrity of the nation's surface waters. Pollutants regulated under the CWA are classified as "priority" pollutants. These include various toxic pollutants; "conventional" pollutants, such as biochemical oxygen demand (BOD), total suspended solids (TSS), fecal chloroform, oil and grease, and pH; and "non-conventional" pollutants, including any pollutant not identified as either conventional or priority.

National Pollutant Discharge Elimination System (NPDES)

Under the CWA, most point sources of wastewater (e.g., discharge pipes or sewers) discharging to waterways require a National Pollutant Discharge Elimination System permit. Permits, issued by

Table 4. Hazardous Wastes Generated from Coatings Operations (EPA, p. 96-97)

EPA Hazardous Waste Number	Hazardous Waste
D006 (cadmium) D007 (chromium) D008 (lead) D009 (mercury)	Wastes that are hazardous due to the characteristic of toxicity for each of the constituents.
F001	<i>Halogenated solvents used in degreasing:</i> tetrachloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; all spent solvent mixtures/blends used in degreasing containing, before use, a total of 10 percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F002	<i>Spent halogenated solvents:</i> tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, trichlorofluoromethane, and 1,1,2-trichloroethane; all spent solvent mixtures/blends containing, before use, one or more of the above halogenated solvents or those listed in F001, F004, F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F003	<i>Spent nonhalogenated solvents:</i> xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcohol, cyclohexanone, and methanol; all spent solvent mixtures/blends containing, before use, only the above spent nonhalogenated solvents; and all spent solvent mixtures/blends containing, before use, one or more of the above nonhalogenated solvents, and a total of 10 percent or more (by volume) of one of those solvents listed in F001, F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F004	<i>Spent nonhalogenated solvents:</i> cresols and cresylic acid, and nitrobenzene; all spent solvent mixtures/blends containing, before use, a total of 10 percent or more (by volume) of one or more of the above nonhalogenated solvents or those solvents listed in F001, F002, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F005	<i>Spent nonhalogenated solvents:</i> toluene, methyl ethyl ketone, carbon disulfide, isobutanol, pyridine, benzene, 2-ethoxyethanol, and 2-nitropropane; all spent solvent mixtures/blends containing, before use, a total of 10 percent or more (by volume) of one or more of the above non-halogenated solvents or those solvents listed in F001, F002, or F004; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.

Wastewaters from Coatings Processes

- ◆ Wastewaters from equipment cleaning and surface preparation
- ◆ Rinsing of a surface after paint removal
(IHWRIIC, p. 11)

either EPA or an authorized state (EPA has presently authorized 40 states to administer the NPDES program), specify levels of toxicity and other characteristics that must be achieved prior to discharge. Pretreatment of the wastewater is generally necessary. Wastewater generated from coating application might be regulated because of the presence of organic solvents or heavy metals (IHWRIIC, p. 11).

Pretreatment Program

Another type of discharge that is regulated by the CWA is one that goes to a publicly-owned treatment works (POTWs). The national pretreatment program controls the indirect discharge of pollutants to POTWs by industrial users. Facilities regulated under this program must meet certain pretreatment standards. The goal of the pretreatment program is (1) to protect municipal wastewater treatment plants from damage that can occur when hazardous, toxic, or other wastes are discharged into a sewer system and (2) to protect the quality of sludge generated by these plants.

For more information about the CWA, see 40 CFR Part 433.

3 Planning Pollution Prevention Programs at Coating Facilities

How can assistance providers and regulatory compliance staff sell pollution prevention options to a facility? The most important point that an assistance provider can make is that pollution prevention can help the facility achieve regulatory compliance while saving money. The savings associated with recapturing and reclaiming materials is obvious; but the value of reducing the regulatory burden and the expense from wasted raw materials, can, in many cases, exceed the cost of pollution prevention projects. Overall, the benefits associated with pollution prevention include:

- ◆ **Reduced Operating Costs/Overhead**
These savings can result in reduced utility charges, water/sewer fees, wastewater treatment costs, waste disposal expenses, permit discharge fees, analytical monitoring, and reporting costs.
- ◆ **Reduced Manufacturing Costs**
Facilities can save money on reduced material costs (paint and solvent purchases), water costs, and energy costs.
- ◆ **Product Quality Improvements**
Pollution prevention techniques often increase the quality of the coating process. Improving process controls makes coating operations more efficient and allows them to run within tighter operating parameters, often resulting in decreased reject rates.
- ◆ **Environmental Risk Reduction**
Pollution prevention projects can result in reduced noncompliance enforcement actions; reduced environmental and worker health liability; and reduced risk of on-site contamination via spills, releases, and leaks.

Potentially, a facility can realize other benefits from the implementation of a comprehensive pollution prevention program. Source reduction can lower insurance costs, protect property

values, and improve relationships with financial institutions. Even though pollution prevention has clear economic advantages and the techniques can be simple, inexpensive, and time proven, many facilities still do not have significant source reduction programs (Haveman, 1995).

This chapter provides information on how to conduct an assessment of a facility that has a coating process. It provides information on a general facility assessment as well as specific information on assessing the coating process. Technical assistance providers should be aware that while a facility may have one process or chemical that is of major concern, assessing the entire facility is critical. In this way they can identify processes that are impacting the coating process and that might be increasing pollution generation.

Characterizing a Facility

Numerous factors can influence whether a facility adopts and implements pollution prevention techniques. Understanding what motivates a facility can help a technical assistance provider develop a message for the facility that will influence their decision to implement pollution prevention. The following list divides firms into categories and describes some characteristics of firms and their motivating factors:

- ◆ **Environmentally proactive firms** that actively pursue and invest in strategic environmental management projects: Most often these firms are in compliance with environmental regulations. They actively pursue and invest capital in continuous improvement projects that go beyond compliance in order to maintain their places as environmental leaders in their sector. These firms are often driven by public recognition, and pride in industry performance. They

understand the economic payoffs of strategic environmental investments and believe that flexibility in compliance would promote innovative approaches and increase their willingness to help other firms.

- ◆ Firms that are in compliance but do not or cannot seek opportunities to improve environmental performance because they lack the necessary resources: Regulatory compliance is what drives this potentially large middle tier. Barriers to proactive performance include a lack of capital and information, and a lack of positive reinforcement.

The barriers that generally apply to some or all of these facilities are:

- ◆ Regulatory compliance and/or enforcement actions: Many shops lack the personnel and capital resources to move beyond compliance. Liability may be a barrier to obtaining loans for capital improvements. Existing liability can overwhelm their ability to pay for remediation or new, cleaner technologies.
- ◆ Development of safer products: In some cases, suppliers might be reluctant to suggest environmentally proactive processes or product changes because these could result in lower product sales.
- ◆ Uncertainty about future regulatory activity: Inconsistency in existing regulatory requirements and enforcement actions at the federal, state, and local level creates uncertainty and, at worst, competitive imbalances throughout the industry. This climate generates distrust of EPA and state programs and can inhibit meaningful communication.
- ◆ Lack of awareness of changes in product/process technology: Facilities may not have the time or resources to research new technologies and the benefits these technologies could provide them (Haveman, 1995). In some cases, facilities may be aware of the new technologies but are unwilling to implement them because they cannot field test the new systems at their facility.

Planning

The key to developing a successful pollution prevention program is planning. Assistance providers can work with facilities to implement planning programs, assist in establishing baseline measures, and identify potential pollution prevention projects. The key steps to starting a pollution prevention program include:

- ◆ Obtaining management support and involvement
- ◆ Establishing an in-house pollution prevention team
- ◆ Attracting company wide involvement

The following pages outline an ideal planning process. Often, there are issues and limitations that inhibit a company's ability to carry out all of the outlined activities. Therefore, this process should be viewed as a flexible model.

Management Support

The support of company management is essential for developing a lasting and successful pollution prevention program. The level of success that a facility can achieve in reducing waste generation appears to depend more on management interest and commitment than on technical and economic feasibility, particularly for source reduction technologies that require process modifications or housekeeping improvements. In some states, the technical assistance programs will not work with a facility until top management has shown that it is willing to support a long-term pollution prevention program.

At the outset of the P2 planning program, management endorsement is needed to help identify the pollution prevention team and give credence to the planning effort. Throughout the program, company management can support the team by endorsing goals and implementation efforts, communicating the importance of pollution prevention, and encouraging and rewarding employee commitment and participation in the effort (Dennison, p. 61).

At some companies, technical assistance providers may find that employees see only the barriers they

face in implementing a project, which they use as excuses to not implement pollution prevention. At other firms, motivated employees are empowered to find solutions to overcome obstacles, and the companies can reap the benefits of successful pollution prevention projects. Technical assistance providers should stress to management that a successful program has a wide range of benefits. These benefits include cost savings, reduced liability, and enhanced company image as described earlier.

Assistance providers should inform management that some initial labor costs will be incurred as a result of organizing and implementing a pollution prevention program. Usually, however, companies find this up-front investment is repaid several times over. Case studies often highlight the benefits that other companies have realized from implementing such programs.

Technical assistance providers can help facilitate management support by developing a plan that sells pollution prevention to a company's executives. Successful management initiatives that have promoted pollution prevention include: developing a corporate policy that makes pollution prevention a mandate; incorporating pollution prevention success into performance evaluations; and offering financial incentives for meeting pollution prevention goals or for finding pollution prevention opportunities.

Obviously, each firm is different. The assistance provider's approach to each company's leadership should attempt to address their specific interests and priorities as manifested by the corporate culture. Identifying these interests and priorities is a challenge for any assistance team. On these visits the teams discuss their priorities and pollution prevention in relation to those priorities. Technical assistance providers should also stress to management that planning is an ongoing task. Once the initial plan is completed, the facility should continue to reevaluate their operations to identify areas that can be improved (CAMF, 1995).

Establishing the Team

A successful pollution prevention program requires not only support from management, but

CASE STUDY: **Using Employee Participation to Reduce Hazardous Waste**

The VALSPAR company in Beaumont, Texas, is a paint manufacturer with 45 employees. The company produces solvent-based coatings for maintenance and marine use. To reduce hazardous waste, VALSPAR instituted a program in which solvent used to clean mixing tanks is recycled back into batch production. VALSPAR's pollution prevention program also found innovative ways to elicit valuable employee participation. The program included forming P2 teams composed of union workers and offering a 2% bonus for each waste reduction goal attained.

Within the first months of the program, the team found a way to recycle 60 gallons of additional spent solvent per week, leading to a 20% reduction in annual waste generation. Eventually, the program was able to recycle 95% of all solvent used in the clean-up process. In addition, VALSPAR accepted and reworked unused paint into new batches. In 1993, the company recycled 52,000 gallons of solvent and reworked an additional 20,000 gallons of returned paint. These efforts resulted in a reduction of approximately 250 tons of hazardous waste at a cost savings of \$103,000, not including savings from reduced purchases of raw material.

(PPIPTI)

also input and participation from all levels of the organization. To champion the effort, every pollution prevention program needs an effective pollution prevention coordinator. Assistance providers can help identify the team leader, work with the leader on developing their team, and suggest ways for the facility to implement its pollution prevention program.

A team approach allows tasks to be distributed among several employees and enables staff from different parts of the company to have input into the planning process. Members of the team are typically responsible for:

- ◆ Working with upper management to set preliminary and long-term goals

- ◆ Gathering and analyzing information relevant to the design and implementation of the program
- ◆ Promoting the program to employees and educating them on how they can participate in the effort
- ◆ Monitoring and reporting to management on the progress of the program (Dennison, p. 61)

The pollution prevention team should include employees who are responsible for planning, designing, implementing, and maintaining the program. The ideal size of the team depends on the size of the organization. In small companies, the team can consist of one person who wears many hats, or the company manager and a technical person. In larger companies, the team might include environmental managers, building supervisors, technical staff, maintenance staff, marketing staff, purchasing staff, and other interested employees (Dennison, p. 63).

External personnel, such as technical assistance providers or consultants, can complement the team by providing technical or managerial expertise. Often these people can offer auditing expertise as well as knowledge of pollution prevention, and environmental laws and regulations. However, external contributors will be unfamiliar with the facility's operation. Once the team is established, assistance providers and regulatory staff should encourage the facility to take the following steps to properly evaluate the options for reducing pollution:

- ◆ Define and Identify the Facility's Objectives: Clearly identify, quantify, and rank the facility's objectives. For example, at some facilities compliance with air quality standards is a primary concern while optimized worker efficiency and cost are secondary concerns.
- ◆ Define Criteria for Evaluating Pollution Prevention Options: Clearly define what constitutes a feasible option. Items to consider in addition to technical feasibility include economic feasibility, quality standards, and the effect of the option on the overall process.

The following pages provide an overview of the typical steps involved in assessing a facility and

coatings processes in particular. These steps include:

- ◆ Characterizing the facility
- ◆ Gathering baseline facility data
- ◆ Analyzing workplace practices
- ◆ Developing process flow diagrams
- ◆ Identifying pollution prevention options
- ◆ Analyzing and selecting options for further investigation
- ◆ Pilot testing preferred options
- ◆ Implementing the new system
- ◆ Evaluating and maintaining the pollution prevention program

While the facility may have brought in a technical assistance provider to suggest methods for a single process or problem, the entire facility must be evaluated because the coating process will be affected by outside issues. Consider the case of a facility that wants to change from solvent cleaning to aqueous cleaning but has problems with removing cutting fluids. The machining process would need to be examined to see if the facility could use alternative cutting fluids that are easily removed using aqueous cleaning.

Assess the Facility

Once the team has defined its objectives and criteria for a pollution prevention program, the next step is to assess the facility. Beyond the facility tour, useful information for the assessment can be obtained from sources such as:

- ◆ Engineering interviews and records
- ◆ Accounting interviews and records
- ◆ Manifest documents
- ◆ Vendor data
- ◆ Regulatory documents
- ◆ Sampling data

Map the Facility

Locate or prepare drawings of the layout of the process and storage areas. These drawings should be to scale, showing the location of all relevant equipment and tanks, and identifying:

- ◆ Floor space of the facility
- ◆ Coating and other process lines
- ◆ Gutters, sumps, and sewer lines
- ◆ Water lines, control valves, and flow regulators
- ◆ Ventilation/exhaust systems

Gather Baseline Information

The first step in P2 assessments of coatings processes is to collect as much information as possible about the coating process from company personnel. Background information should establish the sources and nature of wastes generated, and can include:

- ◆ Specific information about emissions (e.g., current releases, desired reductions) and other wastes generated from coatings operations (e.g., wastewaters and paint wastes)
- ◆ Details about the type of coating used and application techniques
- ◆ Information about the types of parts to be coated and performance specifications of the finish
- ◆ Details about the surface preparation and equipment cleaning processes (e.g., equipment and methods used)

Technical assistance providers should also review all operations of the facility that relate to chemical, energy, or water use. Some of the information that technical assistance providers should request includes:

- ◆ Estimates of production units, such as square meters coated and number of parts that pass through a line sequence, or production rates (i.e., square feet processed per hour)
- ◆ Material purchases
- ◆ Material inventory
- ◆ Material use rates (where each material is used and how much is used in each process)
- ◆ Waste management costs
- ◆ Raw material costs
- ◆ Compliance problems
- ◆ Control processes
- ◆ Sampling and analysis information
- ◆ Process line design and condition
- ◆ Actual operating procedures
- ◆ Operating parameters

The information listed above should be used in conjunction with the information obtained in the walk-through of the facility to determine what pollution prevention options are technically and economically feasible. This information should

also provide the technical assistance provider with information to determine which processes in a facility need to be addressed to reduce pollution generation.

Analyze Workplace Practices

A great deal of data should be accumulated so that assistance providers can determine the best pollution prevention approaches for a facility. The first pieces of information gathered should be material/resource use, general operating procedures, and facility information. This information usually can be gathered prior to a facility tour and used to start a facility map that will be valuable during the site visit. Table 5 provides an overview of the basic operational information that technical assistance providers should obtain from the company prior to the technical assistance visit.

Additional information is gathered during the facility tour. When touring the coatings operations at a facility, technical assistance providers should observe or ask employees about workplace operating practices. Often, employees can provide valuable insight both into why waste is being generated and into some of the obstacles a plant may face in implementing new projects or methods. The following lists present some of the questions technical assistance providers might want to ask (KSBEAP, p.33):

Personnel

- ◆ Do employees view overspray as lost product?
- ◆ Are paint and solvent records maintained for each spray gun operator?
- ◆ Are gun operators or paint crews rewarded for high quality work using less paint?
- ◆ Are there written guidelines on how much paint should be prepared and used for frequent jobs?
- ◆ Are employees provided with proper devices to measure the correct amount of paint?
- ◆ Are operators given spray gun training?
- ◆ Is technique training routinely provided?
- ◆ Are performance monitors in place?

Housekeeping/Maintenance

- ◆ Is spray equipment maintained according to manufacturer or vendor instructions?
- ◆ Are paint containers tightly closed when not in use?

Table 5. Overview of Assessment Information (BCDNRP)

Process	Data
Production Processes and Operational Procedures	<ul style="list-style-type: none"> ◆ Production rates ◆ Process description and efficiencies ◆ Condition of process equipment ◆ Sources or potential sources of leaks/spills ◆ Operating procedures ◆ Maintenance procedures and schedules ◆ Energy/utility use and costs ◆ Operating and maintenance costs
Material Use, Handling, and Storage	<ul style="list-style-type: none"> ◆ Paint and solvent use ◆ Raw material accounting (how much of the material is used in the process, how much is lost through evaporation or other means, and how much enters the waste stream) ◆ Raw material costs ◆ Material transfer and handling procedures ◆ Storage procedures ◆ Sources of leaks or spills in transfer and storage areas
Waste Stream	<ul style="list-style-type: none"> ◆ Activities, processes, or input materials that generate waste streams ◆ Physical and chemical characteristics of each stream ◆ Hazardous classification of each waste stream ◆ Rates of generation of each waste stream and variability in these rates
Waste Management	<ul style="list-style-type: none"> ◆ Current treatment and disposal system for each waste stream ◆ Cost of managing waste stream (e.g., fees, labor, and disposal costs) ◆ Efficiency of waste treatment units ◆ Quantity and characteristics of all treated wastes ◆ Waste stream mixing (hazardous wastes mixed with non-hazardous waste)
Waste Reduction	<ul style="list-style-type: none"> ◆ Current waste reduction and recycling methods being implemented ◆ Effectiveness of those methods

- ◆ Are there regular inspections and repairs for paint and solvent leaks?
- ◆ Are tight-fitting spigots used?
- ◆ Are spigots or pumps used to transfer paint from storage containers to smaller containers?

Inventory Control

- ◆ Are good records kept on paint inventory and use?
- ◆ Are paint purchase expenses allocated to the painting department?
- ◆ Are paint containers adequately labeled?

- ◆ Are paints stored on the floor according to manufacturer's instructions?
- ◆ Are paints used on a first-in, first-out basis?
- ◆ Is access to the paint room controlled?
- ◆ Is access to solvents controlled?
- ◆ Are unused or expired paints returned to vendors or manufacturers?
- ◆ Is a computerized paint-mixing system used?

Scheduling

- ◆ Are certain production runs scheduled around the same time each month?
- ◆ Are jobs scheduled so that jobs using the same color are scheduled together?
- ◆ Are production runs scheduled to go from lighter to darker colors?

Equipment and Materials

- ◆ Are efficient spray guns being used (e.g., HVLP, electrostatic)?
- ◆ Are paints maintained at proper viscosity?
- ◆ Is the correct gun setup being used for the paint and the workpiece?
- ◆ Is it possible to reduce gun pressure and achieve an acceptable finish?
- ◆ Are gun operators keeping the spray pattern over the workpiece?
- ◆ Are gun operators holding the gun perpendicular to the work surface?
- ◆ When part size allows, are operators making a pass over the full length of the work surface?
- ◆ Are paints with less or no hazardous ingredients being used?
- ◆ Are high-solids or powder coatings used?

Rework

- ◆ Is touch up done only on the imperfection or reworks?
- ◆ If paint is stripped, are mechanical methods being used instead of chemical ones?
- ◆ If using chemical stripping, are less toxic strippers being used?

Cleanup and Disposal

- ◆ Are waste paint handling and solvent handling charges allocated to the production units or departments that incur them?
- ◆ Are guns, nozzles, and lines cleaned immediately after use?
- ◆ Are enclosed paint gun cleaners used?
- ◆ Is compressed air used to clean lines instead

of solvent?

- ◆ Are spatulas or scrapers used to clean equipment and paint containers prior to using solvents?
- ◆ Are polystyrene filters used?
- ◆ Is unused paint stored properly so that it can be used again?
- ◆ If waste paint cannot be used onsite, are there potential employee or local uses?
- ◆ Is solvent recycled onsite?
- ◆ Is solvent gravity separated from waste sludge?

If the technical assistance provider uses the team approach described above, many individuals from all areas of the company will have a chance to share their perspective on pollution problems and solutions. Working with this information, technical assistance providers can develop a process map, including data information. Using these tools, the P2 team can go onto the plant floor to discuss the process with those directly involved (e.g., supervisors and front-line production workers) to determine appropriate P2 projects and develop a baseline to measure all future efforts.

Develop a Process Flow Diagram

Once all the information has been gathered and a map of the facility is drawn, technical assistance providers can develop a process-flow diagram. Process-flow diagrams break the facility down into functional units, each of which can be portrayed in terms of material inputs, outputs, and losses. Developing a process map helps the facility understand how the production process is organized, thereby providing a focal point for identifying and prioritizing sources of emissions and waste (EPA, 1996).

The process map should cover the main operations of the facility and any ancillary operations (e.g., shipping and receiving, chemical mixing areas, and maintenance operations). Separate maps can be generated for these ancillary operations. Another important area to cover is "intermittent operations" or operations that do not occur on a regular basis. The most common intermittent operations are cleaning and maintenance. A great many pollution prevention opportunities can be found by examining these intermittent operations (EPA, 1996).

Assistance providers should also help the facility to include operations that are upstream and downstream of the coating operation. For example, machining operations could have a major impact on cleaning operations. Pollution and waste issues often cross process boundaries. An understanding of the origins of the pollution can assist the facility in identifying opportunities for pollution prevention.

Identify Pollution Prevention Opportunities

Using the information obtained in the facility assessment, the team should compile a list of P2 options that are technically feasible. Brainstorming sessions with the P2 team can provide innovative ideas. Researching case studies of other companies also can provide valuable information. Other potential sources of ideas include suppliers and consultants. At this point, all ideas should be taken seriously, and none should be rejected automatically for reasons such as "that's already been tried," or "it will never work," or "it's too expensive."

After all options have been identified, the team should screen the options based on the objectives and criteria that were established in the assessment phase. Each option should fit into one of the following categories:

- ◆ Ideas that are impractical
- ◆ Ideas that need more detailed information and study
- ◆ Ideas that can be implemented with a minimum of effort and cost

This initial evaluation will assist the company in identifying a subset of options that deserve further investigation. Generally, the number of options requiring detailed information and study should be pared to a minimum (Ferrari, 1994).

When screening ideas, assistance providers should keep in mind that an important principle of excellence in manufacturing is maximizing the productivity of the coating process. Some pollution prevention options can increase productivity while others can decrease productivity, sometimes substantially. Technical assistance providers

should be aware of how their suggestions can affect the productivity of the coatings process when screening options. By gaining information on these types of issues, technical assistance providers can provide better suggestions on pollution prevention options when assessing a facility.

Analyze and Select Options

Once a short list of options has been identified, the team should begin the process of deciding which options are appropriate for the facility. During this phase, the team should be clear on the company's objectives and criteria. Depending on the goals of the company, cost effectiveness might not be the overriding goal. The following questions should be asked when screening options:

- ◆ Which options will best achieve the companies waste/emissions reduction goals?
- ◆ What are the main benefits to be gained by implementing this option?
- ◆ Does the technology exist to implement the option?
- ◆ How much does it cost?
- ◆ Can the option be implemented without major disruptions in production?
- ◆ Does the option have a good track record?
- ◆ Does the option require additional space?
- ◆ What are other areas that might be affected by implementation of the option?

In addition, a company that believes cost effectiveness is critical should consider the long-term costs associated with a particular option. For instance, the team might be inclined to disregard an option because the initial capital outlay is high; however, upon examining the total cost associated with the project, the team might find that the measure could yield impressive savings in several years (Dennison, p. 75). In order to identify the total costs associated with both existing and new processes, the facility could consider costs that traditionally have not been incorporated into capital acquisitions. For more information on identifying these costs, assistance providers can refer to *Improving Your Competitive Position: Strategic and Financial Assessment of Pollution Prevention Projects*, a training manual developed by NEWMOA for conducting financial assessments of pollution prevention projects.

Pilot Test or Validate Preferred Options

Once the facility has determined its preferred option(s), the facility can pilot test the program prior to full facility implementation. A pilot test can highlight any installation or implementation issues. At this point, the technical assistance provider has completed most of his or her job. However, if issues arise in the pilot test phase, he or she can be called in to troubleshoot and suggest other alternatives. The technical assistance provider could brief the facility's P2 team on how to anticipate and prevent problems and issues during implementation of the new system. This could be useful because the cost to correct a failed system can greatly exceed the cost of proper initial implementation.

Procure and Implement New System

Once the new system is installed, the company's employees should be informed about the project and the importance of their cooperation and involvement. Operators should be trained on how to properly operate the system. Companies should update employees on the expected benefits of and the progress made in achieving the goals of the new system.

Frequent updates on the progress of the overall P2 program can increase a staff's stake in the program. In order to sustain employee interest in P2, facilities should encourage staff to submit new ideas for increasing the effectiveness of the program.

A few critical rules should be kept in mind when helping a company consider new projects:

- ◆ No single system or process is right for all applications. A vast range of variables can affect the coatings process which, in turn, affects the selection and performance of a pollution prevention system. Specific variables include work type, work loading rate, workpiece geometry, substrate materials, and finish requirements.

- ◆ Prior to investing in any new system, the team should take the time to evaluate and understand the process, preferably including a rigorous pilot test in the facility.
- ◆ The team should recognize that the provider of any new system (including the designer and sales staff) is a new partner at the facility (Ferrari, 1994).

Evaluate and Keep the Program Going

Assistance providers can suggest that the facility develop a mechanism for soliciting input from all employees in the future. Communicating the success of the program also can keep employees involved. The facility can use the baseline information developed from the facility assessment phase to communicate any progress that has been made. Technical assistance programs can follow up with a facility (usually within 6 months to one year from their final visit) to report on the successes and failures of the company's P2 program and learn of new projects that the facility may have implemented.

4 Overview of Pollution Prevention in Coating Application Processes

Significant amounts of pollutants are generated from paint and coatings processes. The exact amount for the nation is difficult to calculate, because use is spread across numerous industry groups (EPA, p. 158), and companies do not report emissions by manufacturing process to EPA. Wastes from paint application include leftover paints, dirty thinner from the cleaning of spray guns and paint cups, air emissions of VOCs and HAPs, dirty spray booth filters, dirty rags, debris from area wash downs, and outdated supplies. Simple and cost-effective ways to reduce these wastes include rigid inventory control, good housekeeping practices, proper paint mixing, increased operator training, high transfer efficiency equipment, proper cleaning methods, alternative coatings, reusable paint booth filters, recycling solvents, and the use of waste exchanges (KSBEAP, p. 21). This chapter presents an overview of these techniques while detailed information on specific technologies are covered in subsequent chapters. Table 7 presents a broad overview of pollution prevention opportunities in coating operations.

Rigid Inventory Control

Rigid inventory control is an efficient and effective way of reducing indiscriminate use of raw materials. The facility should monitor employee operations and make verbal or written comments on product use. Another option is to limit employee access to storage areas containing raw materials. This inaccessibility can force employees to stretch the use of raw materials (EPA, p. 8). Rigid control can reduce solvent use by as much as 50%.

Good Housekeeping

Improvements in better operating practices, or "good housekeeping" methods apply to all emissions and waste streams, require minimal capital outlays, and can be very effective in reducing

wastes and pollutants. Good housekeeping includes the development of management initiatives to increase employee awareness of the need for, and benefits of: pollution prevention; preventative maintenance to reduce the number of leaks and spills; and efficient use of raw materials. Table 6 presents a summary of good housekeeping measures that are described in detail in this chapter.

Many methods are available to control and minimize material losses. The following approaches to bulk material drum consolidation, material transfer methods, evaporation, and drum transport can effectively limit material loss:

- ◆ Control inventory by storing drums together in an area of limited accessibility
- ◆ Reduce leaks and spills by placing drums at points of highest use
- ◆ Use spigots or pumps to transfer materials from storage containers to "working" containers
- ◆ Control evaporation by using tight-fitting lids and spigots
- ◆ Use drip pans
- ◆ Use secondary containment in bulk storage areas
- ◆ Move drums correctly to prevent damage or punctures that could lead to leaks or ruptures during future use (EPA, p. 8).

Paint Mixing

In many cases, facilities will mix a fixed amount of paint for each job (e.g., one pint or one quart). For small jobs especially, the amount of paint prepared often exceeds the amount of paint actually applied. Facilities can encourage the use of the correct amount of paint by having various sizes of paint-mixing and sprayer cups available to limit overmixing. Any paint not used for a job is

Table 6. Opportunities for Improved Housekeeping in Coating Operations (KSBEAP, p. 21)

Waste	Method
General	<ul style="list-style-type: none"> ◆ Improve material handling and storage to avoid spills ◆ Segregate waste streams ◆ Perform preventative maintenance ◆ Practice emergency preparedness ◆ Charge departments generating waste for costs associated with management and disposal
Paint Waste	<ul style="list-style-type: none"> ◆ Maintain rigid inventory control to reduce thinner use ◆ Initiate routine maintenance and training to reduce leaks and spills ◆ Mix paint according to need; document use ◆ Provide operator training to improve transfer efficiency ◆ Schedule jobs to maximize color runs
Solvent Waste	<ul style="list-style-type: none"> ◆ Control inventory to reduce use ◆ Substitute coating material for one with low or no solvents ◆ Substitute cleaning solution for one with low or no solvents ◆ Practice proper equipment cleaning methods ◆ Recycle solvents onsite

usually considered a hazardous waste and should be disposed of as such. A disadvantage to this technique is that if too little paint is mixed for the job and more needs to be made, color matching can be difficult (EPA, p. 9).

Operator Training

Operators may be skilled in producing high quality finishes but poorly trained in minimizing paint use. Technical assistance providers can help operators by teaching them to:

- ◆ Avoid arcing the spray gun and blowing paint into the air
- ◆ Maintain a fixed distance from the painted surface while triggering the gun
- ◆ Keep air pressure (which is often set too high) low; this can increase transfer efficiency by 30 to 60%
- ◆ Keep the gun perpendicular to the surface being painted
- ◆ Use proper on/off trigger technique (KSBEAP, p.23)

High Transfer Efficiency Equipment

Less overspray means reduced emissions. Transfer efficiency is a measure of how much paint actually goes on the product, compared to how much paint is sprayed. Typical transfer efficiency from conventional guns ranges from 20 to 40%, making average overspray rates 60 to 80%. For more information on high transfer efficiency equipment, refer to chapter 7.

Alternative Coatings

Painting usually consists of applying a primer/surfacer followed by one or more coats of paint. VOC emissions are directly related to the types of paints used. Technical assistance programs should assist companies in identifying any potential alternative coatings such as powder, waterborne, or high-solids coatings. For more information on alternative coatings, refer to chapter 6.

Proper Cleaning Methods

Reducing solvent use in equipment cleaning can significantly reduce pollution. This can include:

- ◆ Scraping paint cups or tanks before rinsing with solvent
- ◆ Making use of Teflon-lined metal paint containers that are easier to clean
- ◆ Using an enclosed gun-cleaning station
- ◆ Spraying solvent through the gun into the cleaning station where it is condensed for recovery and reuse
- ◆ Scheduling jobs so that large batches of similar items are painted instead of scheduling jobs so that small batches of custom items are painted. This reduces the amount of solvent

and waste paint generated

- ◆ Scheduling jobs from light to dark colors to minimize cleaning between colors (EPA, p.10)

For more information on proper equipment cleaning methods, refer to chapter 8.

Filters

Reducing the amount of filters used in painting can reduce hazardous waste generation. Facilities should handle filters as a hazardous waste if they contain wet paint (e.g., solvents), due to their

Table 7. P2 Options for Coatings Processes (KSBEAP, p. 23 and IHWRI, p. 39-40)

P2 Options	Description	Benefits
Use Low-VOC Paint	<ul style="list-style-type: none"> ◆ Substitute waterborne, powder, UV curable or high-solids paints for solvent-borne paint ◆ Use paints that have less toxic pigments 	<ul style="list-style-type: none"> ◆ Reduces VOC emissions ◆ Reduces toxicity of paint sludge
Increase Transfer Efficiency	<ul style="list-style-type: none"> ◆ Use electrostatic spraying ◆ Use flow coating, roller coating, or electrodeposition ◆ Improve operating practices ◆ Provide operator training 	<ul style="list-style-type: none"> ◆ Reduces paint loss due to overspray
Reduce Quantity and Toxicity of Solutions Used for Surface Preparation	<ul style="list-style-type: none"> ◆ Reduce solvent evaporation by installing tank lids, increasing freeboard space, and installing freeboard chillers in conventional solvent vapor degreasing units ◆ Use aqueous solutions or mechanical methods ◆ Maximize mechanical or aqueous cleaning processes 	<ul style="list-style-type: none"> ◆ Reduces spent solvents, aqueous solutions and rinsewater from surface preparation ◆ Reduces VOC emissions
Reduce Equipment Cleaning Waste	<ul style="list-style-type: none"> ◆ Use less toxic solvents ◆ Install gun washer ◆ Adopt distillation/recycling practices ◆ Use enclosed cleaning devices 	<ul style="list-style-type: none"> ◆ Reduces VOC emissions ◆ Reduces toxicity of cleaning wastes
Adopt Better Housekeeping Practices	<ul style="list-style-type: none"> ◆ Segregate waste streams ◆ Implement rigid inventory control ◆ Improve material handling and storage ◆ Mix paint according to need; document use ◆ Schedule jobs to maximize color runs ◆ Perform preventative maintenance ◆ Practice emergency preparedness 	<ul style="list-style-type: none"> ◆ Reduces paint waste ◆ Reduces solvent use ◆ Reduces leaks and spills

flammability and the existence of toxics in the paint. One method for reducing filter waste is to use a cleanable polystyrene filter or a reusable metal filter. When the filter is too clogged for use, it can be cleaned by blowing compressed air over the filter until it is clean enough for reuse (paint removed in this process would require collection and may still be classified as a hazardous waste) (EPAr, p. 13).

On-site Solvent Recycling

Several alternatives are available for recycling solvents onsite. Gravity separation is inexpensive and relatively easy to implement. This technique enables a solvent/sludge mixture to separate under quiescent conditions. The clear solvent can be decanted with a drum pump and used for equipment cleaning. This reduces the amount of wash solvent purchased. Reclaimed solvent also can be used for formulating primers and base coats, but might create problems if it is not sufficiently pure.

For those facilities that generate large quantities of waste solvent, on-site distillation may provide a more cost-effective solution. Batch distillation of all high-grade solvent wastes can virtually eliminate the need to purchase lower-quality solvents used in priming and cleaning operations. An operator can reclaim 4.5 gallons of thinner, with 0.5 gallons left as sludge. This ratio will vary depending on the specific operation (EPAr, p. 11). For more information on solvent distillation, refer to chapter 5.

Waste exchanges provide another alternative for reducing waste disposal costs. Waste exchanges are organizations that manage or arrange for the transfer of wastes between companies, where one producer's waste becomes another producer's feedstock. Most exchanges exist as information clearinghouses that provide information on available wastes. Opportunities exist for these exchanges to oversee direct transfer (without processing) of waste solvents from one company to another (KSBEAP, p. 24).

5 Surface Preparation

This chapter covers a variety of surface preparation methods along with technology-specific suggestions for optimizing processes in order to reduce waste. Detailed descriptions of techniques for optimizing traditional cleaning methods and alternative cleaning methods, eliminating pollutants from conversion coatings, and modifying or replacing traditional stripping operations are provided below. For an overview of alternative surface preparation technologies, refer to table 8.

General Description

Methods for surface preparation vary depending on the material to be painted, the paint to be used and the desired properties of the resulting finish (IHWRIC, p. 33). Many products require a preparation step prior to painting. This step is commonly called pretreatment for new products, or paint stripping for products that need to be reworked (Ohio EPA, p. 1). Pretreatment of a metal surface can include chemical-assisted cleaning, mechanical cleaning, and chemical or abrasive blasting, application of conversion coatings or stripping methods.

P2 Tips for Surface Preparation

- ◆ Improve current operating practices
- ◆ Set standards for cleaning and stripping
- ◆ Use aqueous cleaners and/or mechanical methods when possible
- ◆ Maximize the cleaning capacity of current methods

Halogenated solvents have traditionally been used as cleaning and stripping agents. Conventional surface preparation generally involves applying some form of a solvent. However, environmental problems with air emissions often arise from solvent use. In addition, after surface preparation, a waste stream composed of the solvent combined with oil, debris and other contaminants is left for disposal (EPA, p. 1). Fortunately, a number of alternative methods are now widely available.

These are discussed in the cleaning section of this chapter. Surface preparation can consist of a variety of processes including several cleaning steps, conversion coatings, and a stripping operation.

Pollution Problem

Surface preparation can generate a number of wastes, including spent abrasives, solvents and/or aqueous cleaning baths, and surface treatment baths; air emissions from abrasives and solvents; rinsewaters following aqueous processing steps; and solvent-soaked rags used for wiping parts before painting. Depending on the complexity of the operation and the nature of the chemicals used, the volume and toxicity of wastes generated can vary widely (Freeman, p. 484-485).

Removing old paints that contain lead, for example, can be particularly problematic, as abrasive stripping of these paints generates a fine lead dust that is highly toxic to workers. The use of sand and other silica-containing materials in stripping processes also has been associated with lung disease in workers (IHWRIC, p. 48).

Mechanical Cleaning

Usually, the first step in the surface preparation process is to mechanically remove rust or debris from the substrate. Wiping loose dust and dirt off the part is an example of mechanical cleaning. Typically, though, more aggressive mechanical action is needed to remove rust or other contaminants. Rust and metal scale can be removed mechanically by sanding, brushing with a wire brush or plastic "wool" pads, or by using abrasive blasting techniques (KSBEAP, p. 1-2). Abrasive blasting can also be used for removing old paint from products; solvent-based chemical stripping is another option. Environmental concerns and rising chemical prices have pushed more companies into using mechanical cleaning to accomplish a larger portion of the cleaning process (KSBEAP, p. 1).

Chemically-Assisted Cleaning

Traditionally, solvents have been used for removing contaminants such as oils and greases. Companies use various solvent-based methods to clean a workpiece. For example, metal parts can be immersed in a solvent tank (i.e., cold cleaning). Solvents also can be wiped or sprayed onto the parts, or solvent vapor degreasing units can be used. There are environmental problems associated with all of these cleaning methods. Dip tanks get dirty as they are used. Spraying can be wasteful if too much solvent is used. Wiping is labor intensive. Vapor degreasers are regulated under the Clean Air Act and OSHA and pose health hazards. Often a combination of techniques can be used to reduce solvent use and still obtain a properly cleaned workpiece. For example, a dip tank can be used followed by wiping or confined spraying. The key to solvent cleaning is to have the part as clean as possible before it enters the solvent cleaning process (KSBEAP, p.2). Optimizing solvent cleaning systems and alternatives to solvent cleaning are discussed in greater detail in the cleaning section of this chapter.

Conversion Coatings

A conversion coating may be applied to the workpiece prior to painting to improve adhesion, corrosion resistance, and thermal capability. Conversion coatings chemically react with the metal surface to create a physical surface that allows for better paint adhesion. In addition, conversion coatings act as a buffer between the coating and the substrate, reducing the effects of sudden temperature changes. Phosphate and aluminum conversion coatings are usually confined to large operations with elaborate waste treatment facilities because of the extensive regulations controlling the disposal of rinse waters and sludges containing heavy metals. For more information on conversion coatings, refer to the section on conversion coatings in this chapter.

Stripping

When a part needs repainting, the old paint usually must be removed before a new coating can be applied. The first thing a technical assistance provider should do is determine why the piece

needs to be reworked. Reducing reject rates can greatly reduce the amount of waste generated from these processes. Once the need for rework has been reduced, alternative stripping methods can be examined.

General P2 Options for Surface Preparation

This section covers general methods to improve the efficiency of the surface preparation process and to reduce the pollution generated during the surface preparation processes. Detailed information on alternative technologies/processes is discussed.

A cost-effective method for reducing these wastes is to minimize the need for surface preparation by (1) improving current operating practices and (2) setting standards for cleaning and stripping. If the need for surface preparation cannot be reduced by these methods, alternative technologies must be assessed (MnTAP, p. 1). Maximizing the cleaning capacity of current methods also can help reduce wastes (KSBEAP, p. 2). Each of these options is discussed below.

Improve Current Operating Practices

To reduce the need for cleaning, technical assistance providers can help companies examine the sources of workpiece contamination. Technical assistance providers should determine how contaminants such as lubricants from machining, dirt from the manufacturing environment, and finger oil from handling by shop personnel are contaminating the workpieces. Once the contamination sources are identified, technical assistance providers can help determine whether some or all contamination sources can be eliminated by improving current operating practices. For example, proper storage of materials and just-in-time delivery of parts can keep contaminants from becoming a problem (KSBEAP, p. 1). To eliminate finger oil contamination, gloves can be used in areas of parts handling; gloves can be made of lint-free material, or lint can be removed with a dry cloth (OH EPAe, p. 1).

In the case of paint stripping, technical assistance providers can help firms examine what causes the need for paint stripping. Possibilities include: inadequate initial part preparation, defects in coating application, improper time/temperature cycle for the curing oven, and equipment problems or coating damage due to improper handling. While no process is perfect, reducing the need for repainting can greatly reduce the volume of waste generated from paint removal (MnTAP, p. 1-2).

Set Standards for Cleaning and Stripping

Next, companies should determine the cleanliness level or cleanliness standard that is needed. Cleaning requirements are generally based on two factors: process specifications and customer requirements. A system to measure cleanliness should be used to prevent over-cleaning and ensure efficient use of cleaning agents (MnTAPe).¹

In the case of abrasive stripping, standards should be set to avoid blasting a surface longer than necessary, creating excess waste and reducing productivity. Measuring devices can be used to define the level of surface scratching or "profile" desired. Most standards use Structural Steel Painting Council (SSPC) classifications for surface cleanliness. There are two types of standards available: visual disk and photographic. A surface profiler instrument also can be used (Freeman, p. 490-491).

Pollution prevention approaches tends to favor mechanical or aqueous cleaning methods, but solvent vapor degreasing can be more economical and suitable for certain types of parts (e.g., parts that slide into each other to form a close fit, preventing some surfaces from being exposed) (MnTAP, p. 2). Advanced technologies have made both of these processes more effective and less harmful to the environment (Freeman, p. 469). More information on this topic is found in the cleaning section of this chapter.

Maximize Cleaning Capacity of Current Methods²

The following practices should be implemented where possible to maximize the cleaning capacity of aqueous or solvent cleaners:

- ◆ Use countercurrent cleaning (i.e., begin with "dirty" cleaner, followed by "clean" cleaner)
- ◆ Add an additional rinse
- ◆ Recycle cleaning solvent and rinsewater
- ◆ For aqueous cleaners, control water temperature and pressure. For example, elevated temperature solutions are more effective for removing greases and oils (KSBEAP, p. 2)

The following sections provide more detail on specific surface preparation processes including solvent vapor degreasing, aqueous cleaning, alternative solvents, phosphatizing, anodizing, stripping, and abrasive blasting.

Cleaning

This section provides information on a variety of conventional and alternative P2 technologies typically used for cleaning and degreasing metal parts prior to coating.

Solvent Vapor Degreasing

The conventional method used for cleaning most metal parts is vapor degreasing using a variety of halogenated solvents. In vapor degreasing, parts are usually suspended over a solvent tank. The solvents are then heated to their boiling point, which creates a vapor that condenses on the parts and dissolves contaminants. The condensate drips back into the tank along with the contaminants. However, because the contaminants usually have higher boiling points than the solvent, the vapor itself remains relatively pure. The cleaning process is complete when the parts reach the temperature of the vapor, and no more condensate is generated (EPAh, p. 2).

Advantages and Disadvantages

Unlike other cleaning processes involving water, solvent vapor degreasing does not require down-

¹ For more information on setting cleanliness standards, see *Is it Clean? Testing for Cleanliness of Metal Surfaces* by Anselm Kuhn in the September 1993 issue of *Metal Finishing*.

² For more information on extending the life of aqueous cleaning solutions, see *Extending the Life of Aqueous Cleaning Solutions* a fact sheet developed by the Office of Pollution Prevention, Ohio Environmental Protection Agency.

CASE STUDY: Crown Equipment Corporation

Crown Equipment Corporation of New Bremen, Ohio, is a manufacturer of electric lift trucks and antenna rotators. Between 1987 and 1991, Crown removed methyl ethyl ketone (MEK), methyl chloride, toluene and 1,1,1-trichloroethane from its cleaning and degreasing operations by changing over to aqueous cleaning.

In painting operations, Crown has removed lead and chromium from most paint formulations, eliminating hazardous paint waste. Paint sludge is recycled into building materials such as quarry tile, asphalt, mastic, and binder.

Savings

Changing over to aqueous cleaning initially cost Crown \$78,000, but the company now saves more than \$103,000 per year (OH EPAc).

stream drying because the solvent vaporizes from the parts over time. However, solvents such as TCE vaporize resulting in significant VOC emissions and solvent losses (Freeman, p. 468). Other common solvents are either toxic, HAPs, and/or ozone depleters. In fact, conventional vapor degreasing units commonly lose 60% of their solvents through evaporation (SHWEC, p. 1).

Solvent Vapor Degreasing Processes

Conventional vapor degreasing units or open-top vapor cleaners (OTVC) use an open tank where a layer of solvent vapor is maintained. Air emissions from an OTVC occur during startup, shutdown, working, idling, and downtime. However, movement of the work load in and out of the vapor degreaser is the main cause of air emissions (EPAi, p. 7). During startup, losses occur as the solvent in the sump is heated and a vapor layer is established in the open tank. Shutdown losses occur when the unit is switched off and this vapor layer subsides. Downtime losses occur due to normal evaporation of the solvent when the OTVC is not in use. Idling losses occur by diffusion from the vapor layer in the period between loads. Completely enclosed vapor cleaners (CEVC) are available, although use

is generally confined to Europe (Freeman, p. 468-474).

Process Optimization

A number of equipment-related and operational changes can reduce solvent emissions from traditional OTVCs by as much as 50%. Many of these practices are required under the MACT standard since solvent degreasers are regulated under the NESHAP. These include:

- ◆ Minimizing solvent drag-out by improving parts drainage over the tank
- ◆ Superheating vapors
- ◆ Minimizing convective losses by lowering and raising parts with a hoist at a speed less than 11 feet per minute
- ◆ Rotating complex parts
- ◆ Building a degreaser enclosure
- ◆ Placing a cover on the OTVC opening during idling and shutdown
- ◆ Minimizing air movement over the degreaser

Degreasing with Liquid Solvents (Cold Cleaning)

This method of cleaning uses traditional solvents in their liquid form rather than their vapor form to clean the workpiece. This is a common practice in painting operations. Typically, solvents such as methyl isobutyl ketone (MIBK), methyl ethyl ketone (MEK), or 1,1,1 trichloroethane are used. The primary advantage of this method is its versatility. Liquid solvents can be used to clean an entire part by spraying or immersing the part in the solvent, or by wiping with a rag. Typically, this process is used to clean small workpieces rather than parts that are large or have complex geometries.

Like vapor degreasing, capital costs for cold-solvent degreasing generally are low, and the system requires minimal equipment, floor space, and training. Also, spent solvent can be distilled and recycled onsite. In states where the solvent is regulated as hazardous material, however, most facilities send exhausted cleaning solution offsite to commercial recycling operations. Assistance providers should be aware that special safety equipment is required by OSHA for distillation systems.

As with vapor degreasing, the principal limitation of cold solvent cleaning is that emissions from the solvents can be damaging to the environment, and may pose a threat to human health. Other limitations include:

- ◆ Moisture can form on the workpiece and cause rusting problems when solvent evaporates too quickly.
- ◆ Some solvents can leave a residue that reduces the adhesion of the coating.
- ◆ Solvents with low flashpoints can be fire hazards.

Best Management Practices for Cold Cleaning

Best management practices for enhancing efficiency in the cold cleaning process include the following:

- ◆ To minimize emissions, cleaning operations should be done in an enclosed area; if the solvent used is heavier than water and not miscible, a water cover should be used as a vapor barrier.
- ◆ Solvent should be replenished using an enclosed pump system.
- ◆ Consider recommending the use of several tanks that extend the period between solvent changes (EPA, p. 83).
- ◆ Investigate alternative solvents. A variety of less toxic solvents are available and are potentially effective substitutes. A recent U.S. Army study identified the following odorless hydrocarbons with d-limonene as alternatives to Stoddard solvent: Breakthrough, Electron 296, Skysol 100, Skysol, and PF.

For many facilities, the most effective way to reduce waste from cleaning operations is to invest in a new cleaning method. The following section provides information on alternatives to solvent degreasing.

Alternative Cleaning Methods

Aqueous Cleaning

Aqueous cleaning involves the use of solutions which are largely made up of water, detergents, and acidic or alkaline chemicals rather than

solvents. Typically, aqueous cleaning solutions contain at least 95% water. Solutions that include larger percentages of other compounds, including terpenes and other solvents, typically are called semiaqueous (Freeman, p. 707).

Both aqueous cleaning and semiaqueous cleaning are usually more environmentally friendly than traditional solvent cleaning and adapt to a wide variety of cleaning needs. Aqueous cleaning is usually used after mechanical cleaning. A spray, dip, or a combination of both is typically used, depending on the workpiece. The particular solution selected depends on both the type of contaminant and the type of process equipment used (EPA, p. 13). Elevating the temperature of

CASE STUDY: Ball Metal Container Group

Ball Metal Container Group of Findlay, Ohio, produces 12-ounce aluminum beverage cans, drawn and ironed containers, and easy-opening ecology ends. The company has virtually eliminated the use of solvent-based materials by switching to water-based products for its cleaning needs. In October 1990, Ball voluntarily stopped using 1,1,1-trichloroethane to clean parts and printing blankets, opting instead for a substitute of alcohol and a water-based Simple Green solution (OH EPA).

the solution can make it more effective in removing greases and oils, which have increased mobility at higher temperatures (KSBEAP, p. 2). However, solutions that have too high a temperature may set some soils and make them more difficult to remove.

Advantages and Disadvantages

Aqueous cleaning can be used on a wide range of substrates and is less toxic than solvent processes. Some disadvantages include a high rate of water consumption and hazardous wastewater discharge (Freeman, p. 707). In addition, some acids used in aqueous cleaning can cause hydrogen embrittlement, reducing the strength of metal substrates (KSBEAP, p. 2). Ferrous parts need to be dried rapidly to avoid rusting.

Aqueous Cleaning Processes

The conventional aqueous cleaning processes are vibratory deburring and hand-aqueous washing, although automated and power washing processes are available.

In vibratory deburring, soiled parts are placed in an open vessel with an aqueous cleaning solution. The vessel is then rotated, which tumbles the parts. The cleaning solution is removed and clean tap water is added to rinse the parts (Freeman, p. 470-472). In this method, the part is simultaneously cleaned and deburred.

In hand-aqueous washing, parts are dipped by hand into a series of tanks containing surfactant solutions and rinsewater. A continuous clean water flow must be maintained in the final rinse tanks, but the surfactant and other rinse tanks (also known as drag-out tanks) can be used for an entire day without changing the solutions (Freeman, p. 470-472).

The most common automated aqueous washer used in coating operations is a 3- to 7-stage spray washer which uses an overhead conveyor and racks to move the parts. Belted conveyor spray washers are also common, as are multistage agitated immersion washers of various types. Centrifugal washers can be part of an automated aqueous system, but they are uncommon in coating pretreatment systems (Callahan, 1997).

Process Optimization

A number of other processes used as part of an aqueous cleaning system can enhance cleaning effectiveness. These include high-pressure sprays, mechanical agitation, and ultrasonic methods. In fact, in the manufacturing environment, many aqueous cleaning systems are multistaged and include several different processes (Levitan et al., p. 54).

Ultrasonic cleaning uses high-frequency sound waves to improve the efficiency of aqueous and semiaqueous cleaners. By generating zones of high and low pressures in the liquid, the sound waves create microscopic vacuum bubbles that implode when the sound waves move and the zone changes from negative to positive pressure. This process, called cavitation, exerts enormous

localized pressures (approximately 10,000 psi) and temperatures (approximately 20,000°F on a microscopic scale) that loosen contaminants and actually scrub the workpiece (Freeman, p. 472). A typical ultrasonic system moves the pieces through three stages: an ultrasonic cleaning tank containing a water-based detergent; two rinse tanks; and a drying stage (Levitan et al., p. 57). Ultrasonic cleaning can be used on ceramics, aluminum, plastic, and glass, as well as electronic parts, wire, cables, rods, and detailed items that might be difficult to clean by other processes (Freeman, p. 472).

Other Cleaning Methods

The methods described below are not widely used to clean metal parts. However, they can be used as substitutes for conventional solvent vapor degreasing.

Vacuum De-oiling. This method uses a vacuum furnace and heat to vaporize oils from parts. Vacuum furnace de-oiling can be applied where vapor degreasing typically is used to clean metal parts. It also can remove oil from nonmetallic parts. Although capital costs for vacuum de-oiling are high, the operating costs are low. Unlike other clean technologies, vacuum de-oiling does not leave the cleaned parts water soaked, so they do not need to be dried. Because the time and temperature of the de-oiling process depends on the material to be cleaned and the oil to be removed, adjustments might be needed for each new material, oil, or combination. Also, the parts must be able to withstand the required temperature and vacuum pressure (Freeman, p. 478-479).

Laser Ablation. In this method, short pulses of high-peak-power laser radiation are used to rapidly heat and vaporize thin layers of material surfaces. Laser ablation can perform localized cleaning in small areas without affecting the entire part. Laser ablation does not use solvents or aqueous solutions and therefore generates little hazardous waste. The only waste generated is the small amount of material removed from the surface of the item being cleaned (Freeman, p. 479). Laser ablation has been used to strip paint from aircraft. At the other extreme, it has been used to remove sub-micron particles and thin fluid films from semiconductor components (SHWEC, p. 16).

Table 8. Alternatives to Chlorinated Solvent Cleaning (NFESC)

Contaminant	Possible Alternatives
Corrosion Inhibitors	◆ Alkaline-soluble compounds
Fats and Fatty Oils	◆ Hand wipe or use alkaline cleaners
Fingerprints	◆ Handle all fabricated parts with gloves ◆ Use alkaline compounds for hand wiping ◆ Use alcohols with hand wiping
Ink Marks	◆ Use water-soluble inks and remove ink with water ◆ Use labels or tags until final marking is applied
Hydrocarbon Greases and Oils	◆ Institute the use of hand wiping stations to remove enough soil for alkaline cleaning ◆ Use water-soluble compounds
Machining (cutting fluids)	◆ Substitute water-soluble fluids for use in machining
Polishing Compounds	◆ Use water-soluble compounds ◆ Clean at polishing station

Supercritical Fluid Cleaning. This process involves the application of fluids at temperatures and pressures above their critical point to remove contaminants from parts. CO₂ is the most commonly used fluid in this process because it is widely available and considered to be nontoxic. Supercritical fluid cleaning is compatible with stainless steel, copper, silver, porous metals, and silica. It leaves no solvent residue after cleaning and has low operating costs. However, capital costs are high (e.g., \$100,000 for small-capacity equipment) (Freeman, p. 708-709). Therefore, supercritical fluid cleaning has been used mainly in precision cleaning (EPAh, p. 27).

Alternative Cleaners

With the phase out of chlorofluorocarbon (CFC)-based cleaners, there has been an increased interest in investigating alternatives to these chemicals. Table 8 lists typical soils and alternative cleaning methods that are effective in reducing the use of chlorinated solvents.

Chemical Alternatives

Many alternatives to methylchlorofluorocarbons (MCF) and CFC-113 are available for use in cold

cleaning and vapor degreasing applications such as wipe cleaning, dip cleaning, immersion soaking, pressure washing, and vapor degreasing. Some solvents are recommended only for specific applications while others are used for many applications. In general, the following properties are desirable when considering solvent alternatives: low surface tension to penetrate small spaces, high density to remove small particles, high volatility to provide rapid drying, non-VOC, good solvency to readily improve organic soils, low cost, low toxicity, nonflammable, little residue, and easy cleanup and disposal (NFESC).

Drop-in solvent replacements for traditional solvents such as MCF and CFC-113 usually are not possible. However, because vapor degreasing is effective in cleaning delicate parts, some facilities might want to consider maintaining the process with a substitute solvent. Some possible CFC-free alternatives include:

- ◆ **D-Limonene**
Common D-limonene solvent blends have flashpoints higher than 140°F. Therefore, they do not pose an ignitability hazard.

◆ **N-methyl-2-pyrrolidone**

Also known as M-pyrol or NMP, N-methyl-2-pyrrolidone has high purity, a high flash point, and low volatility. It is very effective in ultrasonic applications.

◆ **Volatile Methyl Siloxanes**

Volatile methyl siloxanes (VMS) compounds are relative newcomers to solvent cleaning. They are low molecular-weight silicone fluids available in a variety of blends, exhibiting good compatibility with plastics and elastomers. However, all blends are either flammable or combustible, and somewhat toxic. Advantageous characteristics of VMS include good cleaning capabilities for a wide variety of contaminants, rapid drying without leaving residue on the workpiece, rapid spreading, and good penetration into tight spaces. Also VMS can use existing equipment. Finally, VMS fluids can be distilled for reuse.

◆ **Hydrochlorofluorocarbons**

While hydrochlorofluorocarbons (HCFCs) are similar to CFC-113 and MCF in solvency and cleaning effectiveness, the use of HCFCs is severely restricted because of their ozone-depleting potential and negative health effects. A production ban on HCFCs is scheduled for the year 2010, and could be accelerated at any time. Emission controls are also required for safe operating conditions (NFESC).

◆ **Aliphatic Hydrocarbons**

Aliphatic compounds comprise a wide range of solvents such as mineral spirits and kerosene. These solvents have superior cleaning ability and are compatible with most plastics, rubbers, and metals, and are reusable when distilled. However, aliphatic hydrocarbons are flammable, slow to dry, and have low occupational-exposure limits. Because of this fact, aliphatics have not been considered a desirable substitute for traditional solvents.

◆ **Other Organic Solvents**

Organic solvents, such as ketones, alcohols, ether, and esters, are effective but dangerous. Many are HAPS while others have very low flash points. For example, acetone has a flashpoint of 0°F. Extreme caution is required

when handling these organic solvents. In addition, organic solvents can be toxic and malodorous and, as a result, are not generally used in vapor degreasing. Another major concern is fire danger. Also, in development are hydrofluoroethers (HFE) and perfluorocarbons. These contain no VOCs and are not considered ozone depleting chemicals (ODC). EPA has approved them for use under the Significant New Alternatives Program (SNAP). These chemicals are more volatile than 1,1,1 trichloroethane and CFC-113 and would serve as an ideal replacement when quick drying is important (EPAq, p. 32).

Some companies have begun using other HCFC solvents such as trichloroethylene, perchloroethylene, and methylene chloride. These solvents have been used often in vapor degreasing because of their similarity to CFC solvents in both physical properties and cleaning effectiveness. However, using these alternatives has significant disadvantages for the facility. All of the above three alternatives have been classified as Hazardous Air Pollutants (HAPs) by EPA and are targeted by the Emergency Planning and Community Right-to-Know Act as well. Furthermore, these spent solvents are classified as a hazardous waste. As a result, handling and disposal of these solvents is complicated and more expensive.

Once a part has been cleaned, it can receive a conversion coating prior to the painting process. The next section provides information on conversion coatings and techniques to reduce waste from these processes.

Conversion Coatings

Chemical and electrochemical conversion treatments provide a coating on metal surfaces to prepare the surfaces for painting. These conversion treatments include anodizing and phosphating. Conversion coatings are usually confined to large operations with elaborate waste-treatment facilities because of extensive regulations controlling disposal of rinse water and sludges containing heavy metals.

Anodizing

Anodizing is a specialized electrolytic surface finish for aluminum that imparts hardness and

P2 Tips for Conversion Coatings

- ◆ Avoid soiling the substrate prior to the cleaning process.
- ◆ Analyze water for hardness and dissolved solids. Use alkaline cleaners or phosphate compounds with hard-water stabilizers when necessary.
- ◆ Use low-temperature, energy-conserving, alkaline cleaners or phosphate compounds.

corrosion resistance, increases paint adhesion, provides electrical insulation, imparts decorative characteristics, and aids in the detection of surface flaws on the aluminum. This process employs electrochemical means to develop a surface oxide film on the workpiece, enhancing corrosion resistance. Anodizing is a similar process to electroplating but it differs in two ways. First, the workpiece is the anode rather than the cathode as in electroplating. Second, rather than adding another layer of metal to the substrate, anodizing converts the surface of the metal to form an oxide that is integral to the substrate (SME, 1985).

Industry uses three principal types of anodizing: chromic-acid anodizing (called Type I anodizing), sulfuric-acid anodizing (called Type II anodizing), and hard-coat anodizing, which is a combination of sulfuric acids with an organic acid such as oxalic acids (called Type III anodizing). Because of the structure, the anodized surface can be dyed easily. These dyes include organic or organometallic dyes and often contain chrome in the trivalent state. Whether the pieces are dyed, they need to be sealed. Sealing can be performed with hot water, nickel acetate, or sodium dichromate, depending on the required properties (SME, 1985).

- ◆ Type I (Chromic Acid) Anodizing: Chromic-acid anodizing takes place in a solution of chromic acid. The hexavalent chrome solution creates a thin hard coating (Ford, 1994).
- ◆ Type II (Sulfuric Acid) Anodizing: Sulfuric-acid anodizing takes place in a 15% solution of sulfuric acid. During the anodizing process, aluminum dissolves off the surface of the part and changes the surface characteristics to an oxide coating. This process creates a surface structure that is both porous and harder than

the base aluminum. Sealing of this coating provides greater corrosion protection. When the aluminum concentration in the bath solution builds up to a certain level (15 to 20 grams per liter), the process becomes less efficient and requires treatment (Ford, 1994).

- ◆ Type III (Hard Coat) Anodizing: Hard-coat anodizing is a form of sulfuric-acid anodizing in which the acid content is slightly higher (20%) and an organic additive is added to the bath. This additive helps to create a tighter pore structure that increases the hardness of the oxide coating. Hard-coat anodizing has a high resistance to abrasion, erosion, and corrosion. This type of coating also can be applied in much thicker layers than Type I or Type II anodizing (Ford, 1994).

Various methods are used to treat wastes generated from anodizing bath solutions. Technologies that have been employed successfully include: evaporation systems operating under reduced pressure, sedimentation, reverse osmosis, filtration, and anion and cation exchangers.

Substituting Type I Chromic-Acid Anodizing with Type II Sulfuric-Acid Anodizing

Because of federal and state mandates imposed on operations using hexavalent chrome, researchers have investigated the feasibility of substituting Type I anodizing with Type II sulfuric-acid anodizing. A NASA study found that in applications where anodizing is used to impart corrosion protection on aluminum, Type II sulfuric-acid anodizing is superior to Type I chromic-acid anodizing (Danford, 1992).

According to suppliers, conversion from chromic-acid to sulfuric-acid anodizing is not a simple chemical substitution. The conversion requires a complete changeover of anodizing equipment and partial modifications to downstream waste-treatment facilities. Replacement of the anodizing tank often is required because of the differences in material compatibility between the tank (and tank liner) and sulfuric acid and chromic acid. Sulfuric-acid anodizing processes also have different voltage and amperage requirements, necessitating replacement of the rectifier. The operating temperature of the electrolytic bath also is different for the two processes. The chromic process is

CASE STUDY: Substituting Chromic Anodizing with Sulfuric Acid

In December 1988, General Dynamics replaced a 35-year-old chromic-acid/aluminum-anodizing system with a new sulfuric-acid anodizing system that used computerized hoists and on-demand rinsing. The new system, supplied by NAPCO, Inc., enabled General Dynamics to eliminate a major source of chromium emissions. In addition to the chemical substitution which eliminated chromium releases, automated hoist and on-demand water rinse systems helped to reduce wastewater treatment requirements. The computerized automated hoists monitor the time intervals during which the parts are treated and allowed to drain. Compared with manual immersion and draining of parts, this system reduces treatment requirements by avoiding unnecessary dragout of immersion fluids to downstream rinse tanks. Subsequently, the on-demand water system reduces rinsewater use and wastewater treatment requirements by reducing water consumption and monitoring the conductivity of the rinsewater in the tank. Unlike manually-operated rinse tanks, which have constant overflows, the on-demand system adds water only when the conductivity of the tank exceeds a set value (US EPA 1995).

usually maintained by steam heat at an operating temperature of 90 to 100°F whereas the sulfuric acid process must be chilled using cooling water to an operating temperature of 45 to 70°F.

Operation and maintenance costs are typically much lower for sulfuric-acid anodizing than for chromic-acid anodizing because of lower energy requirements. Wastewater treatment costs are lower as well because sulfuric acid only requires removal of copper whereas chromic acid requires more complex chrome reduction techniques. The change in materials also means that the cost of sludge disposal is greatly reduced.

Sulfuric-Acid Anodize Regeneration with Ion Exchange

Traditionally, facilities use ion exchange to remove metallic contaminants from wastewater streams.

However, ion exchange resins also remove the hydrogen and sulfate components of the sulfuric acid/aluminum anodizing solution. As the solution passes through the columns, the acid is removed. Then the waste stream, which consists of a small amount of acid plus all the aluminum from the anodizing solution, flows to the wastewater treatment system. To recover the acid, platers use water to flush the acid components from the resin. This forms a sulfuric acid solution that is low in dissolved aluminum and can be used again in the anodizing process (Ford, 1994).

Sulfuric-Acid Anodize Regeneration with Electrodialysis

Electrodialysis removes metal ions (cations) from solutions using a selective membrane, an electrical current, and electrodes. This technology uses a chemical mixture (catholyte) as a capture and transport media for metal ions. This catholyte forms a metal sludge and requires periodic change-outs. The recovered sludge is hazardous, and companies might want to work with an outside firm to recover the metal in the sludge. Using electrodialysis, facilities can remove all the metal impurities from the anodizing bath, maintaining the bath indefinitely. By keeping the concentration of contaminants in the process bath low, the rinsewater potentially can be recycled back to the bath, closing the loop on the process. The cost to operate this system depends on the size of the acid anodizing bath, the level of metal concentration, the metal removal capacity of the electrodialysis unit, and the company's ability to reclaim metals in the sludge.

Alodine

Alodine is a nonelectrolytic process used to create a chrome oxide film similar to anodizing. It is widely used in military and aerospace applications.

Phosphate Coatings

Phosphating is used to treat various metals (mainly steel and iron) to impart corrosion resistance and to promote the adhesion of finishes such as paint and lacquers. Phosphating treatments provide a coating of insoluble metal-phosphate crystals that adhere strongly to the base metal. Generally, phosphating solutions are prepared from liquid concentrations containing

one or more divalent metals, free phosphoric acid, and an accelerator (Ford, 1994).

The phosphating process consists of a series of application and rinse stages typically involving the application of either an iron, manganese, or zinc phosphate solution to a substrate. A simple iron phosphating system is composed of two stages: an iron phosphate bath that both cleans the part and applies the conversion coating followed by a rinse bath to remove dissolved salts from the treated surface. An advanced zinc phosphating line might feature seven stages of spray/dip and rinse baths. In addition, a final rinse in a low-concentrate acidic chromate or an organic nonchromate solution is often used to further enhance corrosion resistance and seal the coating. Following the conversion application, the parts are dried to prevent flash rusting (Ford, 1994).

Iron and zinc phosphate coatings often are used as paint bases, and manganese phosphate coatings are applied chiefly to ferrous parts for break-in and galling (e.g., to engine parts). The choice of iron or zinc phosphate coating depends on product specifications. In general, the more extensive multistage zinc phosphate processes provide better paint adhesion, corrosion protection, and rust protection than iron phosphate processes. Zinc phosphate baths, however, tend to be more expensive, require more maintenance, and often result in more sludge disposal (SME, 1985).

Phosphate Coatings for Steel

Iron or zinc phosphate coatings are usually used for steel. In the phosphating process, acid attacks the metal surface, forming a protective coating of iron or zinc phosphate salts. Zinc phosphate forms finer, denser crystals than iron phosphate and has better corrosion resistance and paint adhesion. Accelerators and oxidizers are added to the phosphating solution to improve its effectiveness. Molybdic acid, added for corrosion inhibition, gives a purple cast to iron phosphate coatings. A clean surface is critical to successful application of the phosphate coating (KSBEAP, p.3).

Process time, temperature, and chemical concentration affect the acid's reaction with the steel part. Process time is usually fixed because the line

must run at a certain speed, however, temperature can have a great effect on the phosphating process. In order for the process to run at optimum efficiency, the temperature preceding the phosphating process should be higher than the temperature required for phosphating. This allows the part to become heated prior to entering the phosphating process. If the part is not heated prior to phosphating, process efficiency is reduced. For example, if deposition efficiency is reduced, additional chemicals may be required, and more sludge could be generated. Iron phosphating solutions typically operate between 120 and 140°F, but can also be operated at room temperature.

Cleaning and iron phosphating can be combined in a single solution, however, this is usually successful only when the parts are lightly soiled. It is not possible to use a combination process with zinc phosphating (KSBEAP, p. 3).

Phosphate Coatings for Aluminum

Iron and zinc phosphate coatings are used on aluminum parts or products. The choice of solution largely depends on the volume of aluminum in the process. When a company is processing a small amount of aluminum, the same phosphating solution is typically used for all metals that are processed. For instance, if a company processes mainly steel and a small volume of aluminum, iron phosphating will be the only process used.

Iron phosphating solutions can effectively clean the surface of aluminum and improve paint adhesion. However, they leave little or no coating on the substrate. In order to etch the aluminum, a fluoroborate or fluoride additive is required.

Companies often use chromium phosphate coating for small volumes of aluminum. Often, no-rinse chromium phosphate solutions are used because they have the advantage of not being classified as a hazardous waste. However, they typically provide less corrosion resistance due to incomplete coverage. Chromic acid sealers can be used but they contain hexavalent chromium (KSBEAP, p.3).

Issues with Pretreatment Coatings

The most common problems associated with chemical pretreatment systems are poor adhesion and premature corrosion failure. Frequently these problems are caused by the following:

Residual soils: These soils may be caused by (1) conveyor line speed that exceeds the design limits of the cleaning system, causing low dwell time, (2) inappropriate cleaner for the soils present, and (3) incorrect temperature for the cleaner being used. Generally, high temperatures, 120 to 130°F, are best for good cleaning unless the facility is using a low-temperature cleaner. In that case, high temperatures can be detrimental. To determine the cleaning temperature that removes the soil from the parts, the operator can immerse an uncleaned part into a container of water and begin heating it. The operator should use a thermometer to watch the temperature rise while keeping an eye on the point where the water line touches the part. At some point, the water will become hot enough to visibly loosen the soils, causing globules to float to the surface (CAGE).

Flash rust: This can be caused by (1) excessive line speeds that prevent adequate exposure to the sealer in the final rinse, (2) line stops that overexpose parts to chemicals or allow them to dry off between stages, and (3) lack of sealer in the final rinse. When using a solvent-type cleaning system or an iron phosphate conversion process, wiping with a clean, white cloth is an ideal way to check a part's cleanliness before coating (CAGE).

Aluminum oxide: A natural oxide is present on the surface of aluminum parts. This oxide interferes with adhesion if it is not removed. If a facility is using a combination of iron phosphate and cleaner to remove this oxide, they should be certain that the combination is made for steel and aluminum. Their chemical supplier can discuss this with them in more detail (CAGE).

Inadequate rinsing: This is one of the most common mistakes made in metal cleaning. It is caused by both increased line speeds that reduce rinse-stage dwell time and inadequate rinsewater overflow. Simple tests for inadequate rinsing can include slowing down the production line or hand-rinsing parts in deionized water. If the technical

assistance provider suspects that the company's surface preparation system is causing a problem, they should suggest that the company clean test parts with clean rags dipped in a solvent, instead of running the parts through their normal cleaning process. If this fixes the problem, the firm should focus their investigation on the surface preparation system. If they are getting premature and massive lifting of the coating after exposure to water due to exterior weather elements, or after slat-fog tests, this can indicate inadequate rinsing. Water-soluble crystals (salts) are probably present at the coating and metal interface. Moisture can dissolve these salts quickly. When this happens, rapid undercutting of the film occurs and significant rust forms (CAGE).

Pollution Prevention in the Phosphating Process

Reduced water use is the primary waste reduction option for phosphatizing. The water added to maintain the solution in the phosphatizing bath can be reduced by analyzing and controlling the solution's temperature, chemical concentration, and pH level in each step, and recirculating solution or rinse water from one bath to others when possible. This option also reduces chemical use (Ohio EPA, p.1). A facility should analyze incoming water quality. City water can bring in considerable amounts of dissolved solids, and these contaminants can vary seasonally. The contaminant can have a damaging effect on control regimes. Determining control set points, and treating and conditioning incoming water is a good idea.

Properly matching the phosphating chemicals with the metal substrate is another key issue in minimizing waste from phosphating operations. This can significantly minimize sludge generation. For example, processing galvanized steel in an iron phosphate solution results in excess generation of zinc sludge because the acid reacts with the zinc in the substrate.

Ultrafiltration to Maintain Phosphating Baths

Precipitates continuously form in phosphating operations, primarily on the heating coils in the tanks. This presents challenges in maintaining the baths and often results in dumping of the solution.

When the solution is removed from the tank, this accumulation of sludge must be manually removed. The solution should be decanted back into the tank to minimize waste, but because this requires space and time, it is rarely done. A more efficient system involves the use of a continuous recirculation system through a clarifier with gentle agitation in the sludge blanket zone. This allows for indefinite use of the solution and easy removal of dewatered sludge from the bottom of the clarifier (Steward, 1985).

Stripping

Various methods are available for removing old paint from metal substrates. In some cases, stripping also functions as a cleaning method to remove oils, greases, or other contaminants. Chemical stripping has been used in a number of applications, but there are alternative methods that are less toxic and less costly. Alternatives to chemical stripping include plastic media, sodium bicarbonate, wheat-starch, and carbon-dioxide blasting, as well as high-pressure water, high-energy light, mechanical, cryogenic, and high-temperature thermal stripping. Key factors that must be considered when selecting a paint-stripping method include: the characteristics of the substrate to be stripped; the type of paint to be removed; and the volume and type of waste produced. Waste type and volume can have a major impact on the cost and benefits associated with a change (MnTAP, p. 2). The following section describes conventional chemical stripping and the alternatives.

Chemical Stripping

The conventional method for removing paints from metal surfaces is chemical stripping. This process may involve applying solvents by hand directly to a coated surface. The solvents soften or dissolve the coatings and are usually scraped away or otherwise mechanically removed (Freeman, p. 704-705). Facilities often use a water rinse for final cleaning of the part (EPAG, p. 2). Disassembled parts may be stripped in an immersion tank. Immersion strippers are advantageous because they can strip paint from recessed and hidden areas. This is not possible with abrasive blasting methods.

Chemical-based paint strippers are either hot (i.e., heated) or cold. Many hot strippers use sodium hydroxide and other organic additives. Most cold strippers are formulated with methylene chloride and other additives such as phenolic acids, cosolvents, water-soluble solvents, thickeners, and sealants. Handling and disposal of spent baths and rinses is a major problem for facilities employing both types of strippers (Freeman, p. 704-705).

Many new stripping formulations have been developed including strippers based on formulations of N-methyl-2-pyrrolidone (NMP) and dibasic esters (DBE). Although these new strippers are used in the consumer market, they have not been accepted for use in industrial stripping operations because their effectiveness varies from paint to paint. Compared to the stripping achieved with formulations containing methylene chloride and phenol, many of the substitutes suffer from one or more of the following disadvantages: effectiveness varies with type of paint and extent of cure; elevated temperature is required; and increased stripping time is required. In selecting an alternative, technical assistance providers should make sure that the stripper does not attack the substrate or react with the substrate (i.e., is flammable, combustible, or photochemically reactive) (Freeman, p. 491-492).

Abrasive Blasting

Many facilities have reduced their reliance on chemical-based strippers by converting to abrasive blasting. Abrasive blasting uses mechanical energy to hurl particles at high speed, removing paints and other organic coatings from metallic and nonmetallic surfaces (Freeman, p. 704).

Abrasives commonly used for stripping include steel grit, alumina, garnet, and glass beads. Steel grit creates a rough surface profile on the substrate which aids coating adhesion. Because it is so hard and durable, steel grit can be reused repeatedly, and it generates the least amount of waste per unit of surface area stripped. To maximize the reuse of steel grit, companies must keep the blast media dry to avoid rusting. Alumina is considered to be a multipurpose material that is less aggressive and less durable than steel grit, and it results in a smoother surface profile and less removal of substrate material. Garnet and glass beads are the

least aggressive abrasive and often are used in a single-pass operation (i.e., the abrasive is not recycled). Use of garnet and glass beads is most suitable for preparation of soft materials that are easily damaged, and for maintenance of the dimensional tolerance of the part (Freeman, p. 490-491).

Types of Abrasive Blasting

Companies can use abrasive blasting to remove paint from larger metal structures in the field (field stripping) or from smaller metal structures in a hanger, booth, or blasting cabinet.

Field stripping can be performed in an open area. Operators must wear self-contained breathing equipment in order to be protected from the stripping dust. After blasting, the used abrasive can be shoveled or vacuumed from the area and processed through the reclaimer. Some systems combine dust control and abrasive recovery by including a vacuum collection pickup device with the blasting nozzle (Freeman, p. 490-491).

Blast stripping in cabinets is often performed using manual blast cabinets and automated blasting chambers to remove paint from parts. The abrasive is fed into the cabinet or chamber and directed against the part being stripped. Used abrasive and removed paint are then pneumatically conveyed to a reclaimer. Reusable abrasive is separated from the waste and fines (broken-down abrasives and paint chips) are collected in a dust collector (Freeman, p. 490-491).

Process Optimization

Because the main advantage of chemical-based strippers is their inability to scratch or damage the substrate, most of the abrasives that companies consider as feasible substitutes are relatively soft materials. Glass-bead blasting has become popular because it is the least aggressive of the commonly used abrasives. New alternatives include plastic media, wheat starch, ice crystals, carbon dioxide pellets and sodium bicarbonate slurry (Freeman, p. 490-491). The major disadvantage with these processes is that they can only be used for line-of-sight stripping.

Plastic media blasting

Plastic media blasting (PMB) is an abrasive blasting process designed to replace chemical paint-stripping operations and conventional sand blasting. This process uses soft, angular plastic particles as the blasting medium. PMB is performed in ventilated enclosures such as small cabinets (a glove box), a walk-in booth, a large room, or airplane hangers. The PMB process blasts the plastic media at a much lower pressure (less than 40 psi) than conventional blasting. PMB is well suited for stripping paints, because the low pressure and relatively soft plastic medium have a minimal effect on the surfaces beneath the paint (TSPPO).

Plastic media are manufactured in 6 types and a variety of sizes and hardness. Military specifications (MIL-P-85891) have been developed for plastic media. The specifications provide general information on the types and characteristics of plastic media. The plastic media types are:

- Type I Polyester (Thermoset)
- Type II Urea formaldehyde (Thermoset)
- Type III Melamine formaldehyde (Thermoset)
- Type IV Phenol formaldehyde (Thermoset)
- Type V Acrylic (Thermoplastic)
- Type VI Polyallyl diglycol carbonate (Thermoset)

Facilities typically use a single type of plastic media for all of their PMB work. The majority of DOD PMB facilities use either Type II or Type V media. Type V media is not as hard as Type II media and is gentler on substrates. Type V media is more commonly used on aircraft. Type II is better suited for steel-only surfaces (TSPPO).

After blasting, the PMB media is passed through a reclamation system that consists of a cyclone centrifuge, a dual adjustable air wash, multiple vibrating classifier screen decks, and a magnetic separator. In addition, some manufacturers provide dense particle separators as a reclamation system. The denser particles, such as paint chips, are separated from the reusable blast media, and the reusable media is returned to the blast pot. Typically, media can be recycled 10 to 12 times before becoming too small to remove paint effectively (TSPPO).

Waste material consists of blasting media and paint chips. The waste material may be classified as a RCRA hazardous waste because of the presence of certain metals (primarily lead and chrome from paint pigments). An alternative solution to handling the potential hazardous waste is to recycle the media to recapture the metals.

Reusing the plastic blasting media greatly reduces the volume of spent media generated as compared to that generated in sand blasting. When compared to chemical paint stripping, this technology eliminates the generation of waste solvent. PMB is also cheaper and quicker than chemical stripping. The U.S. Air Force and airlines have found PMB effective for field stripping of aircrafts, but PMB could also be used to strip vehicles, ships, and engine parts (IHWRI Cf). However, PMB can cover fatigue cracks at high blast pressures and prevent their detection.

As with any blasting operations, airborne dust is a safety and health concern with PMB. Proper precautions should be taken to ensure that personnel do not inhale dust and particulate matter. Additional protective measures should be taken when stripping lead chromate- or zinc chromate-based paints, as these compounds may be hazardous. Inhalation of lead and zinc compounds can irritate the respiratory tract, and other paint compounds are known to be carcinogenic. Inhalation of paint solvents can irritate the lungs and mucous membranes. Prolonged exposure can affect respiration and the central nervous system. Operators must wear continuous-flow airline respirators when blasting operations are in

progress in accordance with OSHA requirements as specified in 29 CFR 1910.94 (TSPPO).

PMB systems can range in cost from \$7,000 for a small portable unit to \$1,400,000 for a major facility for aircraft stripping.

Vacuum Sanding Systems

A vacuum sanding system is essentially a dry-abrasive blasting process (e.g., sand blasting or plastic media blasting) with a vacuum system attached to the blast head that collects the blast media and the removed coating material (paint or rust). The unit then separates the used blast media from the removed coating material. The remaining blast material is recycled for further use, and the coating material is disposed.

This system is designed to replace chemical paint stripping, and has three added advantages. The first advantage is its collection of both the blasting media (sand, PMB, or other media) and its collection of the waste coating material being removed. The second advantage is that it separates the media from the waste material by a reverse pulse filter, and the media is reused in the system, thereby minimizing the quantity of media required. The third advantage is that, due to the confinement of the blast material, this technology may be used when it is impractical to use traditional sand blasting or chemical stripping (TSSOP).

Vacuum sanding is a stand-alone system, including the air compressor to drive the system. The units are portable (skid mounted) and can be moved by

Table 9. Advantages and Disadvantages of Plastic Media Blasting

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Can be recycled for use (10-12 recycling events) ◆ Eliminates wastewater disposal costs (typical in chemical paint-stripping operations) ◆ Eliminates production of waste solvents when compared to chemical paint stripping ◆ Has a high stripping rate ◆ Has no size limitations 	<ul style="list-style-type: none"> ◆ Requires substantial capital equipment investment ◆ May generate hazardous waste ◆ May require different operator time, maintenance requirements, and handling and disposal methods for waste depending upon material stripped ◆ May limit quality depending on skill and experience level of the operator ◆ May not be used in certain military applications because of limits in specifications ◆ May not remove corrosion

a forklift. The air compressor is a trailer unit (2-wheeled). The waste material may be classified as a RCRA hazardous waste because of the presence of metals in the waste (TSSOP).

This technology reduces pollution because the portable vacuum sander removes coatings and corrosion from composite or metal structures while capturing the media and solid waste. Vacuum sanding eliminates airborne particulate matter and potential lead-dust exposure hazards. When compared to chemical paint stripping, this technology eliminates the generation of waste solvent (TSSOP).

Storage and handling of sand or plastic media and blast waste associated with vacuum sanding pose no compatibility problems. Collection systems should not mix different types of waste, and should ensure that the most economic disposal method can be obtained for each. Prior to using plastic media for de-painting operations, personnel should check applicable military specifications [such as (MIL-P-85891)] and operations manuals for the PMB systems. Some military specifications do not allow PMB for de-painting certain

types of materials (e.g., fiberglass, certain composites, honeycomb sandwich structures, and some applications with thin-skinned aircraft components). In certain cases, PMB can inhibit crack detection on softer alloys used for aircraft components (e.g., magnesium) (TSSOP).

Airborne dust, which is an important safety and health concern with any blasting operation, is essentially eliminated using the vacuum blasting system. However, in order for the vacuum system to be effective, the vacuum and blasting head must be kept in contact with the material being stripped of paint or corrosion. Therefore, training operators in the proper use of the equipment is essential. In addition, eye protection and hearing protection are recommended (TSSOP).

Vacuum sanding systems can range in cost from \$17,000 to \$40,000, excluding the portable generator to operate the system.

Sodium Bicarbonate

Sodium bicarbonate is another media that companies can use to remove paint. The process that

Table 10. Advantages and Disadvantages of Vacuum Sanding Systems

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Improves personnel safety by eliminating airborne particulate matter and potential lead dust exposure hazards ◆ Eliminates the need for the use of respirators while blasting ◆ Separates waste material from blasting media, therefore, the media can be recycled ◆ Is versatile and can use multiple media types ◆ Eliminates wastewater disposal costs (typical in chemical paint-stripping operations) ◆ Eliminates the production of waste solvents when compared to chemical paint stripping ◆ Can be portable ◆ Has self-supplied power/air compressor ◆ Minimizes emissions from portable (mobile source) diesel air compressors so no air permit required ◆ Minimizes the clean-up time because blast material is contained ◆ Contains contaminated coatings 	<ul style="list-style-type: none"> ◆ Requires substantial capital equipment investment ◆ Requires disposal of used blasting materials and waste coating as a hazardous waste ◆ Requires operator training ◆ May vary operator time, maintenance requirements, and handling and disposal methods depending upon material to be stripped ◆ May vary quality of stripping depending on skill and experience level of the operator

uses sodium bicarbonate can be used with or without water. However, it is most frequently applied with water, which acts as a dust suppressant. The water-based process uses a compressed air delivery system that transfers the sodium bicarbonate from a pressure pot to a nozzle, where the sodium bicarbonate mixes with a stream of water. The soda/water mixture impacts the coated surface and removes old coatings from the substrate. The water dissipates the heat generated by the abrasive process, reduces the amount of dust in the air, and assists in paint removal through hydraulic action. Workers do not have to prewash or mask the surface of the material being stripped. The solid residue from the wastewater generated can be separated by filtration or settling (NFESC).

The effectiveness of sodium bicarbonate stripping depends on optimizing a number of operating parameters such as nozzle pressure, standoff distance, angle of impingement, flow rate, water pressure, and traverse speed. In general, sodium bicarbonate stripping systems remove paint more slowly than chemical stripping. The type of equipment used may also bring about significantly different results.

Use of sodium bicarbonate in its dry form (or when it is not fully mixed with water) can create a cloud of dust that requires monitoring and may require containment to meet air-quality standards. The dust is not an explosive hazard nor is it toxic, but air particulates generated from stripping operations can contain toxic elements. This process should be conducted in areas where exhaust particulates can be contained and/or vented to ventilation systems to remove hazardous airborne particulates.

Approximately 150 to 200 pounds of bicarbonate is needed per hour, while PMB requires 800 pounds. In the end, bicarbonate is cheaper than PMB because it neither generates large amounts of waste nor damages the metal. Nevertheless, sodium bicarbonate can have long-term corrosive effects because alkaline compounds that remain on the metal can foster corrosion or interfere with the paint bonding. Corrosion inhibitors can be added; however, the waste might then become hazardous, depending on the type of inhibitor used (IHWRICf).

Wastewater disposal methods and sodium bicarbonate waste disposal methods will depend on the toxicity of the coatings and pigments that are removed in the stripping process. The waste generated from bicarbonate of soda stripping systems in the wet form is a slurry consisting of sodium bicarbonate media, water, paint chips, and residues such as grease and oil. Some facilities are using centrifuges to separate the water from the contaminated waste stream, reducing the amount of hazardous waste. Filtered wastewater containing dissolved sodium bicarbonate may be treated at industrial wastewater treatment plants. In its dry form, the waste includes nuisance dust, paint chips, and residues of grease and oil. This waste may be disposed of in a solid waste landfill; however, due to the possibility of toxics in the paints and the presence of oils, the material should be tested prior to landfill disposal (NFESCa, p.4).

Wheat starch blasting

Wheat starch blasting is a user-friendly blasting process where wheat starch is used in systems designed for plastic media blasting, as well as systems specifically designed for wheat starch blasting. The wheat starch abrasive media is a crystallized form of wheat starch that is nontoxic, biodegradable, and made from renewable resources. The media is similar in appearance to plastic media, but it is softer (TSSPO).

The wheat starch blasting process propels the media at less than a 35 psi nozzle pressure for most applications. The low pressure and relatively soft media have minimal effects on the surfaces beneath the paint. For this reason, wheat starch is well suited for stripping paints without risking damage to the substrate. Examples of suitable applications include removing paint from aluminum alloys and composites like graphite and fiberglass (Kevlar).

The wheat starch blasting process can remove a variety of coatings. Coating types range from resilient rain erosion-resistant coatings found on radar absorbing materials to the tougher polyurethane and epoxy paint systems. The wheat starch system has been shown to be effective in removing bonding adhesive flash (leaving the metal-to-metal bond primer intact), vinyl coatings, and sealants. It has also been found to be effective in

Table 11. Advantages and Disadvantages of Sodium Bicarbonate (NFESCa p. 4)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Significantly reduces the amount of hazardous waste generated when compared to chemical stripping ◆ Reduces the number of hours required for stripping when compared to chemical stripping ◆ Selectively removes individual coating layers ◆ Does not require prewashing and masking in most applications ◆ Avoids size limitations for parts being stripped ◆ Enables wastewater stream to be centrifuged to reduce waste volume or to be treated at an industrial wastewater facility ◆ Reduces costs because blast media is usually less expensive than plastic media, wheat starch, and carbon dioxide pellets 	<ul style="list-style-type: none"> ◆ Requires subsequent washing of the item; thus electrical components cannot be exposed to this stripping process ◆ Although the water can be separated for disposal, cannot recycle sodium bicarbonate solution ◆ May require monitoring ◆ May require containment

removing the paint from cadmium parts, while leaving the cadmium plating intact (TSSPO). Wheat starch blasting is mainly known for its gentle stripping action and is particularly suited for stripping operations on soft substrates, such as aluminum, very soft alloys, anodized surfaces, or sensitive composites.

There are several important components in wheat starch systems. First, a moisture control system is needed to control the storage conditions of the medium. This is especially important when the system is shut down for extended periods of time. Second, to remove contaminants from the wheat starch media, the spent wheat starch residue is dissolved in water and then either filtered or separated in a dense particle separator/centrifuge. The wheat starch media is recycled in the system and may be used for up to 15 to 20 cycles. Low levels of dense particle contamination in the media may result in a rough surface finish on delicate substrates. The waste stream produced from this process consists of sludge generated from the wheat starch recycling system. This system produces approximately 85% less waste sludge compared to the waste sludge produced in chemical stripping (TSSPO).

Wheat starch blasting can be used on metal and composite surfaces. Direct contact of wheat starch

with water must be avoided to maintain the integrity of the blast media. Wheat starch blasting requires explosion protection. If conditions are right, a static electrical charge developed by a high velocity wheat starch particle in the air could ignite the material. Preventive measures must be taken.

As with other blasting procedures, airborne dust is a safety and health concern. Proper precautions should be taken to ensure that personnel do not inhale dust and particulate matter. Additional protective measures should be taken when stripping lead, chromate, zinc chromate, or solvent-based paints, as these components may be hazardous. Inhalation of lead and zinc compounds can irritate the respiratory system and some compounds are known to be carcinogenic. Inhalation of paint solvents can irritate the lungs and mucous membranes. Prolonged exposure to these emissions can affect respiration and the central nervous system. Proper personal protective equipment should be used (TSSPO).

Capital costs for wheat starch blasting systems vary depending upon the application. A PMB system for a small application can be modified for a cost of approximately \$10,000. An automated, closed, dust-free system for a large application (e.g., aircraft) can cost up to \$1.5 million. The operating costs for wheat starch blasting systems

Table 12. Advantages and Disadvantages of Wheat Starch Blasting (TSSPO)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Is biodegradable ◆ Can treat in a bioreactor ◆ Lowers waste volume to an estimated 5% of original volume ◆ Can be used for removing coatings from both metallic and composite materials ◆ Is easily controlled ◆ Can be used to selectively remove from one to all coating layers ◆ Does not cause fatigue to the substrate surface ◆ Can achieve moderate stripping rates while maintaining a gentle stripping action ◆ Is safe on soft-clad aluminum ◆ Has inexpensive and non-toxic material ◆ Eliminates water use ◆ Are no size limitations on parts being stripped 	<ul style="list-style-type: none"> ◆ Has high capital investment cost ◆ Requires complex subsystems for media recovery and recycling and dust collection and control ◆ Requires operator training ◆ May result in a rough surface finish on delicate substrates if low levels of dense particle contamination exist ◆ May require high disposal costs ◆ Typically slow to moderate stripping rate ◆ Requires operators to wear personal protective equipment ◆ May require an air dryer for humidity control

have been estimated to be 50% less than those for chemical paint stripping (such as methylene chloride).

Carbon dioxide

Carbon dioxide (CO₂) blasting is an alternative process to chemical cleaning and stripping. The obvious advantage of CO₂ blasting over chemical stripping is the introduction of inert media that dissipates, in this case CO₂. There are two basic types of CO₂ blasting systems: pellet blasting for heavy cleaning and snow blasting for precision cleaning.

CO₂ Pellet Blasting

CO₂ pellets are uniform in shape and the effectiveness of the pellets as a blast medium is similar to abrasive blasting. However, the pellets do not affect the substrate; therefore, CO₂ pellet blasting is technically not an abrasive operation. This process can be used for cleaning, degreasing, some de-painting applications, surface preparation, and de-flashing (flashing is the excess material formed on the edges of molded parts).

The process starts with liquid CO₂ stored under pressure (~850 psig). The liquid CO₂ is fed to a pelletizer, which converts the liquid into solid CO₂ snow (dry ice flakes), and then compresses the dry ice flakes into pellets at about -110°F. The pellets are metered into a compressed air stream

and applied to a surface by manual or automated cleaning equipment with specially-designed blasting nozzles. The CO₂ pellets are projected onto the target surface at high speed. As the dry ice pellets strike the surface, they induce an extreme difference in temperature (thermal shock) between the coating or contaminant and the underlying substrate, weakening the chemical and physical bonds between the surface materials and the substrate. Immediately after impact, the pellets begin to sublime (i.e., vaporize directly from the solid phase to a gas), releasing CO₂ gas at a high velocity along the surface to be cleaned. The high velocity is caused by the extreme difference in density between the gas and solid phases. This kinetic energy dislodges the contaminants (e.g., coating systems and flash), resulting in a clean surface. Variables that facilitate process optimization include the following: pellet density, mass flow, pellet velocity, and propellant stream temperature.

CO₂ pellet blasting is effective in removing some paints, sealants, carbon and corrosion deposits, grease, oil, and adhesives, as well as solder and flux from printed circuit board assemblies. Furthermore, because CO₂ pellet blasting is not an abrasive operation, it is excellent for components with tight tolerances. This process also provides excellent surface preparation prior to application of coatings or adhesive and is suitable for most

metals and some composite materials. However, thin materials may be adversely affected. Blasting efficiency is approximately equal to that of other blasting operations. CO₂ blasting can be done at various velocities: subsonic, sonic, and even supersonic. Therefore, equipment noise levels are high (between 95 and 130 dB). This operation always requires hearing protection.

Waste cleanup and disposal are minimized because only the coating or contaminated residue remains after blasting. No liquid waste is created because CO₂ pellets sublime to CO₂ gas. They pass from a liquid to a gaseous state, leaving no spent media residue. With regard to air pollution control, small quantities of coating particles are emitted to the air. A standard air filtration system should be utilized.

CO₂ Snow Blasting

In contrast to CO₂ pellet blasting, CO₂ snow blasting is a low impact process. This process applies primarily to precision cleaning. A typical precision cleaning operation must clean small contaminant particles that, due to electrostatic attraction, attach to surfaces and/or surface layers of adsorbed moisture or soil. These particles are so small that a large fraction of their surface area attaches to the surface layers. CO₂ snow blasting is most effective in breaking the adhesive forces and dislodging particles from the substrate surface. Small flakes of dry ice transfer their kinetic energy to submicron particulate contaminants and then sublime, lifting the particulate matter from the substrate surface as the adhesive bonds are broken. This process is often used as a final cleaning process for submicron particulate removal and light soils removal.

CO₂ snow is generated from liquid CO₂, and is discharged directly from the nozzle of the blasting device. The liquid CO₂ is partially vaporized as it passes through the nozzle, while the rest of the stream solidifies as pressure is reduced. The fine particles of "snow" are propelled by the fraction of CO₂ that vaporizes. No compressed air or other inert gas is needed to propel the snow.

Many of the blasting media described in the previous sections cannot be used in precision cleaning because either they are too aggressive, or

they contaminate the component with media residue. CO₂ snow, however, is ideal for this application because it is relatively gentle in application, leaves no media residue, is highly purified, and does not introduce new contaminants. CO₂ snow blasting is often done in a clean room or cabinet purged with nitrogen to provide a dry atmosphere, minimizing moisture buildup on the component (TSSOP).

As a completely oxidized compound, CO₂ is a nonreactive gas, and thus is compatible with most metals and nonmetals. Dry ice processes are cold and can cause thermal fracture of a component. In addition, prolonged use in one spot will cause condensation and ice buildup. However, this is rarely a problem for CO₂ blasting because it is a fast-acting, nonstationary process. Particulate and organic contamination is either quickly removed or unable to be removed by continued blasting. Therefore, the component temperature does not change much, because contact time is short. Nevertheless, should component temperature drop below the dew point of the surrounding atmosphere, moisture will accumulate on the component. This problem can be mitigated by heating the component in some manner so that its temperature remains above the surrounding atmosphere's dew point after blasting. If components cannot take heat, then blasting can be done in an enclosed space purged with a dry gas to lower or eliminate the dew point problem (TSSOP).

CO₂ does not support combustion and it is nontoxic; however, it is an asphyxiant. CO₂ will displace air because its density is greater than that of air, causing CO₂ to accumulate at the lower level of enclosed spaces. When blasting with CO₂ pellets, additional ventilation should be provided for workers in enclosed spaces. Companies should also require use of personal protection equipment (PPE) when blasting (TSSOP).

Static energy can build up if grounding is not provided. CO₂ blasting should not be done in flammable or explosive atmospheres. High-pressure gases should be handled with great care. Companies should always chain or secure high-pressure cylinders to a stationary support such as a column.

CO₂ Pellet Blasting:

1. Units come in several different configurations.
2. The blasting unit can be purchased. Prices range from \$25,000 to \$50,000.
3. The blasting unit can also be rented. Monthly payments range from \$1,500 to \$2,500.
4. Units that combine pelletizing and blasting are also available, but generally are not economical unless the blasting operation is performed 24 hours/day, 7 days/week.
5. Pellet blasting jobs can be done on a contract basis for a cost between \$200 to \$300 per hour including labor, pellets, and equipment (not including travel time or travel expenses).
6. A stand-alone pelletizer can be purchased for between \$50,000 to \$130,000 (the cost to make pellets from delivered liquid carbon dioxide is about \$0.10 to 0.15/lb).

**Purchased directly from a manufacturer for between \$0.10 and \$0.50/lb delivered, depending on the purity and the distance from the manufacturer (pelletizer purchase is reported to be economical only if blasting is done more than 40 hours/week). (TSPPO)*

CO₂ Snow Blasting:

Units are much lower in cost and operation as compared to CO₂ pellet blasting, and again there are several different configurations to choose from:

1. All manual units cost about \$2,000.
2. Semi-automated units, which can also be used in assembly applications, cost between \$3,000 and \$5,000.
3. For the highest quality of precision cleaning with substantial volume requirements, CO₂ purifiers are also available. Units that can purify commercial grade liquid CO₂ start at about \$5,000. (TSPPO)

Sponge Blasting

Sponge blasting systems are a class of abrasive blasting that uses (1) grit-impregnated foam and (2) nonabrasive blasting media using foam without grit. These systems incorporate various grades of

water-based urethane-foam cleaning media. Firms use the nonabrasive media grades to clean delicate substrates. The abrasive media grades are used to remove surface contaminants, paints, protective coatings, and rust from a variety of surfaces. In addition, the abrasive grades can be used to roughen concrete and metallic surfaces. A variety of grit types are used in abrasive media including aluminum oxide, steel, plastic, or garnet (TSPPO).

The foam cleaning medium is absorptive and can be used either dry or wet with various cleaning agents and surfactants to capture, absorb, and remove a variety of surface contaminants such as oils, greases, lead compounds, chemicals, and radionuclides. The capability of using the foam cleaning medium in a wet form provides for dust control without excessive dampening of the surface being cleaned. The equipment consists of three transportable modules, which include the feed unit, the classifier unit, and the wash unit (TSPPO).

The feed unit is pneumatically powered for propelling the foam cleaning medium. The unit is portable and produced in several sizes. A hopper, mounted at the top of the unit, holds the foam medium. The medium is fed into a metering chamber that mixes the foam cleaning medium with compressed air. By varying the feed-unit air pressure and type of cleaning medium used, sponge blasting can remove a range of coatings from soot on wallpaper to high-performance protective coatings on steel and concrete surfaces (TSPPO).

The classifier unit removes large debris and powdery residues from the foam medium after each use. The used medium is collected and placed into an electrically-powered sifter. The vibrating sifter classifies the used medium with a stack of progressively finer screens. Coarse contaminants, such as paint flakes and rust particles, are collected on the coarse screens. The reusable foam medium is collected on the corresponding screen size. The dust and finer particles fall through the sifter and are collected for disposal. After classifying, the reclaimed foam medium can be reused immediately in the feed unit. The abrasive medium can be recycled approximately six times and the nonabrasive

Table 13. Advantages and Disadvantages of Carbon Dioxide Blasting (TSPPO)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Significantly reduces the amount of hazardous waste and hazardous air emissions generated compared to chemical stripping. ◆ Reduces the time required for cleaning/stripping processes by 80 to 90% ◆ Leaves no residue on the component surface ◆ Is effective in precision cleaning ◆ Introduces no new contaminants 	<ul style="list-style-type: none"> ◆ Is not always a one-pass operation; an effective blasting operation usually requires multiple passes to achieve the desired effect ◆ Requires operator training ◆ Can have high capital costs ◆ Can damage the components surface in fixed position blasting operations ◆ Generates solid waste containing coating chips that are potentially hazardous; media does not add to the volume of solid waste ◆ May carry coating debris that can contaminate workers and work area ◆ May redeposit some coating debris on substrate ◆ Can increase workers fatigue in non-automated systems because of cold temperature, weight, and thrust of the blast nozzle ◆ Can increase potential hazards from compressed air or high velocity CO₂ pellets

medium can be recycled approximately 12 times (TSPPO).

During degreasing applications, the foam medium must be washed every 3 to 5 cycles. The washing of the foam medium takes place in the wash unit, which is a portable centrifuge, closed-cycle device. The contaminated wash water is collected, filtered, and reused within the wash unit (TSPPO).

This system removes paint, surface coatings, and surface contaminants from a variety of surfaces. Waste streams produced from this system include: coarse contaminants, such as paint flakes and rust particles; dust and finer particles; and the concentrated residue from the bottom of the wash unit.

This technology helps prevent pollution for two reasons: the stripping media can be recycled (i.e., every 10 to 15 events), and the quantity of wastewater that is typically generated using conventional methods (e.g., chemical stripping) is greatly reduced. Sponge blasting systems are compatible in most situations where other types of blasting media have been used.

As with any blasting operations, airborne dust is a safety and health concern. Proper precautions should be taken to ensure that inhalation of dust and particulate matter is avoided. Additional protective measures should be taken when stripping lead chromate- or zinc chromate-based paints, as these compounds may be hazardous. Inhalation of lead and zinc compounds can irritate the respiratory tract, and some compounds are known to be carcinogenic. Proper personal protective equipment should be used.

High- and Medium-Pressure Water Stripping

High- and medium-pressure water blast systems are used for paint stripping surfaces with low-volume water streams at pressures ranging from 3,000 to 15,000 psi (medium-pressure operations), and 15,001 to 55,000 psi (high-pressure operations). These systems remove paint by spraying a stream of high-pressure water at the surface of the part. The advantages of this process include a readily available medium (water), an easily treatable waste stream, and an absence of fume and hazardous waste production. A disadvantage of this process is the necessity for an automated system that usually uses robotics. Robotics is required for application due to the

Table 14. Advantages and Disadvantages of Sponge Blasting Systems (TSPPO)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Is safer for operators compared to other blasting media and chemical stripper systems ◆ Is easily transportable ◆ Achieves waste minimization by recycling the sponge media (i.e., can recycle sponge media an average of 10 to 15 times) ◆ Absorbs and removes contaminants ◆ Reduces dust generation 	<ul style="list-style-type: none"> ◆ Costs are more expensive than sand blasting media ◆ Requires reasonably large capital investment

extremely high pressure of the water stream (Freeman, p. 491).

Medium-pressure systems may be augmented. For example, sodium bicarbonate may be added to the water stream, or environmentally compliant chemicals may be applied to painted surfaces prior to water blasting. High-pressure systems typically use pure water streams. With both medium- and high-pressure water systems, specialized nozzles can be used to achieve varying effects. A relatively gentle, layer-by-layer process may be used for removal of organic paints versus the use of a different nozzle for the removal of metal flame spray coating and other tough, tightly adherent coatings. The process water, paint, and residue are collected by an effluent-recovery system that filters the paint and residue. The recovery system removes leached ions (e.g., copper, cadmium, and lead), microparticulates, chlorides, sulfates, nitrates, and other contaminants from the water. The water is then passed through a coalescing tank for removal of oils and film, then through charcoal filters, microfilters, and finally, a deionization system to ensure that the water is Grade A deionized water. The recovered deionized water is recycled back into the process (TSSOP).

No material compatibility problems have been documented for use of high- and medium-pressure water processes to de-paint metallic surfaces. The use of specific chemicals to augment medium-pressure water processes must be evaluated on a case-by-case basis. The automotive industry currently uses high-pressure water jets to remove paint from the floor of painting booths (IHWRI Cf).

The capital costs for high- and medium-pressure water processes vary considerably depending on the process and its application. Capital costs for medium-pressure systems range from \$40,000 to \$70,000, and capital costs for high-pressure systems range from \$850,000 to \$1,500,000.

Fluidized Bed Stripping

The fluidized bed paint removal process is an alternative method to chemical paint stripping and degreasing of nonaluminum and nonheat sensitive metal parts. In fluidized bed stripping, an air stream is pumped into a tank of quartz sand or aluminum oxide, making it a fluid. Natural gas is mixed with the air and ignited above the tank, creating temperatures of approximately 800°F. Objects to be stripped are lowered in a basket into the tank. The paint is vaporized, and the gases and unburned natural gas are burned in a postcombustion chamber above the tank. A wet scrubber removes the solids from the final exhaust before it is vented into the air. The most notable advantage of this process is that it produces no solvent wastes. This method works for steel parts but not for aluminum parts (IHWRI Cf). Technical assistance providers should not recommend the fluidized bed paint stripping (FBPS) process for use with aluminum and aluminum alloy parts because these materials lose essentially all of their hardness or temper when exposed to the 700 to 800°F process temperatures (TSSOP).

The FBPS process typically consists of the following four components: 1) fluidized bed furnace or retort, 2) fluidized bed cooling system, 3) off-gas treatment system consisting of a cyclone, afterburner and scrubber, and 4) low

Table 15. Advantages and Disadvantages of a Water Blasting System (TSPPO)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces hazardous waste by 90% ◆ Selectively removes individual coating layers ◆ Does not need pre-washing, and masking is not needed in most applications ◆ Are no size limitations for parts being stripped ◆ Generates wastewater stream that is compatible with conventional industrial wastewater plants located at many installations ◆ Has low implementation cost utilizing simple robust equipment ◆ Reduces the process material costs significantly ◆ Reduces labor hours for the stripping process by 50% ◆ Generates no dust or airborne contaminants ◆ Requires no cleanup after stripping 	<ul style="list-style-type: none"> ◆ Has high capital costs ◆ Removes one layer at a time ◆ May not remove corrosion ◆ Must consider the substrates to be removed for impact on personal protection and waste collection/disposal ◆ Generates a potential hazardous waste stream ◆ Requires review of wastewater disposal requirements for toxicity of the coating being removed ◆ Must protect employees from direct impingement of water jet ◆ Requires operator training ◆ Can damage joints, seals, and bonded areas by water penetration ◆ Requires additives to the water that may have an adverse effect (i.e., flash rusting) on the surfaces being cleaned ◆ Has variable stripping rates from differences in type of paint, coating condition and coating thickness

energy shot-blast unit. The fluidized bed furnace or hot bed is where pyrolysis of the coatings takes place. A granular material, aluminum oxide (alumina) in most cases, is used as a heat-transfer medium. Air passing through the bed keeps the medium fluidized. Parts to be cleaned are lowered into the fluidized bed, which quickly heats the part and its surface coatings (e.g., paint, grease, and oil) to a temperature at which organic components of the surface material pyrolyze into carbon oxides, other gaseous combustion products, and char. The fluidized bed cooling system, or cold bed, is used to cool the parts after the organics have been pyrolyzed. Carbon monoxide and volatile organic compounds (VOCs) generated during pyrolysis are burned in the afterburner. The thermal decomposition of paint leaves some carbon and inorganic char on the part. Most of the char may be removed in the fluidized bed; however, most parts require further cleaning before they can be repainted. The shot-blast unit is used to remove the inorganic coatings and char to prepare the parts for repainting (TSSOP).

This process removes and destroys paint and grease from nonaluminum or nonheat sensitive materials. Waste streams from this process include spent heat-transfer medium, spent blast media, exhaust air from the afterburner and scrubber, water discharge from the scrubber, and dust from the cyclone separator. The heat-transfer medium, blast media, and cyclone dust contain metals from the stripped paint.

Assistance providers should also inform facilities that this blasting method requires employees to wear equipment to protect them from toxics in the paint. For example, inhalation of lead and zinc chromate paints can lead to irritation of the respiratory tract; some lead compounds are carcinogenic; solvent-based paints can irritate the lungs and mucous membranes; and prolonged exposure can affect respiration and the central nervous system.

Costs for fluidized bed paint strippers can range from \$7,000 for a small parts stripper to \$800,000 for an industrial scale stripper.

Other Methods

The methods that follow can also be used to strip old paints from metal parts.

High-energy Light. High-energy light uses optically directed beams of photon energy emitted by lasers or flash lamps (typically xenon lamps) to ablate the paint. Using high-energy light to remove paint decreases operating cost, minimizes the waste stream, and lowers the possibility of material damage. The disadvantages of this process are its high capital cost and precision robotics requirements (Freeman, p. 490).

Cryogenic Methods. Cryogenic methods generally use liquid nitrogen immersion at approximately -200°F, which causes the paint to contract, breaking the adhesive bond with the substrate. For small components, a tumbler design normally is used, where the parts can impact and abrade each other to assist in removing the paint. If the parts have complex shapes, tumbling media might be added (Freeman, p. 491). Cryogenic stripping has a harder time removing epoxy and urethane coatings than other coatings. Also, this stripping method removes thick coatings more efficiently than thin coatings. In addition, this method may damage or distort parts because of the extreme temperatures needed in the process (IHWIRCF).

High-temperature Thermal Methods. High-temperature thermal methods, such as burnoff ovens and molten salt baths, are sometimes used to strip paint. In general, these methods are labor intensive, and result in emissions of burned paint and metal surfaces that are fouled by heat scale. This heat scale, subsequently, must be removed by abrasive methods, such as sanding or wire brushing. Most thermal methods are limited to heavy metal parts that will not warp because of thermal expansion and distortion (Freeman, p. 490). In burnoff ovens, the ovens simply burn off the paints. This method is limited to steel parts (IHWIRCF).

Molten salt baths remove paint easily from metal. Baths that are only 500 to 700°F significantly reduce any problems with heat distortion. Objects to be stripped are lowered into the salt bath, removed, rinsed with water, lowered in dilute acid, and immersed in water again. Care must be taken in stripping aluminum parts; leaving the parts in the bath for more than 60 seconds could soften the metal and make the parts unusable. Also, salt can solidify or get trapped in an area that cannot be thoroughly rinsed, causing corrosion at a later time (IHWIRCF).

Burnoff ovens and molten salt baths often are used to remove paint overspray from hooks, racks, grates, and body carriers used in automotive plants. Stripped parts are left with a residue of ash, which can be removed by rinsing (Freeman, p. 491).

Table 16. Advantages and Disadvantages of Fluidized Bed Stripping (TSPPO)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Leaves practically no waste paint residue, thus eliminating significant waste sludge disposal costs, as well as avoiding the future liability associated with the hazardous components of the paint sludge ◆ Uses an inert medium to clean parts of any shape, size, or geometry which are coated with any type of paint; the rapid changes in coating technology do not affect the performance of the system ◆ Provides cleaning to the bare metal 	<ul style="list-style-type: none"> ◆ Is not suitable for removal of paint from aluminum and aluminum alloy parts ◆ Is not suitable for parts with crevices, channels, or cavities (e.g. engine blocks) that would retain FBPS media and be difficult to clean after treatment ◆ Has little or no effect on corrosion removal ◆ May require secondary cleaning to remove char and inorganic coatings from parts ◆ May generate more waste than a caustic stripping system

Table 17. Overview of Alternative Surface Preparation Technologies (EPAh, p. 7-10, EPAi, p. 5-6, 24, EPAg, p. 7-9 and IHWRIcf)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Cleaning				
Aqueous Cleaning	<ul style="list-style-type: none"> ◆ Eliminates solvent use by using water-based cleaners 	<ul style="list-style-type: none"> ◆ Used to remove light oils and residues left by other cleaning processes ◆ Used to remove heavy oils, greases, and waxes at elevated temperatures 	<ul style="list-style-type: none"> ◆ Cleaning performance changes with concentration and temperature, so process can be tailored to individual need ◆ Cavitate using ultrasonics 	<ul style="list-style-type: none"> ◆ May generate significant amounts of hazardous wastewater ◆ Some acids can cause hydrogen embrittlement
Ultrasonic Cleaning	<ul style="list-style-type: none"> ◆ Eliminates solvent use by making aqueous cleaners more effective 	<ul style="list-style-type: none"> ◆ Cleaning of ceramic, aluminum, plastic and metal parts, electronics, glassware, wire, cable and rods 	<ul style="list-style-type: none"> ◆ Can clean in small crevices 	
Supercritical Fluids	<ul style="list-style-type: none"> ◆ Nonpolluting when CO₂ is used as the supercritical fluid 	<ul style="list-style-type: none"> ◆ Precision cleaning of stainless steel, copper, silver, porous metals, and silica 	<ul style="list-style-type: none"> ◆ No solvent residue left on parts ◆ Low operating costs 	<ul style="list-style-type: none"> ◆ High capital cost
Vacuum De-oiling	<ul style="list-style-type: none"> ◆ Eliminates solvent use for cleaning 	<ul style="list-style-type: none"> ◆ Removal of oils from metals 	<ul style="list-style-type: none"> ◆ Low operating costs ◆ Does not leave the cleaned parts water-soaked, therefore parts do not need to be dried 	<ul style="list-style-type: none"> ◆ Parts must be able to withstand the required temperature and vacuum pressure ◆ High capital costs ◆ Adjustments might be needed for each application because the time and temperature of the de-oiling process depends on the material to be cleaned and the oil to be removed
Laser Ablation	<ul style="list-style-type: none"> ◆ Eliminates solvent use for cleaning 	<ul style="list-style-type: none"> ◆ Cleans metallic or nonmetallic surfaces 	<ul style="list-style-type: none"> ◆ Localized cleaning 	

Table 17. Overview of Alternative Surface Preparation Technologies (EPAh, p. 7-10, EPAi, p. 5-6, 24, EPAg, p. 7-9 and IHWRICf) (continued)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Stripping				
Abrasive Blasting	◆ Eliminates solvent use in stripping		◆ Blast substitutes available: plastic media, sodium bicarbonate, carbon dioxide, and wheat starch	◆ Harder materials can damage metals
High-energy Light ◆ Lasers ◆ Flash lamps	◆ Eliminates solvent use in stripping		◆ Low chance of material damage	◆ High capital costs ◆ Precision robotics required
Cryogenic Stripping	◆ Eliminates solvent use in stripping	◆ Removes thick coatings from a variety of coating line fixtures and tools		◆ Does not remove epoxy or urethane coats as well as other types ◆ Does not remove thin coats as well as thick ones ◆ Extreme temperatures can damage or distort parts
High-pressure Water	◆ Eliminates solvent use in stripping ◆ Water can be processed and recycled during stripping, reducing wastewater volume		◆ High stripping rate	◆ Misapplied water jet may damage substrate ◆ Blasting generates high noise levels ◆ Water can enter cavities penetrating and/or damaging joints, seals, and bonds
Thermal Stripping ◆ Fluidized bed stripping ◆ Molten salt baths ◆ Burnoff ovens	◆ Eliminates solvent use in stripping	◆ Fluidized bed stripping and molten salt baths can be used only on steel parts	◆ Can process complex shapes	◆ Fluidized bed stripping cannot be used on aluminum

6 Alternatives to Solvent-Borne Coatings

The majority of conventional coatings are solvent borne, traditionally containing about 25% solids and a relatively high organic solvent content. These materials generally have been applied with conventional air spray, which uses compressed air at high pressures to atomize paint, a technique known as low-volume/high-pressure (LVHP). LVHP and other application techniques are discussed in chapter 7. This chapter covers the composition of conventional metal coatings, low-to-no solvent alternatives, and lower toxicity alternatives. The US EPA's Coatings Alternative Guide (CAGE) (available via the Internet at <http://cage.rti.org>) is a helpful tool for assistance providers to use in identifying specific alternative coatings for facilities.

Conventional Paint Composition

The major components of paints and coatings are solvents, binders, pigments, and additives. In paint, the combination of the binder and solvent is referred to as the paint "vehicle." Pigment and additives are dispersed within the vehicle (IHWRI, p. 2). The amount of each constituent varies with the particular paint, but solvents traditionally make up about 60% of the total formulation. Binders account for 30%, pigments for 7 to 8%, and additives for 2 to 3% (KSBEAP, p. 4).

- ◆ Solvents are added to coatings to disperse the other constituents of the formulation and to reduce viscosity, thereby enabling application of the coating. A wide variety of solvents are used in paints, including aliphatic hydrocarbons, aromatic hydrocarbons (toluene, xylene, and the trimethyl benzenes), ketones (methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK)), alcohols, esters, and glycol ethers (IHWRI, p. 5).

A Few Words About Solvents

A solvent is typically selected based on its ability to dissolve binder components (resins), and its evaporation rate. Its ability to dissolve binder components is often referred to as solvent power. Combinations of different solvents are often found in paint formulations. The most widely used solvents are toluene, xylene, MEK and MIBK.

- ◆ Toluene will dissolve a large number of resins. Toluene is miscible with drying oils like linseed oil or tung oil that are often used in oil-based paints and with most other solvents.
- ◆ Xylene has high solvent power with a wide range of resins and a high rate of evaporation. As a result, xylene is widely used in both heat-cured and rapid air-drying coatings.
- ◆ MEK and MIBK are solvents used with a wide range of resins. MIBK is extensively used in both heat-cured enamels and lacquers (EPA, p. 154-155).

Solvents are a major source of environmental concern because at normal temperatures and pressures they can volatilize (i.e., the liquid solvent becomes a vapor). Exposure to these solvent vapors is dangerous for a number of reasons. In the workplace, solvent vapors can result in a number of human health risks. Table 18 presents information on the health effects of solvents used in paint formulations. Solvent vapors also can pose fire/explosion hazards, necessitating careful storage and handling procedures.

When solvent vapors are released, they emit volatile organic compounds (VOCs) and hazard-

Table 18. Health Effects of Solvents Used in Paint Formulations^a (EPAe)

Solvents Used in Paint Formulations	Health Effects
Toluene	<ul style="list-style-type: none"> ◆ The central nervous system (CNS) is the primary target organ for toluene toxicity in both humans and animals for acute (short-term) and chronic (long-term) exposures. CNS dysfunction (which is often reversible) and narcosis have been frequently observed in humans acutely exposed to low or moderate levels of toluene by inhalation; symptoms include fatigue, sleepiness, headaches and nausea. Cardiac arrhythmia has also been reported in humans acutely exposed to toluene. ◆ CNS depression has been reported to occur in people chronically exposed to high levels of toluene. Symptoms include ataxia; tremors; cerebral atrophy; nystagmus (involuntary eye movements); and impaired speech, hearing and vision. Chronic inhalation exposure of humans to toluene also causes irritation of the upper respiratory tract, eye irritation, sore throat, nausea, skin conditions, dizziness, headache and difficulty with sleep. ◆ None of the available data suggest that toluene is carcinogenic. Two epidemiological studies did not detect a statistically significant increased risk of cancer due to inhalation exposure to toluene. However, these studies had many confounding factors. Animal studies have also been negative for carcinogenicity. EPA has classified toluene as not classifiable as to human carcinogenicity.
Xylene	<ul style="list-style-type: none"> ◆ Acute (short-term) exposure to mixed xylenes in humans results in irritation of the nose and throat; gastrointestinal effects such as nausea, vomiting, and gastric irritation; mild transient eye irritation; and neurological effects. ◆ Chronic (long-term) inhalation exposure of humans to mixed xylenes results primarily in central nervous system (CNS) effects, such as headache, dizziness, fatigue, tremors and incoordination. Other effects noted include labored breathing and impaired pulmonary function, increased heart palpitation, severe chest pain and an abnormal EKG, and possible effects on the blood and kidney. ◆ Insufficient data are available on the developmental or reproductive effects of mixed xylenes on humans. Animal studies have reported developmental effects such as an increased incidence of skeletal variations in fetuses and fetal resorptions via inhalation. ◆ No information is available on the carcinogenic effects of mixed xylenes in humans, and animal studies have reported negative results from exposure through gavage (experimentally placing the chemical in the stomach). EPA has classified mixed xylenes as not classifiable as to human carcinogenicity.
Methyl Ethyl Ketone	<ul style="list-style-type: none"> ◆ Acute (short-term) exposure to methyl ethyl ketone in humans, via inhalation, results in irritation to the eyes, nose and throat; and, central nervous system depression. ◆ No information is available on the developmental or reproductive effects of methyl ethyl ketone in humans. Reduction of fetal development and fetal malformations has been reported in mice exposed to methyl ethyl ketone in the air. ◆ Limited data are available on the carcinogenic effects of methyl ethyl ketone. No human data are available and the only available animal study did not report skin tumors from dermal exposure to methyl ethyl ketone. EPA has classified methyl ethyl ketone as not classifiable as to human carcinogenicity.

^aThese solvents are *nonhalogenated hydrocarbons*; that is, they do not contain chlorine or related elements. *Nonhalogenated hydrocarbon solvents* are often used in paint formulations as well as in surface preparation and equipment cleaning. *Halogenated hydrocarbons* are hydrocarbon solvents that contain one or more of the halogens (i.e., fluorine, chlorine, bromine, iodine and astatine). Examples include trichloroethylene (TCE), perchloroethylene (PERC), 1,1,1-trichloroethane (TCA), carbon tetrachloride, methylene chloride (METH) and CFC-113. The halogenated hydrocarbon solvents are preferred for vapor degreasing operations because their flashpoints are in a higher range than those of the nonhalogenated solvents; therefore, they are usually not ignitable. However, halogenated solvents, in general, are more toxic to humans and capable of causing greater environmental damage (IWRC, p. 13-14).

ous air pollutants (HAPs) into the atmosphere. VOCs combine with nitrogen oxides in the presence of sunlight to form ground-level ozone. Ground-level ozone is a precursor to smog, a major pollutant in urban and industrial areas. Smog poses a number of human health risks to respiratory function, particularly among persons with asthma or allergies.

◆ **Binders** are liquid polymeric or resinous materials that are used in coatings to hold the pigment and additives together, to provide adhesion, and to enable the coating to cure into a thin plastic film. The binder provides the working properties of the coating and determines the performance of the film, including flexibility, durability and chemical resistance (EPA, p. 152-154). Most binders are named for their main resin. The resins most commonly used in paints and coatings are natural oils or vegetable oils, alkyds, polyesters, aminoplasts, phenolics, polyurethanes, epoxies, silicones, acrylics, vinyls, cellulose and fluorocarbons (SME, p. 26-3-4). See "A Few Words About Binders" for more information.

◆ **Pigments** are insoluble particles of organic or inorganic materials (either natural or synthetic) that are dispersed in a coating in order to confer color and opacity to a substrate, or to improve the substrate's environmental resistance and the flow properties of the paint. The type of pigment in the paint determines the color and color stability of the paint or coating, while the amount of pigment determines the gloss, hiding power and permeability of the coating (EPA, p. 152-154). Inorganic pigments have high thermal stability and ultraviolet light stability. Organic pigments are brighter and clearer than inorganic pigments (KSBEAP, p. 5).

Many pigments still contain lead, chromium, cadmium, or other heavy metals. These paints cannot be disposed of in a landfill and must be handled as a hazardous waste because the heavy metals can leach out of landfills and contaminate groundwater. Production of paints containing these heavy metals is being phased out due to their toxicity (KSBEAP, p.5). EPA banned the production of certain paints containing lead and

A Few Words About Pigments

The four commonly recognized classes of pigments are: colored pigments; white pigments, which include the primary and extender pigments; metallic pigments; and functional pigments, which provide corrosion resistance, antifouling protection, slip resistance or other desired properties. Colored pigments are available in both inorganic and organic compounds (SME, p. 26-9). Inorganic pigments have high thermal stability and ultraviolet (UV) light stability. Organic pigments are brighter and clearer than inorganic pigments (KSBEAP, p. 5). Examples of each type follow:

- ◆ **Colored pigments:** red/yellow/black iron oxide, blue/green phthalocyanine and gilsonite
- ◆ **White pigments:** lithopone and titanium dioxide
- ◆ **Metallic pigments:** vermiculite (texture), flake aluminum (sparkle/metallic appearance), and titania and surface-modified talc (pearlescence)
- ◆ **Functional pigments:** limestone and clay (fillers); barium metaborate (preservatives against mold, mildew or bacteria); lithopone and zinc sulfide (UV stabilizers); nickel/copper/silver powders and barium titanate (conductive ability); and carbon black, silica, Attapulugus clay and fibers (reinforcement) (Athey, p. 59)

mercury several years ago. However, some facilities may still have these paints in use if they purchased the paints prior to the phaseout.

◆ **Additives** are materials that improve the physical and chemical properties of the coating. Additives include surfactants, colloids and thickeners, biocides and fungicides, freeze/thaw stabilizers, coalescing agents, defoamers, plasticizers, flattening agents, flow modifiers, stabilizers, catalysts and antiskinning agents (SME, p. 26-13). A coating's characteristics can change significantly depending on which additives are included.

A Few Words About Binders

Binders are chosen based on what physical and chemical properties are desired of the finished film. In general, metal coatings are dominated by alkyds; however, water-based acrylics, epoxies, polyurethanes and polyesters also are used for certain applications (MPCa, p. 34).

- ◆ **Acrylics** and **alkyds** contain suspended polymer particles. These materials produce a shiny, hard finish that has good weather resistance. Alkyds are made from chemically modified vegetable oils and are relatively low in cost. They are easily modified in order to change the properties of a paint. They also can react with other chemicals in the curing process to change the finish. In ambient conditions, they react with oxygen to form cross-linked films, making them functional for a wide variety of applications. Because of the versatility and moderate cost, they are considered "general purpose paint" (KSBEAP, p.4). Both acrylics and alkyds are widely used for farm equipment and industrial products that require good corrosion protection at a moderate cost. Silicone modification of these resins improves overall weatherability and durability. These finishes are often used on space heaters, clothes dryers and barbecue grills.
- ◆ **Urethanes** combine high gloss and flexibility with chemical and stain resistance. They are also characterized by toughness, durability and corrosion resistance. They require little or no heat to cure. These materials usually cost 2 to 5 times more than other paints so they are often used in applications where high performance justifies the cost (KSBEAP, p.4). Typical uses are on conveyor equipment, aircraft radomes, tugboats, road-building machinery and motorcycle parts.

Urethanes are produced by a reaction between isocyanate and alcohol. The components can be mixed in a "pot" prior to application or can be mixed in the atomizing portion of the spray gun. Once mixed, urethanes have a limited "pot life," which is the amount of time the components can be mixed before crosslinking occurs. Often, pot life can be adjusted to meet process requirements; typical ranges available commercially are a few minutes to 16 hours (KSBEAP, p.5).

- ◆ **Epoxies** provide excellent water and chemical resistance. They have better adhesion to metal substrates than most other materials. Epoxies are attractive economically because they are more effective against corrosion in thinner films than most other finishing materials. They are often used as primers under other materials that have good barrier properties but marginal adhesive characteristics. They can be formulated in a variety of ways, from one-component formulations requiring elevated temperature curing to two-component systems that cure at or below ambient temperature conditions. Epoxies lose their gloss from ultraviolet exposure but the damage is rarely structural (KSBEAP, p.4).
- ◆ **Polyesters**, are similar to alkyds in chemical structure but require heat to cure. They are used extensively in powder coatings. Polyesters, such as Nylon 11, provide an attractive appearance as well as protection from chemicals, abrasion and impact. Nylon coatings are used on office and outdoor furniture, hospital beds, bending machine parts and building railings. Heavier coats can be used to protect dishwasher baskets, food-processing machinery, farm and material-handling equipment, and industrial equipment such as pipes, fittings and valves (MD, p. 703-704).
- ◆ **Other Binders**, such as silicones have high heat resistance and superior resistance to weather and water. They are used alone or blended with acrylics or alkyds. Vinyls are another binder that can have a wide range of flexibility. They are used extensively in marine applications, interior metal can liners (e.g., polyvinylchloride), or structural wood finishes (e.g., polyvinylacetate) (KSBEAP, p.5).

Switch to Surface-Free Coating

Many manufacturers are finding that they can eliminate unnecessary paints and coatings that are used only for appearance. Not only does this reduce capital, operating and maintenance costs, it also reduces potential liability from toxic chemical use (EPA, p. 159). The use of injection-molded plastic sheets in place of painted metal cabinets in the electronics industry is one example of this trend (Freeman, p. 485). Manufacturers that are considering product redesign to eliminate unnecessary coatings must consider the substrate and its characteristics without a coating. If the coating is needed to provide an engineering function, such as improved corrosion resistance, one option may be to change to a base material that does not require a coating (EPA, p. 160). Currently available materials that are free of surface coats include plastics, aluminum, titanium and other metals. Other materials that are under development for a wide range of industries include: cement-bonded particle boards, pultruded products from fiberglass-reinforced plastic, uncoated metals, weath-

ering steel and polymer film coatings (TURI, p. 2).

Alternative Coatings

The primary advantage of conventional solvent-borne paints is their versatility. However, due to the low solids content of conventional solvent-borne paints, a high volume of paint is required to supply a small amount of coverage. In addition, because the paint solvent is highly atomized along with the paint solids in LVHP application, VOC emissions are high (MnTAP, p. 3-4). See figure 3 for more information.

Vendors have developed a number of alternative coating technologies. Environmental compliance remains the principal driver for the development of new technologies (Tilton). These new technologies include:

- ◆ High-solids coatings
- ◆ Waterborne coatings
- ◆ Powder coatings
- ◆ Radiation-cured coatings
- ◆ Emerging technologies such as vapor permeation of injection coatings and supercritical carbon dioxide

CASE STUDY: Chrysler Corporation

The Chrysler Corporation's manufacturing plant in Belvidere, Illinois, no longer needs to apply zinc-rich primers to car bodies. Chrysler now uses galvanized metal (zinc-plated) instead,* a move that has saved the company \$7,000 per year and eliminated nearly 150 gallons of waste paint. Chrysler also has begun to use more waterborne paints in its production lines.

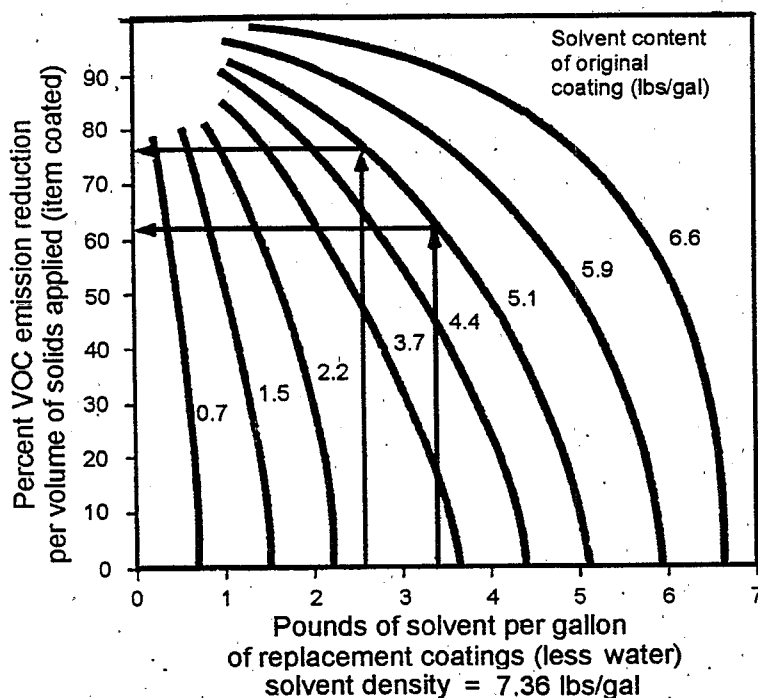
◆ Savings

Chrysler estimates that its pollution prevention efforts so far have saved the company \$350,000.

*Although substituting galvanized metal might reduce the amount of VOCs generated, a lifecycle analysis could reveal that zinc plating produces a number of other wastes. If a company chooses to purchase galvanized metals from outside firms, they could simply be passing along a different pollution burden to their supplier rather than achieving pollution prevention. (IHWRI Cd)

These coating alternatives can reduce emissions of VOCs and, in so doing, reduce the generation of hazardous wastes and decrease worker exposure to toxic air emissions (EPAd, p. 15). Each of the alternatives is discussed on the following pages. Generally, the P2 alternatives are not one-to-one substitutions. In some cases, an alternative requires a process change using a specific application and/or curing method (e.g., powder coating). Alternatives also can raise other issues (e.g., less solvent in the coating generally requires more thorough surface preparation). For an overview of alternatives to solvent-borne coatings, see table 19. Firms should consult with coatings suppliers for more detailed information on product offerings, as a number of hybrid technologies and different chemistries have recently been introduced (Tilton).

The relationship between emissions and VOC content, though obviously direct, is not linear; in other words, the transfer efficiency of the application method also can have a significant impact on

Figure 3. Emissions versus VOC Content (EPA-450/2-77/008)

the amount of VOCs emitted. This issue is explored in chapter 7 (Falcone, p. 35).

High-Solids Coatings

General Description

High-solids coatings have a higher percentage of paint solids and a lower percentage of solvent carriers than conventional solvent-borne coatings (MnTAP, p. 4). EPA defines high-solids paints as systems with volatile organic contents of less than 2.8 pounds per gallon. Paints with more than 85% solids content by weight are also generally referred to in the coatings industry as high-solids paints. In practice, paints with a solids content of 60 to 80% can be called high-solids paints per EPA's definition, especially if the equivalent solvent-borne paint contains more than 50% solvent (EPA, p. 162).

To achieve solids contents exceeding 70%, the binder in a high-solids paint must be chemically

modified so that it has a much lower intrinsic viscosity than binders of conventional solvent-borne paints. To overcome performance limitations, additives often are used to increase crosslinking during curing (EPA, p. 15). The binders in high-solids paints include alkyd resins, polyester resins, polyurethanes, acrylic resins, epoxy resins and polyvinyl chloride plastisols. Nondrying alkyd resins crosslinked with melamine during heat curing are often used for industrial coatings (EPA, p. 162-163).¹

Advantages and Disadvantages

Because high-solids coatings contain less solvent than traditional formulations, VOC and HAP emissions are reduced in this process (e.g., up to 50%, in some cases) (VT DEC). High-solids paints also provide higher layer thicknesses per application cycle than conventional coatings, resulting in a savings in time. Despite past issues with viscosity, today's high-solids paints can be applied with conventional spray equipment (EPA, p. 162-163). However, surface preparation of the substrate remains a critical issue. This is because a

¹ For more information see, "High Solids, Low VOC, Solvent-based Coatings," by Ron Joseph, part of the *Metal Finishing Special: Organics Finishing Guidebook and Directory* that provides detailed information on the advantages/disadvantages of specific resin types.

Table 19. Overview of Alternatives to Solvent-Borne Coatings (EPAd, p. 12 and KSBEAP, p. 12)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
High-Solids^a	<ul style="list-style-type: none"> ◆ Reduces solvent in coatings (low VOC) ◆ Has less over-spray compared to conventional coatings 	<ul style="list-style-type: none"> ◆ Zinc-coated steel doors ◆ Miscellaneous metal parts ◆ Same as conventional coatings 	<ul style="list-style-type: none"> ◆ Can apply thick or thin coat ◆ Has easy color blending or changing ◆ Is compatible with conventional and electrostatic equipment 	<ul style="list-style-type: none"> ◆ Does not eliminate solvent completely ◆ Has shorter pot life than conventional coatings ◆ Must be heated
Waterborne	<ul style="list-style-type: none"> ◆ Eliminates or reduces solvent in coating (little or no VOC) ◆ Uses water for cleanup 	<ul style="list-style-type: none"> ◆ Wide range ◆ Architectural trade finishes ◆ Wood furniture ◆ Damp concrete 	<ul style="list-style-type: none"> ◆ Can apply thick or thin coat ◆ Has easy color blending or changing ◆ Is compatible with conventional and electrostatic application equipment 	<ul style="list-style-type: none"> ◆ Has coating flow properties and drying rates that can change with humidity, affecting coating application ◆ Is sensitive to humidity; workplace humidity control required ◆ May have poor flow characteristics due to high surface tension of water ◆ Needs special equipment for electrostatic application ◆ Has water in paint that can cause corrosion of storage tanks and transfer piping, and "flash rusting" of metal substrates

(continued on next page)

Table 19. Overview of Alternatives to Solvent-Borne Coatings (EPAd, p. 12 and KSBEAP, p. 12) (continued)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Powder	<ul style="list-style-type: none"> ◆ Eliminates solvent in coating (no VOC) in most cases ◆ Reduces solvent in cleanup ◆ Reduces need for solid paint waste disposal 	<ul style="list-style-type: none"> ◆ Steel ◆ Aluminum ◆ Zinc and brass castings 	<ul style="list-style-type: none"> ◆ Can apply thick coat in one application ◆ Requires no mixing or stirring. ◆ Has efficient material use (i.e., nearly 100% transfer efficiency) 	<ul style="list-style-type: none"> ◆ Requires special handling of heated parts ◆ Has electrostatic application systems that must be electrically conductive; complex shapes difficult to coat ◆ Needs special equipment or extra effort to make color changes ◆ Is difficult to incorporate metal flake pigments
Radiation-cured	<ul style="list-style-type: none"> ◆ Eliminates solvent in coating (no VOC) ◆ Is 100% reactive liquid 	<ul style="list-style-type: none"> ◆ Some metal applications ◆ Filler for chipboard ◆ Wood ◆ "Wet look" finishes 	<ul style="list-style-type: none"> ◆ Can apply thin coat ◆ Has easy color blending or changing ◆ Has efficient material use (i.e., nearly 100% transfer efficiency) 	<ul style="list-style-type: none"> ◆ Has styrene volatility ◆ Is typically best applied to flat materials ◆ Is limited to thin coatings ◆ Has high capital cost of equipment ◆ Can have yellow color

* High-solids formulations do reduce solvent in the coating when compared with low-solids formulations. In many cases, however, high-solids coatings represent the baseline for regulatory limits, and low-solids no longer comply. For this reason, high-solids are considered the baseline for solvent content, and consequently do not have a reduced solvent content even though they qualify as a cleaner technology compared to traditional low-solids coatings.

smaller amount of solvent in the coating mixture means a smaller amount will be available to clean the substrate (TURIB, p. 9).

Types of High-Solids Coatings

High-solids coatings fit into 3 general categories: air/force dry, baking and two-component.

Air/force dry coatings cure by exposure to moisture or oxygen at temperatures less than 194°F. Alkyd resins are most common in air-dry coatings. Air-dry alkyds are often termed oxidizing

or auto-oxidizing because they cure in air without baking or the addition of a catalyst. However, low-temperature ovens can be used to speed cure. The recent development of new acrylic resins has resulted in a range of fast-drying high-solids paints suitable for general metal finishing applications, both indoor and outdoor. These coatings are inexpensive, offer excellent flow and drying properties, good hardness, durability, color and gloss stability, and do not suffer from air entrapment or sagging (EPAd, p. 16).

Bake coatings predominately use acrylic and polyester resins, although some alkyds and modified alkyds are also used. These resin systems cure in an oven at high temperatures (350 to 400°F) to form a crosslinked film. Crosslinking agents, such as melamine-formaldehyde (MF) or blocked isocyanates, are commonly used. MF coatings are usually one-pack systems, catalyzed by a strong acid, such as a p-toluenesulfonic acid. Latent or blocked catalysts are used for fast cure and good pot life. Blocked isocyanates, such as aliphatic polyisocyanates, are recommended for coatings requiring superior weathering properties and resistance to yellowing (EPAd, p. 16-17).

In a two-component reactive liquid coating system, two low-viscosity liquids are mixed just before application. One liquid contains reactive resins, and the other contains an activator or catalyst that promotes polymerization of the resins (NCP2P, p. 4). However, once the two components are brought together, curing starts; therefore, these coatings have very short pot lives after mixing. Short pot life can be overcome by using a twin-headed sprayer that is fed from two different pots. This spray head can proportion the flow of each component to achieve the desired ratio of liquids. Thus, the two components mix both on the way to the workpiece and on the workpiece itself (VT DEC).

Two-component coatings cure at low temperatures, and do not require heating in ovens (MnTAP, p. 4). Epoxies and polyurethanes are the most common two-component systems. Epoxies are the oldest form of high-solids coatings, producing thick films for specialty applications. Two-component polyurethane coatings are suitable for use in the automotive and machine tool industries because of their excellent resistance to solvents, lubricants, cutting oils and other chemicals. However, polyurethane coatings do pose some health and safety concerns. For example, polyisocyanates used as crosslinking agents in polyurethane coatings can impair the respiratory function, causing sensitization and in some cases, permanent lung damage (EPAd, p. 17-18).

Application Methods

High-solids coatings usually are applied by conventional spray guns. Traditionally, the high viscosity of high-solids coatings have made them difficult to atomize, making it difficult to achieve a uniform film thickness. Today, emerging formulations are tending toward lower viscosities and, therefore, easier spraying. These new formulations might be based on new resin systems, or additives that modify viscosity and rheology for easier spraying (EPAd, p. 18-19). In addition, the use of a heated spraying system can also reduce viscosity (VT DEC).

Paint Heaters

If the viscosity of the paint needs adjustment before it can be sprayed, companies generally thin the coating with solvents. Using solvents for thinning increases air emissions and requires the purchase of additional materials. An alternative method for reducing viscosity is to use heat. The benefits from the purchase of paint heaters can include lower solvent use, lower solvent emissions, more consistent viscosities and faster curing rates (MnTAP, p. 3).

Most heaters are stainless steel and are placed between the pump and spray gun. The heaters work best on recirculating systems that return heated material to the container when operators are not spraying. These systems keep the temperature and viscosity constant and avoid cooking the material when spraying stops (MnTAPc, p. 6).

Markets

With the exception of two-component liquid coatings, which are widely used for auto and appliance painting (IWRCb, p. 26), high-solids paints have not made the inroads that other systems (such as powder coatings) have in replacing conventional coatings in product coatings applications. Particular problems have included high viscosity, viscosity changes due to temperature variation, and storage stability, as well as the control of film thickness and the drying characteristics of the film (EPAd, p. 15). A variety of new formulations, however, could mean increased growth in a wider variety of markets.

New Developments

100% Solids Coatings. Because these materials are basically solids, their most distinguishing feature is their viscosity. The 100% solids coatings have a viscosity at room temperature that is approximately 10 times greater than other paint coatings. These materials are not formulated with heavy metals, HAPs or added solvents. Furthermore, once cured, they can be disposed of as nonhazardous solid waste. Because 100% solids coatings have very high viscosities, conventional handling and application methods are ineffective. Instead, mechanical agitation is needed to reduce the viscosity of the coating, making it easy to apply. Increasing the temperature can also reduce viscosity as these coatings are extremely heat sensitive (e.g., an additional 20°F can reduce viscosity by 50%). Application techniques include electrostatic spraying, airless application, roller application and dip tanks. Using these methods the material can be applied in thin layers, providing excellent coverage of the painted object (APC, p. 1.12).

Cost and Implementation Issues

The high-solids coatings that are currently available are generally similar to low-solids coatings in their application, curing and final film properties, and the capital cost for application equipment is approximately the same. The high-solids coatings themselves are slightly more expensive; however,

pollution control costs may be lower. In addition, a paint heater might be required (EPAd, p. 15-21). In many cases, high-solids coatings represent the baseline for regulatory limits, and conventional solvent-based, low-solids coatings no longer comply (EPAd, p. 12).

Waterborne Coatings

General Description

The term waterborne refers to coating systems that primarily use water as the solvent to disperse the resin (IHWRIC, p. iv). Usually, they contain up to 80% water with small amounts of other solvents, such as glycol ethers (TURI, p. 1). Most regulations require waterborne coatings to have a

CASE STUDY:

Freightliner Truck Manufacturing

In 1989, Freightliner Truck Manufacturing's plant in North Carolina substituted high-solids paints for conventional solvent-borne coatings. This increased transfer efficiency while reducing VOC emissions and paint wastes by 30%.

◆ Savings

The substitution resulted in savings of \$28,000 in paint purchases and paint disposal costs (TURib, p. 9).

Table 20. Advantages and Disadvantages of High-Solids Coatings (NCP2P, p. 2)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces VOC and HAP emissions ◆ Reduces solvent use ◆ Reduces inventory ◆ Reduces fire hazards ◆ Reduces number of spray applications to achieve a given film thickness ◆ Improves abrasion and mar resistance ◆ Reduces environmental, safety and odor problems ◆ Compatible for use with conventional spray equipment ◆ Decreases energy costs associated with reduced curing times 	<ul style="list-style-type: none"> ◆ Generally requires high cure temperatures ◆ Is sensitive to inadequate cleaning of substrate ◆ Is extremely sensitive to temperature and humidity ◆ Is difficult to control film thickness ◆ Has tacky overspray; difficult to clean ◆ Might require paint heater in system ◆ Is difficult to control sagging ◆ Has narrow "time-temperature-cure" window ◆ Cannot use dip or flow coating ◆ Is difficult to repair ◆ Solvent use not completely eliminated ◆ Has shorter pot-life than conventional coatings

VOC content of less than 3.5 pounds per gallon less water (EPAd, p. 47).

Advantages and Disadvantages

In addition to reducing VOC emissions during application, waterborne coatings reduce risk of fire, are easier to clean up (creating less hazardous residues) and result in reduced worker exposure to organic vapors (EPAd, p. 46-52). However, special equipment might be required for application, as water in the formulation can cause corrosion. For instance, water-based paints can rust plain steel or attack aluminum; therefore, application equipment must be constructed of a corrosion-resistant material such as 316 stainless steel. Humidity must also be controlled to achieve the best film formation; a microprocessor-controlled water-spray system is one method for doing so (EPAd, p. 52). For more information on other advantages and disadvantages of waterborne coatings, see the box at the end of this section.

Types of Waterborne Coatings

Almost all types of resins are available in a waterborne version, including vinyls, two-component acrylics, epoxies, polyesters, styrene-butadiene, amine-solubilized, carboxyl-terminated alkyd and urethanes (EPAd, p. 47-48). Waterborne coatings are classified based on how the resin is fluidized (KSBEAP, p. 6). The three main types are: water-soluble/water-reducible (solutions), water-dispersible/colloidal (dispersions) and emulsions (latex) paints (the most commonly used form) (TURI). Within each category, physical properties and performance depend on which resins are used (KSBEAP, p. 6).²

Water-soluble paints are paints whose individual molecules of water-soluble resins dissolve completely in water. Water-soluble resins are generally produced via polycondensation or polymerization reactions in an organic medium. As a result, they generally contain organic co-solvents like alcohols, glycol ethers or other oxygen-containing solvents that are soluble or miscible with water (organic content less than 10 to 15%). Because of viscosity anomalies, waterborne paints made with water-soluble binders have only about 30 to 40% solids

content by weight. Resins include alkyds, polyesters, polyacrylates, epoxies and epoxy esters. Despite their sensitivity to water, water-soluble paints have a high gloss and a high level of corrosion protection, along with good pigment, wetting and stabilization (EPA, p. 160).

Water-dispersible paints, or colloidal coatings, are paints that have small clusters of insoluble resin particles that are suspended in water. Mechanical agitation is sufficient to suspend the clusters (KSBEAP, p. 7). Small amounts of organic solvents (usually less than 5% by weight) are used as coalescing agents that evaporate on drying. Resins used in dispersion paints include vinyl acetate copolymers, vinyl propionate copolymers, acrylate-methacrylate copolymers, and styrene-butadiene copolymers and polymers (EPA, p. 161). Colloidal dispersions are used mainly to coat porous materials such as paper or leather (EPAd, p. 49).

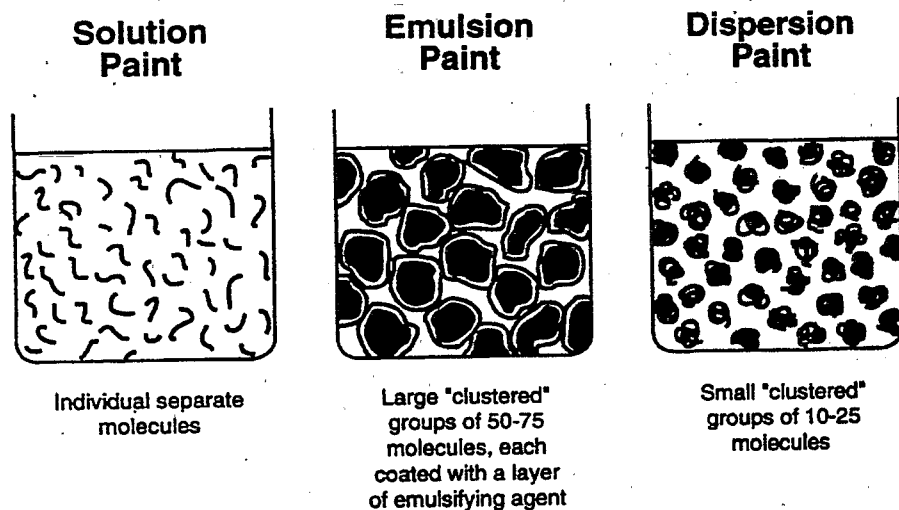
Emulsions, or as they are more commonly known, latex paints, are similar to water-dispersibles. However, resin clusters in emulsions tend to be larger, and an emulsifier is required to keep the clusters in suspension (KSBEAP, p. 7). Emulsion paints are manufactured using a variety of resins including styrene-butadiene copolymers, polyvinyl acetate (the most common), acrylics, alkyds and polystyrene. Emulsion paints are widely used in the architectural market segment (IHWRIC, p. 6). The increased permeability of latex paints allows these coatings to "breathe," reducing the chances for blistering or peeling (EPA, p. 161).

Water-based alkyds may take longer to dry than solvent-borne coatings, but the resulting coatings have similar gloss, flow and leveling properties. These coatings are extremely versatile because they are thinned with water to almost any viscosity. They can be applied with spray or dip applications and are among the least expensive VOC compliant coatings (CAGE).

Application Methods

Application technology for waterborne coatings is comparable to that of conventional solvent-borne

² For more information on the advantages and disadvantages of each resin type see, "High Solids, Low VOC, Solvent-based Coatings," by Ron Joseph, part of the *Metal Finishing Special: Organics Finishing Guidebook and Directory*.

Figure 4. Major Resin Fluidization Methods (KSBEAP p.8)

coatings. If a facility is using a water wash booth, overspray is easily recovered and reused if colors are appropriately segregated. Uncured waterborne coatings can be cleaned from equipment with water (TURI, p. 1).

Electrostatic spray can be used if the electrically conductive waterborne paint is isolated from the electrostatic system. Three methods can be used to avoid grounding out the electrostatics in a waterborne system. The facility can (1) isolate the entire paint system from electrical grounds; (2) isolate a small part of the wetted system with a voltage blocking device; and (3) indirectly charge the paint particles away from any wetted equipment. Each method has its own advantages and disadvantages and should be evaluated for the specific application. The use of a voltage blocking device at each atomizer is often the most cost-effective method (EPAd, p. 51) (VT DEC).

Waterborne coatings can also be applied by electrodeposition for corrosion resistance and coating of hard-to-reach areas (TURI, p. 1). However, some formulations or substrates might require special pumps and piping to prevent corrosion from water in the formulation. In addition, for product finishing, coatings need to dry or cure at elevated temperatures to ensure complete cure in a reasonable period of time. Therefore ovens are required with this process (EPAd, p. 52).

Markets

Waterborne coatings have quickly taken hold in some product-coating market segments; for more than two decades, copiers, fax machines, typewriters, printers and computers have been painted with various combinations of waterborne emulsion and other coatings (McBree et al., p. 35). However, waterborne coatings have been less accepted in market sectors with requirements that are exceptionally high for appearance and engineering. In recent years, however, the automotive OEM sector has increased its use of water-based paints and coatings in all but the heaviest coat applications. An estimated 20% of this sector now uses water-based paints, and that percentage is growing each year. With improved water-based paint technology, manufacturers have been able to change from solvent-borne paint systems and meet emissions regulations while maintaining their ultrahigh finish standards (EPA, p. 162).

New Developments

Waterborne Two-Component Technology. With this new technology, coatings manufacturers can formulate high-performance coatings without cosolvents and achieve the same appearance, properties and ease of use that manufacturers have with the solvent-borne analogs. For example, an epoxy curing agent for water-based epoxy coating formulations has been designed for use with solid epoxy dispersions. This epoxy curing

agent provides corrosion resistance when used as a primer in general metal applications (Iceman, p. 27).

Cost and Implementation Issues

Waterborne coatings are more expensive than conventional coatings per unit of reactive resins. In addition, the capital costs for application equipment tends to be greater (e.g., stainless steel is required to protect against corrosion in storage tanks and transfer piping). However, water-based coatings generally use less organic solvents, reducing environmental and human health risks (EPAd, p. 58-60). Technical assistance providers should remember that, despite the use of water in waterborne formulations, discharge of wastes from coatings must still be in compliance with federal and state wastewater discharge regulations. Paint manufacturers, however, are developing methods for recycling waterborne paints col-

CASE STUDY: ESCO Elevators

ESCO Elevators is an elevator manufacturer with 225 employees located in Fort Worth, Texas. They identified a waterborne coating that could reduce VOC emissions and maintain production quality. To ensure that the coating complied with all environmental standards, ESCO asked the Fort Worth Water Department to determine if the waste generated by this coating could be discharged to the city's sewer system. The waste was tested and approved by the city, which noted that the waste helped balance the sewer system's pH level. To ensure that dust generated from the water-based paint could be disposed of in landfills, ESCO also had to administer a T.C.L.P. test for the paint dust.

◆ Savings

By substituting waterborne coatings for solvent-based coatings, ESCO Elevators was able to reduce its VOC emissions by 10,764 pounds per year. ESCO also saved between \$20,000 and \$30,000 per year by elimination of hazardous waste disposal costs. Additional savings came from lower fire insurance premiums and reductions in reporting requirements for EPA (PPIFTI).

CASE STUDY: Metal Lab Furniture Manufacturer

This facility is a manufacturer of metal laboratory furniture, including base cabinets, wall cases and fume hoods. The facility produces 3,500 units of furniture a year with sales of \$3,000,000 annually. Production processes include punching, forming, cleaning, phosphatizing and painting. Waste streams generated by these processes included solvent waste and paint sludge. The facility implemented a switch from solvent-based paints to aqueous-based paints to minimize both the volume and toxicity of their waste streams. The company chose an acrylic enamel paint for use that is not only nonhazardous but has a longer shelf life than conventional solvent-based paints.

◆ Savings

Investments in this system included purchasing electrostatic spray equipment and retraining operators. The enamel paint is more expensive than the solvent-based paint, but because it can be dried at lower temperatures the company has realized savings in energy costs. The company has also reduced its hazardous waste generation by 75%, and because the paint has a longer shelf life, less obsolete paint is disposed (VT DEC).

lected from communities and industry (EPA, p. 162).

Powder Coating

General Description

Powder coating uses 100% resin in a dry, powdered form (MnTAP, p. 4). Powder coating works on the principle that opposite charges attract. The powder is pneumatically fed from a reservoir through a spray gun where the powder gains a low amperage, high-voltage positive charge. Parts to be painted are electrically grounded so that the positively charged powder particles are strongly attracted to the parts' surfaces. The powder-coated part is then pulled through an oven where

Table 21. Advantages and Disadvantages of Waterborne Coatings (NCP2P, p. 2)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces VOC and HAP emissions ◆ Can use conventional application processes ◆ Reduces toxicity and odor, resulting in improved worker safety and comfort ◆ Has good storage life ◆ Is easy to clean up ◆ Minimizes or eliminates disposal of hazardous waste. ◆ Has good to excellent surface properties, including gloss, rub resistance, anti-sealing effects and non-yellowing film ◆ Can recover and reuse some waterborne paints, increasing transfer efficiency ◆ Some dried waterborne paint waste may be disposed of in a landfill as non-hazardous waste 	<ul style="list-style-type: none"> ◆ Has tendency to foam ◆ Requires clean surface for high quality application; surface must be free of oil and dust ◆ Requires longer drying times or increased oven temperatures ◆ Has difficulty obtaining high gloss finish ◆ Has difficult cleanup once coating is cured ◆ Has great susceptibility to dirt pickup ◆ Has higher cost per gallon on an equivalent solids basis compared with conventional coating ◆ Does not have many resins available for waterborne formulations ◆ Is complex to convert solvent-borne coating line, i.e., stainless steel, plastic lines, valves and other ancillary equipment are needed ◆ Has problems with atomization, i.e., reduced paint transfer efficiencies ◆ Increases runs and sags ◆ Requires good temperature/humidity control ◆ Requires storage area enclosure and heating (i.e., repeated freezing and thawing will damage the coating) ◆ Is difficult to refinish ◆ Has reduced temperature resistance ◆ Can have poor penetration and adhesion properties, particularly with emulsion coatings on porous surfaces

the powder melts and fuses into a smooth coating (IHWRICe). Substrates must generally be able to withstand temperatures of 260°F or higher (EPAd, p. 33).

Advantages and Disadvantages

Powder-coating materials can provide a high-quality, durable, corrosion-resistant coating. Powder coatings do not produce hazardous overspray wastes or wastewater sludges, and most do not release VOCs when cured (some powder coatings will release VOCs, such as caprolactam, a former HAP). With powder coating, users can collect the powder overspray and reuse it, resulting in transfer efficiencies of up to 99% (MnTAP, p. 4). However, powder coating systems require

the complete conversion of a coating line, which can be costly. For more information on other advantages and disadvantages of powder coating, see table 23 at the end of this section.

Types of Powder Coatings

Product manufacturers can specify the properties required in a finish (such as resistance to ultraviolet light, high durability, corrosion resistance and color) to a powder coating manufacturer who then formulates the appropriate powder (IIHWRICe). Coating powders are frequently separated into decorative and functional grades; decorative grades generally have a finer particle size than functional grades. Powders are also divided between thermoset and thermoplastic resins (EPA, p. 163-164).

Thermoset resins crosslink to form a permanent film that withstands heat and cannot be remelted. They are used for decorative and protective coatings for architectural structures, on appliances and furniture, and elsewhere. Thermosetting resins are characterized by their excellent adhesion to metal; they are one-coat systems and do not require a primer (Farrell, p. 81). The five basic families of thermoset resins are epoxies, hybrids, urethane polyesters, acrylics and triglycidyl isocyanurate (TGIC) polyesters as described below:

- ◆ Epoxies are used for both functional and decorative coatings. Their functional properties include outstanding corrosion resistance and electrical insulation. Decorative epoxies offer attractive finishes that are flexible, tough, and have excellent corrosion resistance and high-impact strength. However, these coatings lack ultraviolet resistance and, therefore, are not recommended for outdoor use. In prolonged exposure to sunlight, they tend to chalk and discolor. Various types of hardeners are used with epoxy powder to optimize its properties.
- ◆ Epoxy polyester hybrid coatings are mainly used for decorative applications. They are more resistant to chalking and over-bake yellowing than pure epoxies, but have a lower surface hardness and are less resistant to solvents. They exhibit better transfer efficiency and a greater degree of penetration into recessed areas of a part than other resins.
- ◆ Urethane polyesters are formulated with polyester hydroxyl resin combined with blocked isocyanate hardeners. They exhibit outstanding thin film appearance and toughness as well as good weathering properties.
- ◆ Acrylic-urethane coatings are formulated with acrylic resins crosslinked with blocked isocyanates. They have excellent color, gloss, hardness, weatherability and chemical resistance, and have an excellent thin film appearance. However, they are less flexible than polyesters.
- ◆ TGIC polyesters contain a polyester resin crosslinked with TGIC as a curing agent. They offer very good mechanical properties, impact strength and weather resistance. They

are resistant to chalking and are often used for outdoor parts, such as patio furniture, lawn mowers, as well as aluminum extrusions and panels for large commercial buildings. In Europe, reduced occupational-exposure limits were recommended for TGIC powders as a result of in vivo mutagenicity tests (EPAd, p. 28).

Thermoplastic resins form a coating, but do not undergo a change in molecular structure. These resins can be remelted after they have been applied. Thermoplastic powder coatings melt and flow when heat is applied, but retain the same chemical composition when they are cool and solidified (KSBEAP, p. 10). Although some thermoplastic materials provide adhesion to metal, most require a primer (Farrell, p. 81). Thermoplastic resins are mainly used in functional coatings, such as thick, protective coatings on dishwasher trays. Examples of thermoplastic resins used in powder coating are polyethylene, polypropylene, nylon, polyvinyl chloride (PVC), and thermoplastic polyester. These examples are described below:

- ◆ Polyethylene provides excellent chemical resistance and outstanding electrical insulation properties. These coatings are smooth, and have a medium gloss and good release properties that allow sticky materials to be cleaned from their surfaces. These are often used as coatings for laboratory equipment.
- ◆ Polypropylene produces a surface that is very inert and is often used in applications where the part that is powder coated might be exposed to chemicals.
- ◆ Nylon offers excellent abrasion, wear and impact resistance, and a low coefficient of friction. Nylon is commonly used as a mechanical coating for sliding and rotating bearing applications in appliances, farm equipment and textile machinery.
- ◆ PVC provides good durability as well as flexibility; dishwasher trays are an example of a product coated with PVC.
- ◆ Thermoplastic polyester offers good exterior durability and weatherability. The coating does

not usually require a primer for good adhesion to most metals. These materials are often used on outdoor metal furniture (EPAd, p. 26 and PCI, p. 6-7).

See table 24 for a summary of powder coating resin properties.

Application Methods

There are five powder coating processes: electrostatic spraying, fluidized bed, electrostatic fluidized bed, flame spray, and tribocharge.

Electrostatic Spraying

The main method in use today for the application of powder coatings is the electrostatic process. In the electrostatic process, electrostatic spray guns impart an electrostatic charge to the powder being sprayed via a charging electrode that is located at the front of the spray gun. This technique is called "corona charging," and these guns generate a high-voltage, low-amperage electrostatic field between the electrode and the product being coated. The charge on the electrode can be controlled by the operator. Powder particles become charged as they pass through the ionized electrostatic field, which controls the deposition rate and the powder's location on the part. The field can be adjusted to direct the powder's flow, control pattern size, shape, and powder density as it is released from the gun (KSBEAP, p. 14). The particles are attracted and held to the grounded substrate through electrostatic forces. The substrate subsequently is heated in an oven, or through chemical activation (e.g., by infrared), to fuse the particles to the substrate and to each other to create a continuous film (EPA, p. 164). This method has made it possible to apply thin layers of coatings for higher quality decorative finishes, and has allowed powders to be used on parts that should not be dipped in a fluidized bed.

Powder is supplied to the electrostatic spray gun by the powder delivery system. This system consists of a powder storage container, or feed hopper, and a pumping device that transports a stream of powder into hoses or feed tubes. Compressed air is often used as a pump because it aids in separating the powder into individual particles for easier transport. The powder delivery system is usually capable of supplying

powder to one or several guns. Delivery systems are used in many different sizes, depending on the application, number of guns to be supplied, and volume of powder to be sprayed in a given time period. Recent improvements in powder delivery systems, coupled with better powder chemistries that reduce clumping, have made delivery of a consistent flow of particles to the spray gun possible. Agitating or fluidizing the powder in the feed hopper also helps prevent clogging or clumping of the powder before it enters the transport lines (KSBEAP, p. 9). Innovations in powder delivery systems also allow the powder supply reservoir to be switched easily to another color when necessary. Systems are also available for segregating colors so that several colors can be applied in the same booth (EPAd, p. 36).

Fluidized Bed

Initially, powder was applied using a fluidized bed process in which heated parts were dipped into a vat with the suspended coating powders. As these particles came in contact with heated parts they softened and began to "flow" into other particles to create a coating. The coatings were thick, usually vinyl or epoxy, and demonstrated functional rather than decorative qualities (KSBEAP, p. 9). However, several methods for powder coating exist now, which makes powder coating a more versatile option, however fluidized bed is still used in certain operations.

In a fluidized bed, powder particles are kept in suspension by an air stream. A preheated workpiece is placed in the fluidized bed where the particles coming in contact with the workpiece melt and adhere to its surface. Coating thickness depends on the temperature and heat capacity of the workpiece, and its residence time in the bed. Postheating is generally not required when applying thermoplastic powder coatings. However, postheating is required to cure thermoset powder coatings completely (NEFSC).

Electrostatic Fluidized Bed

An electrostatic fluidized bed is similar in design to conventional fluidized beds, but its air stream is electrically charged as it enters the bed. The ionized air charges the particles as they move

Table 22. Characteristics of Powder Coating Techniques (Misev, p. 350)

Characteristic of Workpiece	Electrostatic Spray	Fluidized Bed or Electrostatic Fluidized Bed	Flame Spray
Size	Larger	Smaller	Not limited
Material	Metallic, must be conductive	Any, except wood, not necessarily conductive	Any, not necessarily conductive
Temperature Resistance	Relatively high	High	Not relevant
Aesthetic Value	High	Low, not suitable for decorative purposes	Low, not suitable for decorative purposes
Coating Thickness	Thinner films	Thick high-build films with excellent uniformity	Thick high-build films; uniformity depends on the operator
Type of Coatings	Thermoplasts and thermosets	Thermoplastic and thermosets	Thermoplasts only
Color Change	Difficult	Relatively difficult	Easy
Capital Investment	Moderate to high	Low	Very low
Labor	Low because highly automated	Moderate depending on the automatization	Relatively high
Energy Consumption	Only postheating	Preheating and often postheating	Low, no preheating or postheating
Coating Waste	Very little	Very little	Depends on the workpiece geometry

upward in the bed, forming a cloud of charged particles. The grounded workpiece is covered by the charged particles as it enters the chamber. No preheating of the workpiece is required. However, curing of the coating is necessary. This technology is most suitable for coating small objects with simple geometries (NEFSC).

Flame Spray

Flame spray was recently developed for application of thermoplastic powder coatings. The thermoplastic powder is fluidized by compressed air and fed into a flame gun where it is injected through a flame of propane, which melts the

powder. The molten coating particles are deposited on the workpiece and form a film upon solidification. Because no direct heating of the workpiece is required, this technique is suitable for applying coatings to most substrates. Metal, wood, rubber and masonry can be coated successfully using this technique. This technology is also suitable for coating large or permanently fixed objects (NEFSC).

Tribocharge

Tribocharging relies on friction between the powder and the spray gun. The action of the powder flowing through the barrel of the gun

generates a frictional charge on the powder. The charged powder is carried by the air stream to the substrate, where it adheres due to electrostatic attraction. Because no high-voltage system is used, the electric field is substantially smaller and the powder tends to follow air currents rather than field lines. The smaller electric field results in a much reduced Faraday cage effect³. Consequently, tribo guns produce smoother finishes, allow deposition of thicker films, and provide better coverage of intricately-shaped objects (EPAd, p. 31).

Markets

Currently, 85% of the total market for powder coatings is represented by four industrial areas: metal finishing (53%), appliances (21%), lawn and garden (8%), and architectural applications (3%) (EPA, p. 164).

Since 1986, all or most automotive manufacturers have powder coated engine blocks, the largest volume job in the history of the powder industry. Now powder has come out from "under the hood" and is being used on a wide range of trim and accent parts. Polyester and acrylic powders are used in these coatings. For example, the "metallic look" powders are delivering luster to aluminum wheels. However, there remains great potential for more powder use in the automotive industry; its use as a primer surface and anti-chip coating on body panels is becoming more common. Powder coatings have undergone extensive testing both as a primer surfacer and antichip coating and have met OEM standards for chip resistance, adhesion, durability, and heat and humidity exposure.

In addition, clear powders over liquid base coats are currently being tested for exterior auto body finishing. The advent of clearcoat finishes for base coats in the mid-1980s made it more economically feasible to use powder as an automotive topcoat. Using specially formulated acrylic and polyester powders, manufacturers are working to meet the automotive industry standard for clearcoats of absolute smoothness, clarity, perfection and performance (Bocchi, p. 21).

New Developments

Can Coating. Development of powder coatings for the coating of can interiors, tops, ends and lids is well underway. In addition, application equipment is now available to apply, recover and recycle the very small particle size powders required to maintain thin films and run at line speeds common in this industry. Food and Drug Administration approval is still pending.

Lower-Temperature Cures. Powder coatings with very high reactivity have been developed to cure at temperatures as low as 121°C (250°F). Such low-curing powders will allow more types of products to be coated with powder, including plastics and preassembled products that contain heat-sensitive fluids or gaskets. In addition, manufacturers can run higher line speeds with the lower-cure powders, thereby increasing production capacity.

Weathering Capabilities. Significant advances have been made in the development of polyester and acrylic resin systems with excellent long-term weatherability, which is needed to meet the extended warranties being offered by manufacturers. Also under development are fluorocarbon-based powders that will match or exceed the weatherability of liquid fluorocarbons, with application costs similar to or lower than conventional powder coatings.

Thinner Films. Powder manufacturers are continually working to develop powders that can form films that are thinner than those previously attainable, resulting in a savings of material and money. Based on epoxy-polyester hybrids, these powder coatings provide applications in the range of 1 to 1.2 mils for colors with good hiding powder. These thin coatings are currently suitable only for indoor applications (Moore, p. 66 and Bocchi, p. 32-34).

Cost and Implementation Issues

Powder coating emits no VOCs and offers several performance advantages. However, to introduce powder coating to an existing paint line,

³ The Faraday cage effect occurs when the electrostatic-field force limits the entry of paint particles in recessed areas. To achieve coating in the recessed area, overpainting of the nonrecessed area or manual touchup often is required. In this situation, real transfer efficiency is less than the quoted transfer efficiency.

a capital investment in special equipment must be made. Pretreatment of the part to be coated also needs to be quite thorough, which can add to the overall cost (EPAd, p. 35). For entirely new lines, however, investment in powder application equipment is comparable to that of equipment for liquid coatings (VT DEC). In addition, the cost of producing a finished coating is typically lower with powder coating than conventional coating because maintenance and operating costs are less, particularly for operations that use a single color (EPAd, p. 42).

Radiation Curing

General Description

Radiation curing uses ultraviolet (UV) and electron beam (EB) electromagnetic radiation to polymerize specially formulated coatings directly on a substrate. Called photopolymerization, the UV-curing process is a photochemical reaction. Specially formulated coatings mixed with a small amount of materials called photoinitiators are

exposed to a UV-light source, initiating crosslinking. The rate of polymerization depends on the intensity of the radiation used (Radtech, p. 40). EB curing crosslinks coatings by exposing them to low-energy electrons; however, because of the high cost associated with EB generators, this method of radiation curing accounts for only about 10 to 15% of the total radiation curing market (Lucas, p. 29).

Advantages and Disadvantages

Radiation curing produces high-performance protective and decorative finishes. Radiation-curable coatings can be 100% reactive liquids, completely eliminating the use of solvents. However, some of the resins in these coatings can volatilize, resulting in VOCs. Although emissions are usually low, the amount of VOCs emitted from radiation curing depends entirely upon the coating formulation (EPAd, p. 68). In addition, the shape of the part will affect the curing; flat surfaces are easiest to cure. Capital investments for UV-curing systems are usually lower than

Table 23. Advantages and Disadvantages of Powder Coatings (NCP2P, p. 3)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces cost due to: <ul style="list-style-type: none"> -no solvent flash required -no coatings mix room needed -minimal oven length required -low ventilation required -less floor space required, i.e., system requires two-thirds to three-quarters of wet paint systems -VOC and HAP compliant, i.e., no solvents ◆ Improves finish quality ◆ Improves finish durability ◆ Has good corrosion resistance ◆ Has coating utilization efficiencies that reach 95 to 99% ◆ Saves energy ◆ Requires little operator expertise ◆ Has quick "packageability" ◆ Has a variety of resins available ◆ Has no hazardous overspray, waste sludge or contaminated water ◆ Reduces worker exposure to solvent vapors 	<ul style="list-style-type: none"> ◆ Has heat requirements that restrict application of powder to metal finishing surfaces ◆ Has powder manufacturing limitations: <ul style="list-style-type: none"> -difficult to make small amounts -control of texture size and distribution limited -metallic powder coatings not as attractive as wet metallic finishes ◆ Has recirculating system that creates negative pressure in booth ◆ Needs gentle air stream to apply powder ◆ Enhances Faraday cage effect (VT DEC) ◆ Is difficult to achieve thin films below 1.0 to 1.5 mils ◆ May cause powder clumping ◆ Is difficult to change colors ◆ Needs cool, dry storage area ◆ Must pretreat substrate

**CASE STUDY:
Knoll Group**

The Knoll Group in East Greenville, Pennsylvania, manufactures office furnishings including office systems, desks, credenzas and chairs. Originally, the company applied solvent-borne coatings using conventional spray techniques. Solvents in the paints included toluene and methyl ethyl ketone (MEK). When Knoll studied the paint process, the company found that paint material loss was nearly 80%.

As a result, Knoll decided to develop a powder coating that would give a high-quality finish. Knoll engineers and scientists experimented with resin and other powder-paint components from various national and international suppliers to develop the new coating. The result was a new powder system that uses approximately 98% of the raw coating material. Excess powder is collected, cleaned and reused.

◆ Savings

The Knoll group realized a payback of its \$500,000 investment in less than a year with total savings of \$639,000 per year. Other bonuses included easier compliance with more stringent environmental regulations, and elimination of fees for incineration of solid and liquid hazardous waste (OH DEP).

investments for conventional ovens and use considerably less space. The cost of the coating is generally higher on a per pound basis, but not always on a coverage basis (RadTech). For more information on other advantages and disadvantages of radiation curing, see table 25 at the end of this section.

Types of Radiation-Curable Coatings

A complete formulation for a radiation-curable coating consists of a blend or mixture of oligomers (low molecular weight polymers), monomers, additives, pigments, and photoinitiators. The oligomer used in the formulation plays an important role in determining the final properties of the

**CASE STUDY:
Swing-N-Slide Corporation**

Swing-N-Slide Corporation's Newco Fabrication Division in Janesville, Wisconsin, is a leading manufacturer of build-it-yourself swing sets. In 1989, Newco installed a liquid spray system for coatings to replace the dip coating operation that had been used there since 1987. However, company officials quickly realized that, while more efficient, spray painting resulted in an increase in air emissions and hazardous waste generation. The Wisconsin Department of Natural Resources began enforcement for air permit noncompliance and classified the facility as a large quantity generator.

As a result, in 1993, Newco installed a powder system to replace the liquid paint system. The system features 10 automatic and 2 manual electrostatic spray paint guns. The facility has reduced hazardous waste generation from 38,350 pounds per year to 4,800 pounds and has been reclassified as a small quantity generator. At the same time, production output has tripled.

◆ Savings

The capital costs for the powder system were \$200,000 with a payback period of 14 months. Newco estimates savings of \$140,670 annually (\$41,000 from elimination of hazardous wastestreams, \$99,670 from savings on labor and materials, and \$23,000 from savings on paint filter cleaning) (WI DNR).

finish (Radtech, p. 40). Resins used in conventional solvent-based coatings can be chemically modified for use in radiation-cured systems by introducing acrylate functionality. The general physical and chemical characteristics of the resins are retained after modification (EPAd, p. 71). The oligomers most commonly found in today's radiation-curable formulations are acrylated urethanes, epoxies, polyesters and silicones (Radtech, p. 40). Coatings that use acrylated resins cure by free radical polymerization and comprise 85% of the total radiation-curable coatings market (Lucas, p. 28).

Table 24. Summary of Powder Coating Resin Properties (EPAd, p. 27)

Coating Property	Epoxies	Epoxy-Urethane Hybrids	Urethane Polyesters	TGIC Polyesters	Acrylics
Hardness	Excellent	Excellent	Very good	Excellent	Very good
Flexibility	Excellent	Excellent	Very good	Excellent	Fair
Resistance to Overbaking	Fair	Very good	Very good	Excellent	Good
Exterior Durability	Poor	Poor	Very good	Excellent	Very good
Corrosion Protection	Excellent	Excellent	Very good	Excellent	Fair
Chemical Resistance	Excellent	Excellent	Very good	Very good	Very good
Thin Coat	No	No	Yes	No	No
Colors Available	All	All	All	All	All
Clears Available	Yes	No	Yes	Yes	Yes
Textures Available	Yes	Yes	Yes	Yes	No

Coatings can also cure by cationic curing, the polymerization of cycloaliphatic epoxies or vinyl ethers. Cationic curing is an attractive option because it withstands pasteurization and promotes adhesion to metals, even during postforming operations (Lucas, p. 28-29).

Application Methods

UV-cured coatings can be applied using traditional spray methods, but roll-coating is often used on flat stock (KSBEAP, p. 11). Varnishes on two-piece cans are applied using an offset process, while curtain coating is used in some specialty applications (RadTech).

Markets

The use of UV-inks and overprint coatings on two-piece metal cans has been commercially successful for more than 10 years. Coating of three-piece composite and metal-can ends has been a commercial reality since the 1970s (RadTech, p. 14). UV-cured coatings are widely used to provide corrosion resistance to galvanized metal tubing. It is also used on metallized plastics. In addition, UV-cured coatings have been formulated for coil coating, in which outstanding resistance and flexibility have been achieved.

Significant growth in other metal markets could occur in the next decade as environmental and

CASE STUDY:**Replacing Solvent-Based Paints with Powder Paint**

Miller Electric Manufacturing Company in Appleton, Wisconsin, is the world's largest manufacturer of arc welding equipment and systems. Founded in 1929, the company employs more than 1,600 people and operates 1,000,000 square feet of manufacturing space. Responding to environmental concerns and a desire to improve corrosion resistance of painted parts, Miller modified their liquid painting conveyor line for metal parts by replacing four of their electrostatic disk applicator booths with two powder booths.

The previous system used high-solids paint and achieved a relatively high transfer efficiency. However, in 1994, nearly 30 tons of VOCs were generated from liquid spray painting operations, and paint-related wastes were disposed of at a cost of approximately \$20,000.

◆ Savings

The new system reduced annual feed stock needs from 13,000 gallons of liquid paint to 80,000 pounds of powdered paint (equivalent to 9,000 gallons of liquid paint). Annual waste generation was reduced from 60,000 pounds per year of paint-related wastes to 15,000 pounds per year of paint-related wastes (90% of the remaining waste was from liquid paint processes). Additional reductions include 50,000 pounds of VOC air emissions, 40,000 pounds of waste paint filters and 5,000 pounds of hazardous waste paint and solvents.

The new powder painting process cost \$545,000 to purchase and install. The new system included a powder paint system, an environmentally controlled application room, oven upgrades, and improvements to metal preparation and cleanup. The new system reduced operation and maintenance costs by \$87,000 per year. This figure includes savings in purchasing and disposal costs. Due to higher transfer efficiency, the total cost of painting was reduced by 25% on a square foot of painting surface, resulting in a payback period of 6.3 years.

This project was approved based on predicted improvements in quality and environmental benefits. Powder painting of parts has significantly improved corrosion resistance and surface finish quality. Employees have also benefitted from the elimination of solvent use and the powder booth's effective dust control system (SHWEC).

productivity requirements increase. The use of UV curing is growing rapidly for wood finishes, medical appliances, consumer products, automotive head lamp assemblies, optical fibers and electronics. Growth will be further enhanced with the development of cationic-cured epoxies, which provide improved adhesion to, and protection of, metal substrates (MPC, p. 29-36).⁴

New Developments

Water-Reducible, UV-/EB-Curable Formulations. These formulations have been developed for a number of coatings and products, including flexo and gravure inks, clear coatings for wood furniture, and dip-coated or spray-coated plastics.

Water dilution of a compatible resin system provides lower viscosity, thinner films, improved flow and leveling, lower applied costs and lower amounts of monomers and solvents. The use of water as a viscosity reducer can minimize or eliminate the use of lower molecular weight diluents, which tend to be skin irritants. Some research has indicated that small amounts of water (1% of water) can reduce the viscosity of oligomers substantially, and larger amounts of water can be used as a formulation tool to vary gloss and reduce web temperatures in critical applications. Disadvantages include the increased time and energy required to remove any added water, as well as the negative effects of water on

⁴ For more information on the use of radiation curing in can manufacturing, refer to the EPA document *Project Summary: Evaluation of Barriers to the Use of Radiation-Cured Coatings in Can Manufacturing*.

the drying and curing system and the substrate to which it is applied. If the material is cured before the water is fully evaporated, then the film properties will be reduced (Lawson, p. 16).

Cost and Implementation Issues

The UV-radiation source most commonly used in industry is the medium-pressure mercury-electrode arc lamp. These lamps can be retrofitted easily to existing production lines, but they require an extraction system to remove excess heat and ozone that is generated by UV action on oxygen in the air (EPAd, p. 72). The cost of an electrode arc system is approximately \$6,400 for a 10-inch lamp, shields to contain the UV light waves that are harmful to skin and eyes, reflectors, shutters, a high-voltage power supply, and an air cooling fan (EPRI). An alternative UV system produces UV radiation through microwave excitation of the mercury vapor (EPAd, p. 72). A microwave-powered UV-curing system costs approximately \$7,500. This system includes a standard-length lamp, a power supply, an air cooling system, a cable, and a detector to ensure that microwave radiation leaks do not occur (EPRI).

EB generators are expensive, complex and large. In addition, oxygen has an inhibiting effect on crosslinking initiated by EB; therefore, companies must establish an inert atmosphere of nitrogen, with oxygen concentrations of less than 100 parts

per million (ppm) if adequate curing is to be achieved (EPAd, p. 72).

Emerging Technologies

This section presents coating systems that have only recently become commercially available. Knowledge of other technologies that are still under research and development is important for technical assistance providers. However, presenting information on experimental systems is not within the scope of this manual. Technologies covered in this section include vapor permeation of injection-cured coatings, supercritical carbon dioxide and unicoat paint. For more information on coating research and development, consult the trade journals listed in appendix A.

Vapor Permeation of Injection-Cured Coatings (VIC). After a reactive resin is applied as a liquid, curing is induced by exposing the liquid to a vapor-containing compound that initiates polymerization. Examples are polyol-isocyanate coatings that cure by tertiary amine vapor injection (NCP2P, p. 4). The amine vapor is made by an amine generator in a predetermined concentration and is dispersed in an air stream channel in the spray gun. The generator uses dried and filtered air at 90 to 120 psi. The coating material and catalyst are mixed as they leave the spray gun.

Table 25. Advantages and Disadvantages of Radiation-Cured Coatings (NCP2P, p. 4)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Uses coatings with lower VOC and HAP content than conventional coatings ◆ Has lower capital investment than conventional ovens ◆ Increases production rates because curing periods are reduced to seconds ◆ Has low energy costs ◆ Has consistent performance ◆ Requires small ovens ◆ Has low air movement that reduces dust and dirt contamination ◆ Is easily installed/retrofitted ◆ Reduces fire and explosion hazard 	<ul style="list-style-type: none"> ◆ Can have interference of photocure by pigments ◆ Has higher costs for EB and UV coatings ◆ Has potential problems with acrylate skin irritation if proper safety techniques are not used ◆ Has shrinkage and adhesion problems with acrylate ◆ Is not applicable to all finish types because it produces a specific "look" ◆ Has curing sensitive to shape of part

CASE STUDY: Adolph Coors Company

The Coors can manufacturing plant, located in Golden, Colorado, is the largest single aluminum can manufacturing plant in the world, producing approximately 4 billion cans a year. The plant currently produces aluminum cans exclusively for the beer beverage market.

Since 1975, Coors has been using UV curing in full-scale can production. The initial push to convert to UV was caused by a desire to increase can printing speeds, reduce energy consumption and lower air emissions.

◆ Savings

According to company estimates, the UV system saves the firm \$90,000 per billion cans produced versus conventional technology. In addition, Coors estimates that since 1975, VOC emissions have been reduced by 1,740 tons (Donhowe). For additional information on Coors use of UV curing, see EPRib.

This technology is a high-solids coating system because the coating still uses solvent in the formulation. However, its ease of use and rapid cure times can improve production efficiency (EPAd, p. 80).

Advantages and Disadvantages

VIC can produce a variety of finishes with good performance characteristics including chemical, solvent, and stain resistance; high humidity and water resistance; high mar and abrasion resistance; and color and gloss retention. These coatings can

be used on a broad range of substrates including plastic, steel, aluminum, wood and castings. Heat-sensitive parts such as thermoplastics and thermosets are ideally suited to the low-temperature cure used with VIC (EPAd, p. 80). For other advantages and disadvantages of VIC, see table 26.

Cost and Implementation Issues

VIC is compatible with LVHP, HVLP, electrostatic and airless spray systems. However, electrostatic equipment might need to be modified to accommodate the amine generator. In addition, some types of spray guns might have rubber or plastic seals that degrade when exposed to the amine. Capacity is limited to two spray guns (EPAd, p. 80).

UNICOAT Paint Technology: The UNICOAT technology is a one-coat painting system for aircraft that replaces the combination of a coat primer system and a top coat system. Since only one coat is applied instead of two coats, VOC emissions and waste generated from cleanup operations can be reduced by 50 to 70%. This technology, developed by the Naval Warfare Center (NAWC), consists of a self-priming topcoat for aircraft and other industrial parts. It is applied directly to the metal substrate without priming (NFESC).

UNICOAT, which is formulated without lead or chrome, replaces the two-coat system with a blend of organic and inorganic zinc compounds that are non-toxic. UNICOAT contains polyurethane as do traditional coatings; however, corrosion inhibitors and adhesion promoters have been added to UNICOAT.

UNICOAT has performed at levels equivalent to, and superior to, the performance levels for

Table 26. Advantages and Disadvantages of VIC (NCP2P, p. 4)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Eliminates or reduces solvent ◆ Has low-temperature processing ◆ Has unreacted overspray that can be collected for reuse ◆ Can be used on heat-sensitive substrates 	<ul style="list-style-type: none"> ◆ Has limited industrial experience ◆ Has a highly complex process ◆ Requires high level of operator skill ◆ Has high capital cost

Table 27. Advantages and Disadvantages of Unicoat Paint Technology (NFESC)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Contains no toxic pigments (e.g., chromate, lead) ◆ Reduces VOC emissions and hazardous waste generation ◆ Reduces paint and primer costs ◆ Reduces paint weight on equipment and aircraft ◆ Reduces labor costs because one coat is applied ◆ Reduces stripping cost due to less paint on workpiece 	<ul style="list-style-type: none"> ◆ May not be suitable for all applications

conventional paints (in applications by the U.S. Navy and U.S. Air Force). To avoid adverse reactions, freshly painted wet surfaces must not come in contact with alcohols, amines, water or acids. Costs for the UNICOAT system varies depending on the specific application (NFESC).

7 Application Techniques

Various application methods are available to coat metal, the most common being spray painting and electrodeposition (EPA, p. 20). Coatings also can be applied by dipping parts into tanks filled with paint and then allowing the excess paint to drain off, or by direct application methods such as roller coating and flow coating. This chapter provides information on: conventional air-spray guns; high-volume/low-pressure spray guns; airless spray guns; electrostatic spray guns; electrodeposition; roll coating; flow coating; and plural component systems. Which paint application process is chosen depends on the type of substrate to be coated, the type of coating, and the size and shape of the surface (IHWRI, p. 35).

General Description of Spray Systems

Paints and coatings can be applied to surfaces in a number of ways. Industrial coatings often are applied on a production line using spray application techniques. Curing is done usually by an accelerated curing operation involving heat, surface catalysts or radiation (EPA, p. 155-156).

In general, spray methods use specially designed guns to atomize paint into a fine spray. For industrial applications, the paint is typically contained in a pressure vessel and fed to the spray gun using compressed air. Traditionally, hand-held or automated guns (mounted on a mechanical control arm) have been used to apply liquid paints to metal substrates.

Although spray systems are easy to operate and have low equipment costs, they have a certain amount of overspray and rebound from the sprayed surface and, therefore, are unable to transfer a substantial portion of the paint to the part (Freeman, p. 710). Spray booths with an open front and exhaust at the rear are generally used to remove the overspray as it is generated (EPA, p. 155).

P2 Tips for Coatings Application

- ◆ Eliminate the need to paint by using surface-free-coatings materials
- ◆ Substitute low-VOC paints for solvent-borne paints
- ◆ Increase transfer efficiency
- ◆ Train operators to practice proper spray painting techniques
- ◆ Improve housekeeping, maintenance and operating practices
- ◆ Use a paint heater to adjust viscosity
- ◆ Set application standards

Pollution Problem

During conventional spray painting, some of the paint is deposited on the surface being painted; while much of it, in the form of overspray, is sprayed into the air. As the paint dries, the solvent evaporates into the air in the form of VOCs. Often exhaust from paint booths is run through dry filters to capture the particulates. Though it can be run through a water scrubber that separates the paint from the air, scrubber water is normally recycled, and paint solids are concentrated in the scrubber sump. When the sump fills with paint sludge, it is removed and put in drums for disposal. Paint sludge that fails the TCLP test must be disposed of as a hazardous waste (Higgins, p. 118).

General P2 Options

Emissions of VOCs from coatings application can be significantly reduced by substituting a paint with a lower solvent content (e.g., high-solids, waterborne or powder), and by increasing transfer efficiency. The type of coating and the application method selected can have a significant effect on transfer efficiency (MnTAP, p. 2). For more information on alternatives to solvent-borne coating formulations, see chapter 6.

Whatever type of paint and application method is chosen, the best environmental solution may be to redesign the product to eliminate unnecessary coating. This is a P2 option known as surface-free coating. Many of the resins used in alternative paints are made from regulated chemicals, and surface-free coating can eliminate the use of these substances (EPA, p. 165).

A number of other P2 techniques in coating applications also are available. For coating operations that involve manual spray application, for example, training operators to practice proper spray techniques is a cost-effective method for reducing VOC emissions and other wastes. Wastes generated during the application of paints and coatings (as well as during surface preparation and equipment cleaning) can also be reduced by adopting improved housekeeping, maintenance and operating practices. Additional P2 options include: installing a paint heater to reduce the need for paint thinning with solvents, and setting application standards to avoid unnecessary coating. Each of these options is discussed below.

Transfer Efficiency and Paint Application

Improvements in transfer efficiency can lead to less paint waste and lower emissions of VOCs. Transfer efficiency depends on a large number of parameters. Some of these parameters are under the control of the operator, while others are not. Important parameters that should be considered when optimizing spray gun application include:

- ◆ Spray application technique.
- ◆ Target configuration and size. Higher transfer efficiency rates are easier to obtain on large flat objects than on small complex parts.
- ◆ Spray booth configuration. Stray crossdrafts and downdrafts may reduce transfer efficiency by deflecting the paint away from the target. Temperature control and humidity control in a facility can significantly affect the transfer efficiency of electrostatic systems.
- ◆ Paint characteristics.
- ◆ Paint/air flow rates. Spray guns are designed to operate at maximum optimum flow rates.

Exceeding these flow rates can reduce transfer efficiency by increasing the amount of blowback (paint bouncing off part) and overshoot. Excessive air pressure can also lead to premature drying of the paint before it reaches the target (paint fog).

- ◆ Spray gun distance from part. When the gun is placed too close to the part, bounceback increases and can result in poor finish quality (i.e., sags and runs). Too much distance results in overshoot and paint fog.

- ◆ Operator error (Jacobs, p. 7-8).

By definition, transfer efficiency is the amount of paint solids deposited on an object, divided by the amount of paint solids sprayed at the object, multiplied by 100%. The definition of transfer efficiency does omit some related factors for optimum material use. Minimizing waste is not necessarily achieved by simply using the application technique that has the highest rated transfer efficiency. "Real" transfer efficiency depends on a number of other factors including:

- ◆ Quality of finish. The quality of the finish generally improves as the size of spray particles is reduced. Unfortunately, as the size of spray particles decreases, transfer efficiency also decreases. Some of the finest particle sizes are achieved with conventional LVHP air spray; however, this is the least efficient means of applying paint. To meet finish requirements, a compromise must be reached between transfer efficiency and quality.
- ◆ Production rate. A desired production rate should be established before determining the transfer efficiency of the coating system, especially if coating is being done on a conveyORIZED system that includes other operations. This is because the efficiency of spray devices will vary with the rate of application.
- ◆ Desired film thickness. To determine real transfer efficiency, the thickness of the applied film versus the thickness desired should be established. For example, if a 1-mil-thick film is specified, but the spray method can only deliver a quality film of 2 mils or greater, then at least 50% of the paint is wasted. Even if all

of the paint used is applied to the workpiece, the real transfer efficiency is only 50%.

- ◆ **Uniformity of applied film thickness.** A flat, fan-shaped spray pattern can hold film thickness variations to within 10% of the ideal in a well-engineered painting system. However, a round doughnut-shaped pattern is used in some spray systems. This type of pattern delivers a film thickness variation of approximately 1 mil. In other words, if the desired film thickness is 1 mil, the coating can have areas that are 2 mils thick. Even when all the paint is applied, 25% is wasted. Therefore, at best the real transfer efficiency is 75%.
- ◆ **Edge buildup.** In electrostatic painting, edges of parts can attract paint spray that would normally pass by the workpiece. Paint builds up on the edges, which represents wasted paint even though the paint is transferred to the workpiece. This buildup may have to be sanded down and the edges may have to be touched up manually.
- ◆ **Need for manual touchup/Faraday cage effects (in electrostatic spraying).** In addition, in electrostatic painting, the electrostatic field force can prevent paint particles from reaching recessed areas. To coat these areas completely, overpainting or manual touchup of the nonrecessed areas often is required. In this situation, real transfer efficiency is less than the quoted transfer efficiency.

In summary, real transfer efficiency depends on the particular coating situation. Replacing a system (manual or automatic) will not reduce VOC emissions by improving transfer efficiency alone, hence another step must be taken to use less paint. This may require changing the flow rates, triggering times, and/or spray tip sizes. For instance, electrostatic can be added to increase transfer efficiency, but if nothing else is changed, VOC emissions will stay the same and paint thickness on the part will increase. A study by the Research Triangle Institute found that real transfer efficiency depends heavily on solids content, wet film thickness, application equipment and operator experience. Therefore, if a firm is considering a change in paint application methods to improve transfer efficiency, careful testing should be done

to ensure that paint and solvent waste are truly being minimized. When comparing application techniques for possible use in a particular plant, spray efficiency and the above factors should all be considered (VT DEC).

Strategies to Improve Transfer Efficiency

Following are methods that facilities can use to increase their transfer efficiencies:

- ◆ **Stand closer to the workpiece.** A typical gun-target distance is 8 to 12 inches. In general, as the distance increases, transfer efficiency diminishes. As the distance decreases, however, the operator needs to reduce the fluid and/or air pressure to avoid applying too much coating to the part.
- ◆ **Optimize fan size.** The operator must appropriately size the fan for the workpiece on a regular basis. A spray painter uses a fan size of 6 to 8 inches when painting small- or narrow-shaped parts such as metal tubing or angle brackets. Adjusting fan size is not a major problem for operators who work on production lines that coat one type of part or work in long production runs. For those facilities whose parts continuously change size, the most practical strategy is to purchase a cap that the operator can change quickly and easily. Because not all spray guns can be fitted with adjustable caps, facilities may need to contact a variety of vendors to locate this equipment.
- ◆ **Reduce atomizing air pressure (where applicable).** In HVLP, conventional air atomizing, and electrostatic guns reduce air pressure to the lowest possible levels, which results in marked improvements in transfer efficiency rates. For airless, and in some cases, air-assisted airless guns, using a smaller orifice can achieve the same atomizing results.
- ◆ **Reduce fluid pressure.** If the fluid pressure and corresponding fluid flow rate are high, the stream of paint emerging from the spray gun travels a relatively long distance before bending and falling to the ground. Such a flow rate has a very short residence time within the

spray gun and requires a large amount of energy for atomization. As fluid pressure decreases, the stream emerging from the spray gun shortens and less energy is needed for atomization. Longer residence times lead to more efficient atomization, which in turn leads to higher transfer efficiencies.

Many spray painters argue that lowering fluid delivery rates slows down production speed and raises the cost of painting. This argument is true only for a very small percentage of facilities that have already optimized their fluid delivery rates. At most facilities, fluid delivery rates are considerably higher than the job requires.

- ◆ Space workpieces closer together. Many facilities that use conveyor systems suspend parts on hooks that are spaced 18 to 24 inches apart. This spacing is appropriate for medium or large parts but reduces transfer efficiency on small parts. Facilities should try to use hooks and racks specifically designed for the parts they are coating. This will result in increased transfer efficiency and an optimized speed for the process line.

Operators, however, cannot always work well with close spacing. For instance, parts with complex geometries often require the operator to access the part at a variety of angles to ensure the quality of the coating. Also, when using electrostatic spray guns, painters must provide sufficient spacing to allow for some wrap to take place.

- ◆ Reduce air turbulence in spray booth. Paint facilities that use several spray booths that all pull from one air make-up system may experience violently turbulent air velocities that change direction from one second to the next. Correcting this problem can be difficult and often requires air conditioning and air ventilation consultants. While this remedy can be costly, having a uniform, laminar air flow through a spray booth improves transfer efficiency and significantly reduces overspray and booth maintenance.
- ◆ Reduce the air velocity in the spray booth (not below recommended OSHA limits). OSHA

requires a minimum air velocity of 100 to 120 feet per minute through spray booths in which operators use manual spray guns (the automated electrostatic gun's minimum air velocity is 60 feet per minute). Many paint facilities inadvertently run their booths at velocities well above the limit because they are unaware of the effect this can have on transfer efficiency. Lower air velocities are especially important in electrostatic operations because too high a velocity can prevent the coating from wrapping the parts.

- ◆ Reduce leading and trailing edges. In cases where a high-quality finish is required, trailing edges are needed to ensure that there are no fat edges. In many cases, however, operators set the spray guns so that they trigger sooner than is necessary, and/or cease too long after the part has passed. When painting small- or medium-sized parts, even a small decrease in leading and trailing edges results in significant improvements in transfer efficiency.
- ◆ Select the most efficient spray gun for the intended application. Selecting a spray gun that meets finish requirements and has the highest transfer efficiency is important in optimizing the efficiency of a coating system.

Before deciding whether an operation can improve transfer efficiency, determine the current transfer efficiency rates. Appendix G provides information on how to estimate current transfer efficiency (EPAq, p. 74-76).

Table 28 provides an overview of the relative costs and benefits of the different spray application methods relative to conventional air spray guns.

Set Application Standards

The monitoring of applied film thickness is critical to ensure that a uniform and consistent coating of paint is being applied. Too thin a coat will result in premature failure in the field, while too thick a coat represents excess cost and waste. Other standards that should be established include the levels of crosshatch adhesion, film hardness and solvent resistance. Specification of and adherence to standards can do much to minimize the level of

Table 28. Cost/Benefit Summary for Spray Application Methods

Method of Application	Capital Cost	Process Complexity	Waste and Emissions	Additional Considerations
HVLP Spray	Low	Low	Medium/High	
Air-Assisted Airless Spray	Low	Low	Medium/High	
Electrostatic Spray	Medium	Medium	Medium	Only conductive parts can be painted
Powder Coating	Medium	Medium	Low	Extensive parts washing and a curing oven are required

NOTE: Capital cost refers to the cost of the system in comparison to conventional air spray. The higher the process complexity, the higher the associated costs (i.e., training for employees and maintenance)

rejects and ease troubleshooting when problems arise (Freeman, p. 487). Different tests have been used over the years for liquid and cured paints. A consistent system should be used for evaluating coating properties. The American Society for Testing Materials (ASTM) standards has developed many useful standards; see appendix E for more information (KSBEAP, p. 25).

Adopt Proper Manual Spray Techniques

Untrained and hurried workers using poorly maintained equipment can contribute to the need to rework products and to clean up and dispose of wasted coatings, thereby increasing costs. A well-trained operator is far more important than the type of gun used. By training operators on proper equipment setup, application techniques and maintenance, companies can reduce the use of materials by 20 to 40% (Callahan). These savings will depend on the parts coated, material sprayed, and operator technique and experience level (MnTAPd, p. 6). The fundamentals of effective spray technique that operators can follow are:

- ◆ Proper gun setup. Use the paint gun manufacturer's suggested air cap and fluid tip combination for the viscosity of the product being sprayed. Check the spray gun to see that it produces a proper spray pattern, and keep

the air and fluid pressures at the lowest possible settings.

- ◆ Spray distance and angle. Keep the distance between the gun and the part being sprayed as close as possible to the manufacturer's recommendations at all times (e.g., 6 to 8 inches for conventional spraying, 12 to 15 inches for airless spraying, and 10 to 12 inches for electrostatic spraying). Move the spray gun parallel to the work, keeping the gun at a right angle.
- ◆ Triggering and overlap. Overlap each successive stroke (e.g., 50% for conventional spraying or 25% for airless spraying), using a crosshatch overlap when required. Trigger the spray gun at the beginning and end of each stroke, making sure that the gun is in motion before triggering. In so doing, operators can minimize the lead (i.e., the distance between where the gun is triggered and the point where the gun pattern hits the part) and the lag (i.e., the distance between the point where the pattern leaves the part and the point where the gun is untriggered), thereby reducing overspray (Binks and IWRC, p. 2-8).

Whenever helping companies adjust the spray technique of operators, technical assistance providers should keep in mind that, over a period

of time, the firm may have selected a coating and application equipment to conform to an incorrect technique. Equipment settings and materials might need to be changed to conform to an improved technique (De Vilbiss).

Improve Current Operating Practices

Improving operating practices is another cost-effective pollution prevention method for reducing the amount of wastes generated. The following methods require minimal capital outlays, and can be very effective (KSBEAP, p. 21):

- ◆ Segregate waste streams to prevent mixing of hazardous and nonhazardous waste
- ◆ Perform preventative maintenance for quality control of finishes
- ◆ Improve materials handling and storage to avoid spills
- ◆ Practice emergency preparedness to minimize loss during accidents
- ◆ Schedule jobs to maximize color runs
- ◆ Implement strict inventory control by purchasing only the amount of paint required
- ◆ Standardize paints and colors to minimize the number of different types of paint used
- ◆ Return expired materials to suppliers for rebinding (KSBEAP, p. 21, EPAc, p. 84-85 and Freeman, p. 487-489)

The following sections provide more detailed information on specific application equipment and on methods to optimize their performance.

Conventional Air Spray (LVHP)

General Description

Conventional air spray technology, which has been the standard for the past 40 years, uses a specially designed gun and air at high pressures (i.e., 40 to 90 psi) to atomize a liquid stream of paint into a fine spray. This technology is known as low-volume/high-pressure (LVHP) but is commonly referred to as conventional air spray. Air is usually supplied to the LVHP gun by an air compressor, and paint is supplied via a pressure feed system (siphon and gravity systems are also

used). A typical picture of an air spray gun features clouds of overspray around the part.

Conventional air spray produces a smooth finish, and can be used on many surfaces. It offers the best control of spray pattern and the best degree of atomization. This system produces the finest atomization and, therefore, the finest finishes. It also sprays the widest range of coating materials (CAGE). However, this technology produces a great deal of overspray, resulting in low transfer efficiencies (i.e., 30 to 60%) and uses large amounts of compressed air (7 to 35 cfm at 100 psi). In addition, because the solvent in the paint is highly atomized along with the paint solids, transfer efficiency is low and VOC emissions are high (MnTAP, p. 3).

The essential components of an air atomizing system are gun body, fluid inlet, fluid nozzle, fluid needle assembly, fluid control assembly, air inlet, air nozzle, air valve, fan control and trigger. Other parts of the spray coating system may include a compressed air supply, fluid supply and paint heater. Recirculation booths are often used with these systems. These booths are designed to reduce process exhaust volumes while maintaining minimum ventilation flow rates in order to lower operating costs for both emission control systems and the facility in general (e.g., heating, ventilation and air conditioning). These systems have built-in safety limits that are based on the concentration of hazardous constituents present in the recirculated stream.

Advantages and Disadvantages

The main advantages of conventional air spray systems are the high level of control that the operator has of the gun and the versatility of the systems. Disadvantages of this system include high air emissions, low transfer efficiencies and high compressed air use. However, using proper training and setting the gun at low pressure (20 psi), transfer rates similar to HVLP can be achieved (Eck).

Costs

The capital investment for a new conventional air spray system that includes spray gun, two-gallon pressure pot, hoses and fittings can range from \$500 to \$1,500.

Safety

Painters are required to wear respirators to prevent inhalation of overspray, hazardous vapors and toxic fumes. Depending on the noise level in the spray booth, ear protection may also be required.

Alternative Methods

There are a number of alternative spray gun systems, including high-volume/low-pressure (HVLP) air spray, airless spray, and electrostatic spray. There are also variations on each of these techniques. Of the many available methods, electrostatic air-assisted airless spray is considered to have the best transfer efficiency (IWRCb, p. 39). Other available paint application methods include electrodeposition, and dip, roll and flow coating.

High-Volume/Low-Pressure (HVLP) Air Spray

General Description

As the name suggests, this technology uses a high-volume of air at low pressures (i.e., 0.1 to 10 psi) to atomize paint. This technology reduces overspray and improves transfer efficiency. HVLP guns have nozzles with larger diameter openings than LVHP guns for atomizing air. They can be bleeder (i.e., controls only the fluid flow to the gun) or non-bleeder (i.e., controls air flow and

fluid flow to the gun by use of a trigger) types, and may require airflows of 10 to 30 cubic feet per minute. Air can be supplied to the sprayer by turbine air blowers or conventional shop compressors (KSBEAP, 13). Typical transfer efficiencies with HVLP systems are 65 to 75%. Figure 5 shows a typical configuration for a HVLP system.

Advantages and Disadvantages

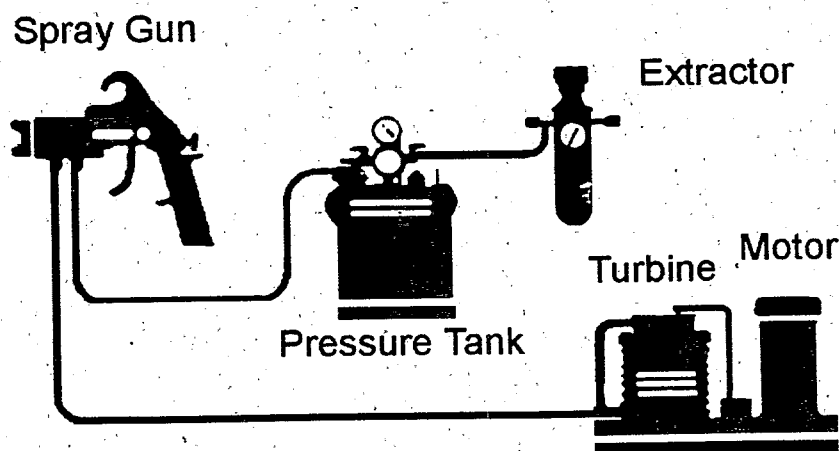
An HVLP gun is portable and easy to clean, and has a lower risk of blowback to the worker. In many cases, HVLP guns are mandated to comply with state air regulations (KSBEAP, p. 14). However, the atomization of HVLP guns might not be good enough for fine finishes, and production rates might not be as high as with conventional LVHP spray. Generally, fluid delivery rates of up to 10 ounces per minute with low viscosity paints work best with HVLP guns (MnTAP, p. 3). For more information on other advantages and disadvantages of HVLP, see table 29.

Types of HVLP Systems

Several different configurations of HVLP systems are available. The specific air supply (i.e., turbine or compressor) and fluid delivery system (described below) will affect the efficiency, ease of use, cost and versatility of the particular system (KSBEAP, p. 13).

In a siphon-fed system, air pressure to the sprayer is used to pull paint from a cup located below the gun, producing a fully atomized pattern for even surface coverage. The simple design of

Figure 5. HVLP System (VT DEC)



siphon-fed guns has made it possible to buy conversion kits for conventional siphon sprayers, making HVLP technology very affordable for small shop owners (KSBEAP, p. 13).

Gravity-fed systems are well adapted to high viscosity paints such as clears, water-based paints, high-solids paints and epoxy primers because of the design of the system. The cup, located on top of the gun, allows paint to completely drain, minimizing paint waste (KSBEAP, p. 13).

The pressure assist cup system uses a cup that is mounted beneath the gun with a separately regulated air line to feed paint to the gun. This design increases transfer efficiency and makes it possible for the operator to spray evenly while the gun is inverted, offering maximum flexibility in application techniques (KSBEAP, p. 13-14).

Although covering every aspect of equipment selection is not possible in this manual, see appendix D for a list of some of the more important points to consider when evaluating HVLP spray equipment.

Cost and Implementation Issues

HVLP paint spray systems can be used in a variety of painting applications. The finer atomization of HVLP systems produce smoother finishes. There are many paint gun models with a variety of tip sizes to accommodate most coatings including solvent-based paints, water-based coatings,

fine finish metallic, high-solids polyurethane, contact adhesives, varnish, top coats, lacquer, enamel primer, latex primer, epoxy and vinyl fluids. The efficiency of these systems is greatly reduced if the painting is done in an exposed area.

LVHP systems can be easily converted to HVLP by retrofitting the air gun and installing the appropriate diameter air hoses (5/16 in. I.D.); however, the air supply system must be able to deliver 10 to 30 cubic feet per minute of airflow at 10 psi or lower. If a firm has a large investment in high-pressure air compressors, conversion air systems (CAS) can be used. The CAS reduces high-pressure compressed air in two ways: 1) by using an air-restricted HVLP gun that is specially equipped to restrict air pressure within the gun body, and 2) by using a small air conversion unit that takes in high-pressure compressed air and restricts its flow, delivering low-pressure air to the HVLP gun (CC and Binksd). Costs can vary depending on specific applications, painting/coating type, paint volume, workpiece specifications and technique. Generally, costs for HVLP paint-spray system equipment range from \$500 to \$1,500 for a gun, hose and paint pot.

Safety

Painters are required to wear respirators to prevent inhalation of overspray, hazardous vapors and toxic fumes when using HVLP equipment. Depending on the noise level in the spray booth, ear protection may also be required.

Table 29. Advantages and Disadvantages of HVLP Spray Guns (NCP2P, p. 5.)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces overspray ◆ Increases transfer efficiency ◆ Reduces paint waste ◆ Lowers booth cleanup costs ◆ Reduces filter replacement costs ◆ Decreases waterwash reservoir treatment costs ◆ Reduces VOC and HAP emissions ◆ Is portable and easy to clean ◆ Sprays well into recesses and cavities ◆ Reduces worker exposure to blowback 	<ul style="list-style-type: none"> ◆ Has atomization that may not be sufficient for fine finishes ◆ May not be able to operate with high production rates

CASE STUDY: Lily Company

Lily Company Drum Reconditioning in Thomasville, North Carolina has experienced a 38% reduction in lacquer paint usage by switching to HVLP guns. Converting to HVLP has saved the company approximately \$3,500 a month in materials and reduced paint booth cleanup. The cost of the HVLP equipment was the same as it would have been to purchase conventional spray gun equipment (VT DEC).

Low-Pressure/ Low-Volume

General Description

Low-pressure/low-volume paint spraying, which is similar to air-assisted airless, is a relatively new development. Paint and air separately exit through the spray nozzle into a secondary fluid tip assembly. The exiting paint stream is of low pressure (less than 100 psig), flattened by the spray nozzle, but unatomized. Atomization occurs by impinging low amounts of compressed air (5-35 psig) from two small holes in the fluid tip assembly into the flattened paint stream. Table 30 presents an overview of the advantages and disadvantages of LPLV Systems.

Airless Spray

General Description

Airless spray does not use compressed air. Instead, paint is pumped at increased fluid pressures (500 to 6,500 psi) through a small opening at the tip of the spray gun to achieve atomization.

Pressure is generally supplied to the gun by an air-driven reciprocating fluid pump (KSBEAP, p. 16). When the pressurized paint enters the low pressure region in front of the gun, the sudden drop in pressure causes the paint to atomize. Airless systems are most widely used by painting contractors and maintenance painters (Binksc).

Advantages and Disadvantages

Airless spraying has several distinct advantages over air spray methods. This method is more efficient than the air spray because the airless spray is softer and less turbulent, thus less paint is lost in bounce back. The droplets formed are generally larger than conventional spray guns and produce a heavier paint coat in a single pass. This system is also more portable. Production rates are nearly double, and transfer efficiencies are usually greater (65 to 70%). Other advantages include the ability to utilize high-viscosity coatings (without thinning with solvents) and its ability to have good penetration in recessed areas of a workpiece.

Table 30. Advantages and Disadvantages of LPLV Spray Guns (Jacobs, p. 15)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Reduces overspray ◆ Increases transfer efficiency ◆ Reduces paint waste ◆ Lowers booth cleanup costs ◆ Reduces filter replacement costs ◆ Decreases waterwash reservoir treatment costs ◆ Reduces VOC and HAP emissions ◆ Sprays well into recesses and cavities ◆ Has moderate capital cost ◆ Low operating costs 	<ul style="list-style-type: none"> ◆ Does not have a proven track record

The major disadvantage of the airless spray is that the quality of the applied coating is not as good as conventional coatings, unless a thicker coating is required. Airless spray is limited to painting large areas and requires a different nozzle on the spray gun to change spray patterns. In addition, the nozzle tends to clog and can be dangerous to use or clean because of the high pressures involved (IHWRIcB). For more information on other advantages and disadvantages of airless spray, see table 31.

Application Considerations

Small fluid nozzle orifices limit the coating materials that can be sprayed with airless systems to those that are finely ground. This rules out fiber-filled and heavily pigmented materials. In addition, airless spraying lacks the feather capability that air guns have. This can result in flooding of the surface and sags or runs if gun movement is too slow. The high pressures used with airless spray deliver a high rate of paint flow through the nozzle, tending to enlarge the orifice, increase flow rates and change spray pattern characteristics. This is especially true at very high pressures and with paints containing high amounts of pigments or abrasive pigments. Strict maintenance is required for this system. Foreign objects in the fluid that are larger than the nozzle tips can block or shut off the system. Equipment maintenance on pumps is high because of the high pressures used (CAGE).

Economics

The capital investment required for a new airless spray system consisting of an airless spray gun, carted mount pump, hoses, and fittings, can range from \$3,500 to \$7,500.

Safety

The high velocity of the fluid stream and spray pattern as it exits the gun and hose is a potential hazard. Operators should never allow any part of their body to come into contact with this high-pressure material. Failure to keep several inches away from the coating as it exits the gun will result in serious injury. As with other spray systems, respirators are required, and hearing protection may be required as well.

Types of Airless Systems

Air-assisted airless systems are a variation of airless spraying. These systems use supplemental air jets to guide the paint spray and to boost the level of atomization. Approximately 150 to 800 psi of fluid pressure and 5 to 30 psi of air pressure are used. Air-assisted airless spray systems atomize paint well, although not as well as air spray methods. The use of air-assisted airless systems improves the quality of the finish, presumably because finer paint particles are formed. The transfer efficiency of the airless, air-assisted spray gun is greater in comparison to airless, and with proper operator training, the manufacturer can obtain finishes comparable to conventional guns (Batelle, p. III-5). This system has the same dangers as airless spraying, but it also requires more maintenance and operator training and has a higher capital cost (IHWRIcB).

The major difference in gun construction between an air-assisted airless gun and an air-atomized gun is found in the atomizing tip. The air-atomized tip incorporates a fluid nozzle and an air nozzle. The fluid orifice in the center of the tip is surrounded by a concentric atomizing ring of air. The air-assisted tip delivers a flat fan spray of partially atomized paint. Jets of atomizing air, exiting from ports in small projections on each side of the tip impacts at a 90 degree angle into the spray. The air jets break up the large droplets and complete the atomization, assisting the airless spray process.

Economics

The capital investment required for a new air-assisted airless spray system, including an air-assisted airless spray gun, 10:1 ratio carted mount pump, hoses and fittings, can range from \$2,500 to \$5,000.

Advantages

- ◆ Low equipment maintenance. The reduced fluid pressures in comparison with airless spray cut down on pump and fluid nozzle wear.
- ◆ Good atomization. The atomization quality of an air-assisted airless gun is rated as superior compared to an airless gun but it is not nearly as good as with an air-atomized gun.

- ◆ Low bounceback. The extremely low atomizing air pressure allows air-assisted airless guns to spray into corners and hard-to-reach areas better than with air-atomized spray.
- ◆ Varied fluid delivery. The paint flow rates can vary considerably from about 5 to 50 ounces per minute.
- ◆ High paint transfer efficiency. With a low-end delivery rate of 5 ounces per minute versus 25 ounces for airless, air-assisted transfer efficiency is even higher than airless.

Table 31 presents an overview of the advantages and disadvantages of airless spray systems.

Air and air-assisted electrostatic spray guns resemble nonelectrostatic guns. An electrostatic gun has a wire charging electrode positioned in front to ionize the air. The ionized air passes its charge to the paint particles exiting the gun. Some guns have no external electrode. Instead, an internal electrode located inside the gun barrel is used to charge the paint. In another variation, a metal electrode is situated in the paint tank, and the paint is delivered to the gun already charged.

Cost and Implementation Issues

LVHP systems cannot be converted to airless systems. Therefore, the capital cost for implementing airless spray is usually high. However, this cost might be offset by the number of advantages that airless spray provides.

Electrostatic Spray

General Description

This spray method is based on the principle that negatively charged objects are attracted to positively charged objects. Atomized paint droplets are charged at the tip of the spray gun by a charged electrode; the electrode runs 30 to 140 kV through the paint at 0 to 225 microamperes (CAGE). Paint can be atomized using conventional air, airless, or rotary systems. The electrical force needed to guide paint particles to the workpiece is 8,000 to 10,000 volts per inch of air between the gun and its workpiece. The part to be painted, which is attached to a grounded conveyor, is electrically neutral, and the charged paint droplets are attracted to that part. If the charge difference is strong enough, the paint particles normally fly past the part and reverse direction, coating the edges and back of the part. This effect is called "wraparound" and increases transfer efficiency (KSBEAP, p. 15). Electrostatic spray is used by most appliance manufacturers (Binksc).

Advantages and Disadvantages

The major advantage of using electrostatic spraying is that it saves in material costs and labor. The labor savings is often associated with a changeover to automated lines, although labor savings for cleanup is significantly reduced in either automated or manual lines. Another benefit of electrostatic is its ability to completely cover an object with a uniform thickness, including areas that are normally inaccessible (Batelle, p. III-10).

Table 31. Advantages and Disadvantages of Airless Spray Systems (NCP2P, p. 5)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high rates of paint flow ◆ Has relatively high transfer efficiency ◆ Has versatile gun handling (no air hose) ◆ Has ability to apply highly viscous fluids 	<ul style="list-style-type: none"> ◆ Has relatively poor atomization ◆ Has an expensive nozzle ◆ Reduces fan pattern control ◆ Has coatings limitations ◆ Has a tendency for tip plugging ◆ Has a skin injection danger ◆ Requires increased operator training ◆ Requires increased maintenance

The initial capital investment for electrostatic systems is high (EPA, p. 155). In addition, electrostatic systems must be properly grounded at all stages of paint delivery in order to reduce injuries and fire hazards that can result from shorting or sparking (KSBEAP, p. 15-16). Another problem with electrostatic spray is that the paint is attracted to all grounded objects, including the conveyor and conveyor protection systems in assembly line painting, the paint booth ceiling, the spray gun and the spray gun handler. Work has been done on developing an electrically charged paint repelling panel to protect against stray paint. Such repelling panels are not 100% effective, but they can cut down on problems from stray paint (IHWRIc). For more information on other advantages/disadvantages of electrostatic spray, see table 32.

Types of Electrostatic Systems

Rotary atomization is a variation of electrostatic spraying that uses centrifugal force generated by discs or bells to atomize paint, which drives it from the nozzle. The atomization of this method is excellent as is the transfer efficiency. This method also can be used with paints of different viscosity. However, the equipment needed for this type of application is very specialized and usually requires a major conversion of a painting line (IHWRIc). Typical costs for a new rotary atomization system consisting of a rotary atomizer, 2-gallon pressure-pot, and hoses and fittings may range from \$5,000 to \$7,500.

Implementation Issues

An LVHP air spray system can be converted to an electrostatic system. In most cases, however, airless, air-assisted airless, or rotary atomization is used with electrostatic spray. This is because LVHP air-atomized electrostatic spray has a transfer efficiency of only 60 to 70%. Airless, however, runs from 70 to 95%, and rotary runs from 80 to 90% (IHWRIc).

Part and gun cleanliness are essential for efficient electrostatic operation. Dirt or oversprayed paint can form on a conductive track on the plastic gun tip and short out the system. For top efficiency, the part to be coated should be the closest grounded object to the charging needle on the spray gun. The charged paint particles are at-

tracted to the nearest electrically grounded item; the larger the item, the greater the attraction.

Ungrounded objects in the vicinity of the charged gun electrode can pick up a considerable electrical charge. The charge buildup can arc over or spark if a grounded object is brought near. The intense heat of the arc may be sufficient to ignite the solvent-laden atmosphere typically found in a paint booth.

Paint buildup on hooks or hangers can act as an insulator and block the flow of electric current in the electrostatic circuit. Hangers and hooks should be regularly stripped or otherwise cleaned of paint buildup to maintain good grounding contact between the parts and the conveyor.

Because of high transfer efficiencies, air velocity in spray booths may be reduced from 100 to 60 feet/minute. This results in a 40% reduction in make-up air costs and reduces emissions.

Safety

In 1995, the National Fire Protection Association (NFPA) rewrote the NFPA 33 Standard to require fast-acting flame detectors for all automatic electrostatic liquid painting applications. These are also required for automatic electrostatic powder coating applications. All electrically conductive materials near the spray area such as material supply, containers and spray equipment should be grounded as well.

Cost

The capital investment for a new liquid electrostatic spray system consisting of an electrostatic spray gun, 2-gallon pressure pot, and hoses and fittings can range from \$4,900 to \$7,500. The capital investment required for a new electrostatic powder coating spray system, including powder application equipment, powder booth, cleaning system and bake oven, may range from \$75,000 to \$1,000,000. (CAGE).

Other Methods

This section presents brief descriptions of a variety of other paint application methods, including electrodeposition, various dip processes, and

**Table 32. Advantages and Disadvantages of Electrostatic Spray Guns
(NCP2P, p. 6)**

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high transfer efficiency ◆ Has good edge cover ◆ Has good wraparound ◆ Has uniform film thickness 	<ul style="list-style-type: none"> ◆ Has guns that tend to be bulky and delicate ◆ Requires extra cleanliness ◆ Creates Faraday cage effect ◆ Can be safety/fire hazard ◆ Requires all parts to be conductive (however, special conductive precoatings on nonconductive workpieces can be used to permit electrostatic spray) ◆ Has high equipment and maintenance cost

direct application methods such as roller and flow coating.

Electrodeposition/Electrocoating (E-coat). This process applies paint in a method that is similar to electroplating. In the E-coat process, a paint film from a waterborne solution is electrically deposited onto a part. Parts are usually made primarily of steel. An E-coat bath contains resin, pigment (unless it is a clearcoat), solvent (water and a cosolvent) and additives. The most commonly used resins in this process are epoxies and acrylics. These systems have no or low VOC emissions and produce little toxic waste.

The liquid is a very dilute emulsion of waterborne paint. Reactions between the paint particles and certain bath components cause the resin to be ionic. The electric current causes the paint particles to migrate to the metal surface. As more and more particles collect, water is squeezed out and cross linking of the resin particles occurs. The transfer efficiency of electrodeposition is greater than 90%. High production rates are possible, and production can be automated. However, this method is costly and requires a lot of energy. Also, employees need a high level of training to use this system (IHWRICc).

E-coat is extremely efficient, depositing a mostly uniform coating on all surfaces that can be reached by electricity. Waterborne electrocoating systems may be used to apply uniform, pinhole-free coatings. For films that require high appearance standards, E-coat uses acrylic resins. Electrocoatings are resistant to attack by UV light

CASE STUDY:

Navistar International Transportation Corporation

Navistar International Transportation Corporation's assembly plant in Springfield, Ohio, is the site of painting and final assembly of Navistar's medium- and heavy-duty trucks and school bus chassis. The plant's comprehensive pollution prevention efforts have resulted in significant reductions in environmental releases.

Many of the pollution prevention activities have taken place in Navistar's painting operations. In the prime coating operation, conventional air-atomized, low-solids paint was replaced with waterborne paint, resulting in a 50% reduction in VOC emissions. Electrostatic robotic application of paint has increased transfer efficiency of equipment in topcoat operations. For almost all colors of topcoat, Navistar was able to change from applying two coats of paint to only one coat of paint without lowering product quality, reducing the amount of paint wasted by 65,000 gallons and the amount of solvent used by 138,000 gallons annually.

Other raw material, process and equipment changes have resulted in annual reductions exceeding 65 tons of VOC emissions, 82 tons of HAPs and 27,600 gallons of hazardous waste.

◆ Savings

Navistar reports savings in excess of \$3.5 million. (OH EPA b)

and have good weatherability. Typical applications include truck beds, engine blocks, water coolers, microwave ovens, dryer drums, compressors, furnace parts, housings for the automotive industry, shelving, washers, air conditioners, file cabinets, switch boxes, refrigerators, transmission housings, lighting fixtures, farm machinery, and fasteners.

One drawback to the electrocoating system is that it is limited to one color at a time. Each color requires its own tank.

Autodeposition. Autodeposition is a process used to deposit organic paint films onto iron-, steel-, zinc- and zinc alloy-plated substrates. Autodeposition is typically an 6-step process, including alkaline cleaning, rinsing with plant water and deionized water, autodeposition (immersion), immersion sealing rinse and curing. The part is immersed into a solution containing paint compounds, usually a vinyl emulsion, hydrofluoric acid and hydrogen peroxide. When the part is submersed, the paint compound precipitates out of the solution and coats the part. The part is then removed from the tank, rinsed and cured (KSBEAP, p. 20).

Autodeposition is an effective method for achieving corrosion resistance and coverage of objects. Autodeposited films also provide extremely uniform thicknesses, typically 13 to 30 microme-

ters (0.6 to 1.2 mils). These resins also have excellent hardness, formability and adhesion characteristics. Two other advantages of autodeposition are that organic solvents are not needed, and little or no VOCs are emitted. Autodeposited films have high transfer efficiencies (approximately 95%), further reducing environmental impacts. This system also does not have

CASE STUDY:

Emerson Electronics

In 1977, the Emerson Electronic plant in Murphy, North Carolina, was faced with a decision concerning the type of paint line to install for producing a quality finish on die-cast aluminum, bench power tool parts. Emerson compared an electrostatic spray process for coating solvent-based paint to an electrocoating process applying a water-based paint.

Emerson found that the electrocoating system offered the following advantages:

- ◆ Lower VOC emissions, 70 pounds per day versus 3,040 pounds per day
- ◆ Lower hazardous paint waste, 0 pounds per day versus 160 pounds per day
- ◆ Production cost savings of \$1,080,000 per year
- ◆ Raw material cost savings of \$600,000 per year

(VT DEC)

Table 33. Advantages and Disadvantages of E-Coat Systems (NCP2P, p.7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Utilizes over 90 percent of coating material ◆ Has very thick, uniform coating on all surfaces that can be reached by electricity ◆ Has high production rates ◆ Produces corrosion-resistant coating ◆ Has low VOC and HAP emissions ◆ Can be fully automated ◆ Can apply second coat on uncured electrocoat 	<ul style="list-style-type: none"> ◆ Has substrate limitation ◆ Requires separate lines for each color ◆ Requires high cost to install ◆ Has masking problems ◆ Requires sophisticated maintenance ◆ Has air-entrapment pockets ◆ Has difficulty coating bulky, small parts ◆ Requires corrosion-resistant equipment ◆ Requires de-ionized water ◆ Has difficulty sanding/stripping ◆ Has high energy demands ◆ Is restricted to large volume finishing ◆ Has coating thickness limitation ◆ Requires high level of training for employees

fire hazards. However, autodeposition produces a dull or low gloss finish and has few available colors (IHWRIcC). The largest application for autodeposition coatings have been for nonappearance and under-hood parts in cars and trucks due to their excellent anticorrosion properties. It is also used on drawer slides for office furniture, replacing zinc-plating.

Dip Coating. With this process, parts are dipped (usually by conveyor) into a tank of paint. Dip coating allows for a high production rate and high transfer efficiency and requires relatively little labor. The effectiveness of dip coating depends greatly on the viscosity of the paint, which thickens with exposure to air unless it is carefully managed. The viscosity of the paint in a dip tank must remain practically constant if the deposited film quality is to remain high. To maintain viscosity, solvent must be routinely added as makeup. This results in higher VOC per gallon ratios.

Dip coating is not suitable for objects with hollows or cavities, and generally the finish is of lower quality (IHWRIcC). Color change is slow and not

feasible for most dip operations. This process is usually used to apply primers and to coat items whose appearance is not vitally important. Top coats are not commonly applied by dipping. Coatings applied by dipping have only a poor to fair appearance unless parts are rotated during drippage. Dipping is well suited for automation with conveyerized paint lines.

Capital investment required for dip coating is minimal. All that is required is a tank for the coating. The parts may be dipped manually, or automatically with a conveyor. Given the large surface area of the dip tank, adequate ventilation must be provided to prevent buildup of fumes and vapors. An efficient fire-extinguishing system must be installed as a safety measure if flammable paints are used (CAGE).

Flow Coating. In a flow coat system, 10 to 80 separate streams of paint coat all surfaces of the parts as they are carried through the flow coater on a conveyor. This system has the advantages of dip coating along with low installation costs and low maintenance requirements. The quality of the

Table 34. Advantages and Disadvantages of Autodeposition Systems (NCP2P, p. 7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has excellent anticorrosion properties (no phosphate coating required) ◆ Wets 100% coverage of surfaces (no Faraday cage areas) ◆ Uses waterborne material ◆ Requires no external source of electricity 	<ul style="list-style-type: none"> ◆ Has dull or low gloss appearance ◆ Has few colors available

Table 35. Advantages and Disadvantages of Dip Coating Systems (NCP2P, p. 7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high production rates ◆ Requires low labor ◆ Has high transfer efficiency ◆ Can closely rack parts ◆ Coating thickness does not depend on operator skill ◆ Is well suited to automated applications 	<ul style="list-style-type: none"> ◆ Is extremely dependent on viscosity of the paint ◆ Is not suitable for items with hollows or cavities ◆ Has slow color change ◆ Can be a fire hazard ◆ Has poor to fair appearance ◆ High VOC emissions relative to the amount of coating applied in low VOC applications

finish is also comparable to dip coating (IHWRIc).

Flow coating is usually used for large or oddly shaped parts that are difficult or impossible to dip coat. Coatings applied by flow coating have only a poor to fair appearance unless the parts are rotated during drippage. Flow coating is fast and easy, requires little space, involves relatively low installation cost, requires low maintenance, and has a low labor requirement. Required operator skill is also low. Flow coating achieves a high paint transfer efficiency, often 90% and higher (CAGE).

Principal control of dry-film thickness depends on the paint viscosity. If viscosity is too low, insufficient paint will be applied. If the paint viscosity rises, extra paint will be applied. This can increase paint costs and also plug small holes in the part (CAGE).

Curtain Coating. Instead of the multiple streams of paint found in flow coating, curtain coating uses a waterfall flow of paint to coat parts on a conveyor belt. The paint flows at a controlled rate from a reservoir through a wide variable slot. Curtain coating has a high transfer efficiency and covers parts uniformly, but is suitable only for flat work. The quality of the finish depends on the viscosity of the paint (IHWRIc).

Roll Coating. Roll coating is the process of applying a coating to a flat substrate by passing it between rollers. Paint is applied by one or more auxiliary rolls onto an application roll, which rolls across the conveyed flat work. After curing, the coated substrate is then shaped or formed into the final shape without damaging the coating. The paint-covered rollers have large surface areas that contribute to heavy solvent evaporation. This can pose a fire hazard from flammable solvents in solvent-borne formulations.

Roll coating is divided into two types: direct and reverse roll coating. In direct roll coating, the applicator roll rotates in the same direction as the substrate moves. In reverse roll coating, metal feed stock is fed between the rolls as a continuous coil. The applicator roll rotates in the opposite direction of the substrate.

Roll coating is limited to flatwork and is extremely viscosity dependent. Coating properties should be checked often to ensure proper results. These tests should include adhesion, impact resistance, flexibility and hardness. A well-known application of roll coating is coil coating, in which coiled metal strip is uncoiled, pretreated, roller coated with paint, cured and then recoiled (IHWRIc, p. 36).

Roll coaters are typically custom made for each application. Roll coaters can be made-to-order to

Table 36. Advantages and Disadvantages of Flow Coating Systems (NCP2P, p.7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high transfer efficiency ◆ Has low installation cost ◆ Requires little maintenance ◆ Has high production rates ◆ Requires less labor. 	<ul style="list-style-type: none"> ◆ Has poor to fair appearance ◆ Requires principal control of dry-film thickness to control viscosity of paint

Table 37. Advantages and Disadvantages of Curtain Coating Systems (NCP2P, p. 7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high transfer efficiency ◆ Enables uniform coating thickness 	<ul style="list-style-type: none"> ◆ Is suitable only for flat work ◆ Is highly dependent on viscosity

Table 38. Advantages and Disadvantages of Roll Coating Systems (NCP2P, p. 6)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high transfer efficiency ◆ Has high production rates 	<ul style="list-style-type: none"> ◆ Cannot paint hard-to-reach areas ◆ Is limited to flat work

accommodate widths ranging from 14 to 100 inches.

Plural Component Proportioning System for Epoxy Paints. Plural component proportioning systems are self-contained epoxy paint measuring and mixing systems. These systems accurately mix the epoxy paint components, produce the precise amount of paint required by an application, and consequently minimize waste.

Epoxy paint mixtures are prepared by premixing a base and a catalyst and then combining them in appropriate proportions in a separate container. After mixing and waiting the specified time, application of the paint to the workpiece may proceed. Once mixed, epoxy paints have a limited pot-life that cannot be exceeded without affecting the characteristics of the paint. If the pot life is exceeded, the mixture must be disposed of, and the application equipment must be cleaned. Under conventional methods, these mixtures are prepared by hand, a process that frequently leads to the generation of excess paint. The solvents used to cleanup and dispose of excess paint generates hazardous waste consisting of spent solvents and waste paint.

Plural component proportioning systems are used in conjunction with application devices. A typical proportioning and application system layout includes the following components: proportioning pump module, mix manifold, mixer, application device, materials supply module, and purge or flush module. These systems optimize painting operations by maximizing efficiency and minimizing waste generation.

The plural component proportion system for epoxy paints provides for total control of materials from container(s) to application. The system is accurate and can provide more consistent material quality than hand mixing. These systems can also

keep pace with higher production requirements. The systems mix the coating on demand (i.e., as the gun is triggered). This does not result in significant quantities of waste materials because no excess paint is mixed. Material cleanup requires less labor and maintenance, and generates less waste because the mixed material can be purged with solvent from the mix manifold, mixer, hose, and applicator before it cures. The plural component system is a closed system and, as a result, there are fewer spills, less contamination or waste to cleanup, and less exposure of toxic materials to personnel. In addition, the proportioning system makes bulk purchase of material practical.

If an epoxy paint requires significant induction time (i.e., 15 minutes or longer), the plural component system can still be used, provided that the mixed paint is allowed to stand in a separate container prior to application.

Capital costs for plural component proportioning systems can range from \$6,000 to \$7,500 for basic units that mix two materials, up to \$50,000 to \$70,000 for systems that mix multiple materials. Application systems are an additional component, and their capital costs can range from \$500 to \$5,000. Each application needs to be evaluated on a case-by-case basis with respect to material and labor costs and savings.

Supercritical Carbon Dioxide (CO₂). Supercritical fluid spray application allows substitution of supercritical carbon dioxide for up to two-thirds of conventional solvents concentration in spray-applied coatings, reducing VOC emissions by 30 to 70%. The proportioning and supply system from Union Carbide (UNICARB) mixes supercritical CO₂ solvent with coating concentrate and supplies the material to a specially designed spray gun (i.e., internal mixing). The CO₂ solvent is compatible with high molecular weight resins and existing painting facilities and procedures;

Table 39. Advantages and Disadvantages of Plural Component Proportioning Systems (NCP2P, p. 7)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Provides total control of materials from container to application ◆ Generates paint on an as-needed basis, eliminating the generation of excess paint (Under conventional methods, this excess paint is frequently disposed of as hazardous waste) ◆ Minimizes solvent cleanup ◆ Reduces chance of spills ◆ Reduces worker exposure 	<ul style="list-style-type: none"> ◆ Needs to be designed for specific applications

therefore, this compatibility enables the use of solvent-borne formulations with substantial VOC reductions.

Advantages and Disadvantages

In the supercritical CO₂ spray process, the solvent-like properties of supercritical CO₂ are exploited to replace a portion of the solvent in the conventional solvent-borne coating formulation. The addition of supercritical CO₂ acts as a diluent solvent to thin the viscous coating just before application, so that the coating can be atomized and applied with a modified spray gun (EPAI). Supercritical fluid spray application can be used to coat metal and plastics. The applied coating has a higher viscosity that allows thicker coatings without runs or sags. However, care is required in working with high-pressure gas at high operating temperatures (100 to 150°F) (TURI, p. 2).

Cost and Implementation Issues

This system requires investment in new equipment for paint mixing, handling and spraying. In 1991, five coating formulators were licensed to develop, manufacture and market UNICARB systems, including Akzo (automotive components, furniture), BASF (automotive), Guardsman (furniture), Lilly (furniture, plastics, heavy equipment) and PPG Industries (automotive, heavy equipment) (EPAd, p. 82).

Paint Booths

A paint booth is an enclosure that directs overspray and solvent emissions from painting operations away from the painter and toward an entrainment device. Spray booths are designed to capture particulate matter that is released into the air during coating operations. They are not

Table 40. Advantages and Disadvantages of Supercritical Carbon Dioxide (NCP2P, p. 3)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Has high quality finish ◆ Needs fewer coating applications ◆ Reduces VOCs and HAPs ◆ Reduces operating costs ◆ Is easy to retrofit ◆ Has high transfer efficiency ◆ Reduces worker exposure for solvent vapors 	<ul style="list-style-type: none"> ◆ Has limited industrial experience ◆ Has lower fluid delivery rates than airless or air spray guns ◆ Has bulky gun and supply tubing ◆ Has royalty costs

Table 41. Transfer Efficiencies of Various Application Technologies
(IHWRIC, p. 37, KSBEAP, p. 23 and CC)

Technology	Transfer Efficiency	Operating Cost	Finish Quality	Recess Coverage
Conventional Air Spray	30 to 60%	Low	High	Good
HVLP Spray	50 to 90%	Low	High	Good
LPLV Spray	60 to 80%	Low	Unknown	Good
Airless Spray	65 to 70%	Medium/high	Low	Good
Electrostatic Spray	65 to 95%	Medium/high	Low	Poor
Electrodeposition	90 to 99%	NA	NA	NA

NA=not applicable

abatement devices for VOCs. A spray booth's primary function is to protect the painter and other employees from exposure to potentially toxic vapors and particulates. Another function of the booth is to prevent fires within a facility by venting high concentrations of flammable solvent vapors out of the building (EPAq, p.149).

Pollution Problems

Discharges from paint booths consist of particulate matter and organic solvent vapors. Particulates result from solids in the paint that are not transferred to the part. Organic solvent vapors are from the solvent, diluent or thinner that is used with the coating to reduce the viscosity of the paint. Much of the particulate matter is captured by a dry, water-wash or baffle filter (these are discussed below). Solvent vapors are controlled or recovered by the application of control technologies such as condensation, compression, absorption, adsorption or combustion. Solvent vapors can be minimized by using more efficient equipment, and low or no VOC materials. Increasing the transfer efficiency of the painting operation can result in both reduced particulate and solvent emissions (EPAq, p. 149).

Types of Paint Booths

There are two basic types of enclosures that are used in most painting applications: dry booths and wet booths. The key difference between the two is that a dry booth depends on a filter of paper, fiberglass or polystyrene to collect overspray, while the wet booth uses water with chemical

additives to collect overspray. The type of booth selected can affect the volume and type of paint waste. A third type of booth is used exclusively in powder coating operations.

Although a spray booth is generally thought of as an enclosed painting area, this is not always the case. For instance, facilities that paint very large pieces may have a booth that only has one side, consisting of an exhaust plenum that draws solvent and particulates away from the operator. It is also not uncommon to see two spray booths opposite one another. This set-up allows for very large workpieces to be transported in between the booths either by a conveyor or a forklift truck that runs between the booths. Often neither booth has a ceiling, and they draw air from the surrounding factory (EPAq, p. 149).

Regardless of the size or design of the booth, they consist of one of three basic designs for directing air flow.

- ◆ Cross-draft. In a cross-draft booth, air moves from behind the operator toward the dry filter or water curtain (parallel to the floor). This type of booth is ideal for systems where the parts are moved through the facility in a rack or conveyor system, and the painter applies the coating from only one direction. However, these types of systems can be used if the paint must be applied in more than one direction. This type of ventilation system is usually the least expensive.

Table 42. Overview of Application Technologies (IHWRI, p. 36-37; IHWRIb,c; and Binksc)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
HVLP Spray	<ul style="list-style-type: none"> ◆ Reduces overspray, increasing transfer efficiency ◆ Reduces VOC and HAP emissions ◆ Lowers risk of blowback to the worker 	<ul style="list-style-type: none"> ◆ Can be used on many surfaces 	<ul style="list-style-type: none"> ◆ Is portable and easy to clean ◆ Allows operator to vary the air pressure, air volume, paint pressure and spray pattern 	<ul style="list-style-type: none"> ◆ Has production rates that are not as high as conventional air spray
LPLV Spray	<ul style="list-style-type: none"> ◆ Has a high transfer efficiency rate ◆ Has low operating costs ◆ Has moderate capital costs 			<ul style="list-style-type: none"> ◆ Is widely used
Airless Spray	<ul style="list-style-type: none"> ◆ Has a transfer efficiency of 65 to 70% ◆ Cuts overspray by more than half, and is cleaner and more economical 	<ul style="list-style-type: none"> ◆ Hydraulic atomization used most widely by painting contractors and maintenance painters ◆ Heated atomization used by furniture manufacturers and industrial finishers 	<ul style="list-style-type: none"> ◆ Is twice as fast as air spray and produces a higher film build; is more portable than air spray 	<ul style="list-style-type: none"> ◆ Is limited to painting large areas, requires a different nozzle to change spray patterns; nozzle tends to clog and can be dangerous to use or clean because of the high pressures involved
Air-Assisted Airless Spray	<ul style="list-style-type: none"> ◆ Has higher transfer efficiency and lower chance of blowback 	<ul style="list-style-type: none"> ◆ Used by furniture and industrial finishers 	<ul style="list-style-type: none"> ◆ Has material savings that are 50% better than air spray ◆ Has higher film build per pass than air spray 	<ul style="list-style-type: none"> ◆ Has same dangers as airless, but requires more maintenance and operator training, and has a higher initial capital cost
Rotary Atomization	<ul style="list-style-type: none"> ◆ Has excellent efficiency 		<ul style="list-style-type: none"> ◆ Can be used with paints of different viscosity 	<ul style="list-style-type: none"> ◆ Requires high degree of cleanliness

(continued on next page)

Table 42. Overview of Application Technologies (IHWRI, p. 36-37; IHWRIb,c; and Binksc) (continued)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Electrostatic Spray	<ul style="list-style-type: none"> ◆ Has high transfer efficiency ◆ Produces little overspray and uses relatively little paint 	<ul style="list-style-type: none"> ◆ Is good for painting oddly shaped objects ◆ Is used by most appliance manufacturers 	<ul style="list-style-type: none"> ◆ Produces a uniform coat because the paint itself acts as an insulator 	<ul style="list-style-type: none"> ◆ Has limited coverage with complicated parts because of Faraday cage effects ◆ Can paint only conductive parts ◆ Presents a possible shock hazard ◆ Is limited to only one coat ◆ Is more expensive, slower and has higher maintenance costs than air spray ◆ Is limited to chargeable paints ◆ Surface of the object must be extremely clean
Auto-deposition	<ul style="list-style-type: none"> ◆ Uses water-borne paints 	<ul style="list-style-type: none"> ◆ Is limited to iron, steel, zinc and zinc-alloy plated materials 	<ul style="list-style-type: none"> ◆ Is effective for anti-corrosion properties and coverage of the objects ◆ Uses no electricity 	<ul style="list-style-type: none"> ◆ Is limited to dull or low gloss finish; few available colors
Electro-deposition	<ul style="list-style-type: none"> ◆ Has transfer efficiency of more than 90% 	<ul style="list-style-type: none"> ◆ Is limited to metallic or other electrically conductive objects (e.g., autobody coating) 	<ul style="list-style-type: none"> ◆ Can accommodate high production rates; production can be automated 	<ul style="list-style-type: none"> ◆ Requires that objects be metallic or electrically conductive ◆ Is costly and requires a lot of energy ◆ Requires that employees receive high level training to use this system

(continued on next page)

Table 42. Overview of Application Technologies (IHWRI, p. 36-37; IHWRI_{b,c}; and Binksc) (continued)

Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Dip, Flow and Curtain Coating	◆ Has high transfer efficiency	◆ Is well suited for parts that are always the same color and have minimum decorative finish requirements, such as agricultural equipment	◆ Has high production rate ◆ Requires relatively little labor	◆ Depends greatly on the viscosity of the paint, which thickens with exposure to air unless carefully managed ◆ Is not suitable for objects with hollows or cavities ◆ Has lower quality finish
Roll Coating	◆ Has high transfer efficiency	◆ Is limited to sheet materials (e.g., strip metal and boards); used to decorate cans and other metal objects	◆ Has high production rates	◆ Is limited to flat work

◆ **Down-draft.** Down-draft booths move air from the ceiling of the booth vertically downward toward an exhaust plenum in the floor. This type of booth is preferred when the paint operator must be able to walk around the part, particularly in the case of painting large machines. These booths usually cost more than cross-draft booths because they require building a pit beneath the booth. The operating expenses with a down-draft are also usually higher because these systems draw more air.

◆ **Semidown-draft.** This type of booth moves the air down and then to the side where the exhaust is located. Semidown-draft booths offer a compromise between the cross-draft and down-draft configurations (EPAq, p. 149).

Decisions about equipment should be made based on the type and volume of painting done and the volume of waste generated.

Choosing between a dry filter, water-wash or baffle spray booth encompasses many different issues. The following section provides information on these three systems. Analysts estimate that 80% or more of the spray booths in use today are of the dry filter type (EPAq, p. 151). In recent years, however, many facilities have switched to water-wash booths because of their lower maintenance and hazardous waste costs. However, there are other concerns with these booths. The following section provides more detail on dry filter and water-wash booths.

Dry Filter Booths

There are many types of dry filter systems, however, they all operate on the same principle:

particulate-laden air flowing toward the filter medium is forced to change directions rapidly. The particulate, having more inertia than the surrounding air, impacts the filter medium and is removed from the air flow. The scrubbed air is then vented to the atmosphere.

There are four general types of filters currently used: fiberglass cartridges, multilayer honey-combed paper rolls or pads, accordion-pleated paper sheets, and cloth rolls or pads. Each type of filter has different characteristics for particulate capacity, removal efficiency, cost and replacement time. Filter performance is characterized by three basic parameters: particulate capacity, resistance to air flow and particulate removal efficiency. Filter replacement is required when the filter becomes heavily laden with captured particles, resulting in a reduction in removal efficiency and an increase in the pressure differential across the filter face. The primary waste stream generated by dry booths is spent filters. When using lead or zinc chromate paints, the dry filter will eliminate 50 to 90% of the hazardous waste generated by water-curtain paint booths.

Generally, small-volume painting operations find that the lower cost of a dry-filter booth meets their requirements. This equipment requires a low capital investment relative to wet-booths and are simple in design. The filters act to remove paint in airborne particles by capturing them as they are forced through the filter. Ease of replacing a relatively low number of filters produced by small operations makes such an approach attractive. As paint volume increases, though, filter replacements must be made more often. This may increase costs for labor and materials significantly (Mitchell, p.10).

Dry filters effectively remove up to 95 to 99% of particulates. These systems are also versatile. They can be used in booths of all designs (small, large, cross-draft, down-draft and semidown-draft). These booths can also be operated for a variety of coating technologies, including polyurethanes, epoxies and alkyds. However, they cannot be used for nitrocellulose paints and some waterborne coatings (proper filter selection is critical in these cases). They are inexpensive to purchase, and depending on the nature of the

paint (i.e., pass or fail TCLP test), they are also inexpensive to operate.

A disadvantage of dry filter booths is that they are generally not appropriate for facilities with high coating use (i.e., greater than 5 gallons per square foot of filter areas per day). They also have problems with VOC emissions, since they do not remove VOCs.

Regarding safety, dry filters are a potential fire hazard, especially if dry overspray is allowed to build up. Typically, the majority of this waste is the filter media, which can be contaminated by a relatively small amount of paint. Reusable filters may decrease waste volume and reduce disposal cost. In some applications, such as powder coatings, overspray can be reused.

Choosing the proper type of dry filter is important for a facility's operations. Dry filter characteristics that should be considered include:

- ◆ Efficiency—its ability to remove particulates before they enter the stack
- ◆ Resistance—this is the pressure differential that ensues when the high velocity of air passes across the filter bank
- ◆ Holding capacity—the amount of overspray that a filter can hold or retain during its service life
- ◆ Incineration profile—can spent filters be burned?
- ◆ Biodegradability—does the product degrade naturally?
- ◆ Landfill option profile—does it meet landfill standards?
- ◆ Flammability—does it meet the National Fire Protection Bulletin number 33 requirement and Underwriter's Laboratories Approved Class 2 list?
- ◆ Suitability for various coatings—some waterborne coatings may complicate filter choice; facilities should check to make sure filter is compatible with all coatings that will be used

Filters made from expanded polystyrene are also available. Facilities can reuse these types of filters after carefully brushing the overspray off the surface with a bristle brush. Hence, the same filters can be used several times until they break or become unusable. Manufacturers have promoted the practice of dissolving the filter in a

drum of solvent and paint waste when a facility is ready to scrap the filter. The solvents dissolve the filter into the waste, which must then be treated as a hazardous waste. Some facilities have argued that this is counterproductive due to disposal costs of liquids versus solids. Others argue that this qualifies as treatment of a hazardous waste and therefore is a violation of RCRA regulations¹ (EPAq, p. 151).

Water-Wash Booths

Water-wash booths capture overspray paint by using positive air pressure to force the particles into a cascading curtain of water. As a result of being captured in the water curtain, uncured particles of paint accumulate in a wash-water pit, located either beneath a grating that the painters stand on or above ground behind the booth itself.

When overspray enters the water, it remains sticky and can plug up holes, nozzles, pipes and pumps. In addition, it can form a deposit on the water curtain, slowly building up a layer that eventually impedes the smooth water flow down the water curtain's face. With time, the water becomes contaminated with bacteria and requires disposal. To prevent this from occurring, the water needs to be treated with chemicals designed to de-tack overspray particles (EPAq, p. 152).

If overall painting volume can justify the investment, a water-wash booth has substantial advantages. This type of booth eliminates disposal of filter media and allows waste to be reduced in

weight and volume. This is achieved by separating the paint from the water through settling, drying, or using a centrifuge or cyclone. However, the primary disadvantage of this technology is the resulting generation of large quantities of wastewater and paint sludge. Typically, spent wastewater and sludge requires offsite treatment, and the paint sludge is disposed of as a hazardous waste. Depending on the amount of coating used, this option could use more energy, require more maintenance time, add to chemical use for water treatment, and/or result in additional cost to dispose of "wet," low BTU value, heavy paint sludges than a dry filter booth. These units are also more expensive to install and to operate than dry filter booths.

The water-wash booth design faces substantial challenges and more restrictive landfill regulations than they have in the past. Prior to 1993, some liquid nonhazardous special wastes could be disposed of in a landfill with little or no treatment. EPA's decision to redefine liquid wastes and ban certain materials from landfill disposal pertains to sludge generated from water-wash booths.² This material still can be disposed of, however, the material must be processed prior to disposal, resulting in a significant increase in waste treatment costs (Mitchell, p.10).

Baffle Booths

A baffle spray booth is an uncommon alternative to both dry filter and water-wash booths. In a baffle spray booth, the face of the booth has steel

Table 43. Advantages and Disadvantages of Dry Filter Booths (NFESC, p. 3)

Advantages	Disadvantages
<ul style="list-style-type: none"> ◆ Decreases operating costs when compared to water curtain spray booths due to reduced chemical, electrical, sewer and water costs ◆ Reduces waste generation of wastewater and sludge ◆ Eliminates need for daily skimming and removal of sludge from the booth ◆ Increases efficiency of particulate removal 	<ul style="list-style-type: none"> ◆ Is not compatible with powder paint applications ◆ Has filter selection that depends on paint type and application ◆ Requires frequent downtimes if improper filter is used

¹For more information, see the May 1995 issue of *Metal Finishing*.

²EPA's definition of "liquid wastes" is: any material that will exude droplets of liquid through a standard conical paint filter within a prescribed period of time.

baffles that run the height of the booth and are several inches wide. The baffles usually overlap each other, forcing the air that passes through the booth to change direction in order to reach the back of the booth. When the air does reach the entrainment section in the back, the paint particulates that the air is carrying fall into the trough for reuse. These booths are used less frequently because unless the facility is reclaiming paint, this type of booth offers no advantages.

Powder Coating Booths

In most powder coating operations, the coating is reclaimed and reused in the process, optimizing material use. Powder coating booths have smooth sides with steep, hopper-like sloping bottoms that empty into collectors and an exhaust system that removes powder suspended in the air. The powder is drawn into a cylindrical chamber that has a centrifugal blower to force the powder to the outside walls where the powder collects and then falls through an opening in the cone-shaped bottom. The air flows through a filter at the top to remove any fine suspended powder particles. The reclaimed powder can then be blended with fresh material.

Best Management Practices to Minimize Coating Defects from Paint Booths

There are a number of steps that a company can take to minimize the defects that result in rejected work. Most of the defects require painters to perform rework or, in some cases, completely reject a part. Higher reject rates result in increased waste generation and reduced profits. The most common coating defects that relate to paint booths include:

- ◆ Poor wrap when using electrostatic paints. Poor wrap can happen for a variety of reasons. However as they relate to paint booths, assistance providers should ensure that the spray booth has a proper ground. Wrap may also occur as a result of turbulent air flow.
- ◆ Dust and dirt in the finish. This is probably the most common cause for reworks and rejects. Facilities can take several steps to avoid this including: avoid having sanding or other dirty operations take place immediately outside the booth; make sure that air filters at air intakes of the booth are not dirty, or have too large of a mesh size; make sure that the booth is operating under negative pressure; make sure that the air make-up system draws fresh air into the booth and that the intake stack is not too close to the exhaust ducts from sanding or other dirty operations; keep booth walls, floor and ceiling free of loose, dry, overspray or the booth blowers may pry particles loose, allowing them to fall onto freshly painted surfaces; and make sure that proper booth size is selected.
- ◆ Water spots in the finish. When using a water-wash booth, operators must properly clean the nozzles above the water curtain. Omitting this step creates the opportunity for water droplets to settle on the painted finish.
- ◆ Hazeiness (blushing) that reduces gloss. This problem occurs when humidity is high and moisture condenses on freshly painted surfaces. This is more likely to occur in a water-wash booth than a dry-filter booth. To avoid this, parts should be moved out of the booth shortly after painting is completed.
- ◆ Dry overspray on the finish. The most common reason for this dry overspray is that the solvent is too fast. As the solvent flashes off during application, the overspray loses its wetness. This problem is usually not a result of the booth but a result of high air velocity. Proper monitoring and control of booth air flow should assist in reducing this problem. Dry overspray on the finish also arises when more than one dry filter spray booth is being operated at the same time. If the air flow within the larger spray room is not uniform, overspray from one booth can settle on the freshly painted surfaces in another booth. Maintaining proper air flow between the two booths or providing each booth with its own air make-up system can solve this problem.
- ◆ Nonuniform coating finish with gloss, patches, orange peel and voids. Numerous causes exist for this defect, however, causes solely associated with spray booths are often related to poor lighting. Investment in ad-

equating lighting and regular cleaning of the cover plates can have quick payback in the form of better looking finishes and fewer touchups (EPAq, p. 154).

8 Curing Methods

Once a coating is applied to the workpiece it then undergoes a curing or drying process. While the terms drying or baking are commonly used in the painting industry to refer to curing, there is a distinction between drying (baking) and curing. In curing, the resin must be converted into a new resin, while drying refers to the loss of the solvent so that the resin remains the same. Curing and drying both use the two same methods to harden a coating: air/force dry and baking (newer curing methods such as radiation curing are discussed as they apply to specific coatings in the preceding chapters). Table 44 compares air/force dry and bake methods.

◆ **Air Drying.** In air drying, a coating film is formed by the evaporation of solvent, which leaves behind a solid film. The rate of drying is governed by how quickly the solvent evaporates. Moderate heat (below 194°F) can be applied to accelerate evaporation (called force drying), however, the process still basically remains one of air drying.

◆ **Elevated Temperature Curing/Baking.** Elevated temperature curing uses one of three means: conduction, convection or radiation to apply heat to the coated part (SME, p. 28-7).

Selecting air/force dry or bake coating (baked at elevated temperatures above 250°F) is an important consideration in choosing a P2 alternative. Baked coatings usually have better physical and chemical-resistant properties, but they also have some limitations. Air/force dried coatings (defined by EPA as those that cure below 194°F) have special VOC limits that are usually higher than baked coatings (EPAq, p. 92). Table 45 lists the typical RACT VOC limits for metal part coating.

Table 44. Air/Force Dry vs. Bake (EPAq, p.91)

	Air/Force Dry	Bake
Curing Time	◆ Takes longer to achieve thorough hardness, which can affect production schedules	◆ After baking and cool-down, the coated parts are usually ready for assembly or shipping
Clean-Up Requirements	◆ Overspray dries on spray booth filters, floors and walls; therefore, maintenance is not a significant problem.	◆ Uncured overspray remains sticky, making it awkward to walk on spray booth floors ◆ Maintenance is more costly because of difficulty handling the sticky material

(continued on next page)

Table 44. Air/Force Dry vs. Bake (EPAq, p.91) (continued)

	Air/Force Dry	Bake
Substrate Versatility	<ul style="list-style-type: none"> ◆ Can be applied to all substrates (e.g., metal, plastics, wood, rubber and masonry) ◆ Can be applied over porous materials such as sand castings, wood and paper 	<ul style="list-style-type: none"> ◆ Can only be applied on metals and substrates that can withstand high baking temperatures. Generally not suitable for heat-sensitive products such as plastics, wood and rubber. ◆ Should not be applied over machined or other surfaces that are sensitive to warpage, unless taking adequate precautions ◆ Can cause outgassing on sand castings and other porous substrates. Preheating workpiece can often overcome problem but adds an additional step to the process
RACT Regulations	◆ Some regulations have higher VOC limits for air/force-dry than for bake coatings	◆ Same
Heating Requirements	<ul style="list-style-type: none"> ◆ Can dry and cure at temperatures from ambient up to 194°F by EPA definition ◆ Solvent-borne coatings do not require an oven, although a low temperature oven will speed up the drying process ◆ Water-borne coatings would benefit from a low temperature oven that will speed up the drying process ◆ Offers lower energy use 	<ul style="list-style-type: none"> ◆ Generally must cure at a minimum of 250°F. A typical curing schedule is 10 minutes at 350°F. Curing times are inversely proportional to temperature. A cool-down staging area is required. ◆ Requires high temperature oven, and therefore greater energy use
Physical/Chemical Requirements	<ul style="list-style-type: none"> ◆ Most single-component coatings, such as alkyds and modified alkyds, do not exhibit superior physical and chemical properties ◆ Single-component moisture-cured polyurethanes, however, do perform comparably to two-component polyurethanes and baked coatings. 	◆ Often have excellent physical and chemical-resistant properties, sometimes similar to two-component polyurethanes
Appearance Defects	◆ Surface defects, such as orange peel, often do not flow out during the drying and curing process. Force drying at elevated temperatures below 194°F can partially alleviate this.	◆ Films tend to flow out better when in the oven, providing smooth finishes and eliminating surface defects such as orange peel.

**Table 45. Typical RACT Limits for Miscellaneous Metal Parts Coating
(EPAq, p. 93)**

	Air/Force Dry		Bake	
	lb/gal	g/L	lb/gal	g/L
California	2.8	340	2.3	275
Most other states	3.5	420	3.0	360

9 Equipment Cleaning

When a painting process is completed, a color change is needed, or maintenance is required, the metal coater must clean the equipment. There are numerous P2 opportunities for reducing waste and air emissions in equipment cleaning operations.

General Description

All coating practices require some type of equipment cleaning. For spray painting, the most common coating operation, spray guns and accessories must be cleaned between color changes, when orifices clog and often at shift changes (IWRC, p. 15).

Pollution Problem

External equipment surfaces generally are cleaned by soaking, wiping or flushing with solvent. If equipment cleaning is done in an open container, a significant quantity of solvent is lost to evaporation. Internal parts and passageways as well as paint guns are commonly cleaned by flushing solvent through the gun and orifice. This practice also results in significant evaporation and loss of usable product (IWRC, p. 15).

P2 Options

A cost-effective method for reducing wastes is to eliminate unnecessary cleaning. For equipment that requires cleaning, making improvements in operating practices that minimize solvent use and reduce evaporation should be implemented wherever practical. Using a gun washer to clean spray guns is one example. Various solvent recovery and reuse technologies are also available. In addition, alternative cleaning solutions can be used. Each of these options is discussed below.

Scheduling Improvements

Implementing better operating practices and scheduling can significantly reduce waste gener-

P2 Tips for Equipment Cleaning

- ◆ Eliminate unnecessary cleaning
- ◆ Improve current operating practices
- ◆ Use a gun washer
- ◆ Recover and reuse spent solvents
- ◆ Use alternative nontoxic cleaning solutions

ated from cleaning operations. The amount of waste generated is directly related to the number of times paint color or paint types are made. For this reason, scheduling improvements have perhaps the largest effect on the volume of waste produced from cleaning equipment. Making large batches of similarly produced items instead of small batches of custom items, increases the time between cleaning. Additionally, scheduling paint jobs so that they move from the lightest color to the darkest can also reduce the need to clean.

Eliminate Unnecessary Cleaning

When assessing the cleaning process, all the typical cleaning tasks should be reviewed to learn whether cleaning is necessary. While most coaters assume that spray guns, tips and lines must be cleaned for reuse, cleaning some low-cost items might not be advisable. Costs from cleaning solvent purchases, solvent waste disposal and solvent emissions could be higher than simply replacing the item being cleaned. However, the costs of proper disposal must be factored into any decision (MnTAP, p. 5).

Improve Current Operating Practices

A technical assistance provider should also help a client company review the ways in which cleaning solvents are handled. All solvents should be stored in covered containers when not in use. Leaving solvents in the open air creates unnecessary solvent waste and VOC emissions. In addition, the company should set a standard for the minimum

CASE STUDY:**Crenlo, Inc. - Spray Nozzle Selection Reduces Solvent Waste Volume**

Crenlo, Inc. manufactures products from steel and aluminum. Finished products are coated with baked enamel paint. Most colors are prepared onsite. Paint from any batch may be stored for future reuse. To ensure proper quality, the paint is remixed and strained to remove solids larger than the 90 mesh screen size, before delivery to spray booths.

In the past, the straining equipment was cleaned using fresh solvent sprayed from a hose fitted with a nozzle spraying a flat fan of solvent from a 0.172 inch diameter orifice. This nozzle is rated for 4.3 gallons per minute (gpm) flow with a 30 pounds per square inch (psi) supply pressure. Annual cleaning of the straining equipment produced about 14,000 gallons of waste costing at least \$16,000 per year. The cleanup solvent is a recycled blend that is distilled offsite and returned to Crenlo. A single charge covers both purchase and processing costs. The 4.3 gpm nozzle was originally selected because this size nozzle was already in use on an aqueous spray wash line at the plant, so a supply was available onsite. A technical assistance assessment identified that nozzle size was the key factor affecting the volume of solvent used.

Three nozzles were purchased and tested in the cleaning system. Flow rates for these nozzles ranged from one-fourth to one-fiftieth of the original flow rate. The smallest of these nozzles' orifices (0.026 inches) cleaned the equipment at an acceptable level in 60 to 90 seconds at 30 psi, and used 80% less solvent than the original nozzle. Waste accumulation from this source was monitored over the next two months and confirmed the improved efficiency using the new nozzle.

Foreign particles (such as rust) in the solvent feed line plugged the nozzle orifice frequently over the first 2 weeks of operation. Plugging was eliminated by installing a small in-line basket filter to remove solids before they reached the nozzle. Cleaning time with the low-flow nozzle was doubled or tripled compared with the original nozzle. The 60 to 90 second cleaning time was judged acceptable, although operators were not pleased with this change. Cleaning time was reduced by 30 seconds by instituting a presoak step. The presoak used a dirty solvent bath to remove or loosen most of the paint. The equipment was then sprayed with fresh solvent for a final rinse. The presoak resulted in additional waste reduction.

◆ Savings

There was no capital investment for this project. Supplies included the purchase of three nozzles for testing (\$70) and a small, in-line basket filter (\$50). Six hours of labor were needed to test the nozzles, and approximately 4 hours were spent unclogging the nozzle orifice for the first 2 weeks of operation. Total implementation costs were approximately \$270. Reduction in waste resulting from the new nozzles came to about 11,000 gallons less of spent solvent waste generated per year with savings of approximately \$13,500 per year.

(MnTAP 6/91-83)

strength necessary for cleaning in order to ensure that used solvent is disposed of or recycled only when it loses its cleaning effectiveness, not just because it looks dirty (MnTAP, p. 5).

Use a Gun Washer

The use of a gun washer can also help to reduce wastes generated during equipment cleaning. An automatic gun washer operates like a dishwasher.

The paint gun is partially disassembled and placed in the unit. Cleaning is accomplished by recirculating solvent sprays. These units reportedly reduce solvent waste by 50 to 75%. VOC emissions can be reduced by up to 20%, and a 60% labor time savings can be achieved (IWRC, p. 15).

Units range in cost from \$600 for small units to approximately \$1,500 for industrial type units

(i.e., gun and paint hose wash). Similar units may also be leased through various chemical suppliers and waste management companies at a cost of \$165 to \$195 per 5 gallon waste solvent change out interval (IWRC, p. 15-17).

Pressure Pot Liners

For maintenance of pressure pots, many companies use a polyethylene inner liner with the pressure pot. The main advantage of this practice is that only a small amount of paint comes into contact with the steel or stainless steel body, and cleaning the liner requires only a small amount of solvent. After pouring solvent into the liner, the operator should swirl it around for a few seconds. The operator can then discard the spent solvent into a hazardous waste drum and the liner is ready to be reused.

Some operators choose to allow the paint that sticks to the side of the liner to dry out, which causes it to flake off with ease. If the solid paint is shown to be hazardous per RCRA guidelines the facility must manage it as a hazardous waste. If it

is not hazardous, it can be discarded with the rest of the solid waste. The liner should then be reused (EPAq, p. 137).

Use Alternative Cleaning Solutions

Because of the increased need to reduce VOC emissions, alternative cleaning solutions are available. They include dibasic esters (DBE), N-methyl-2-pyrrolidone (NMP), and a variety of other alkaline-, citric-, and water-based solvents such as d-limonene, naphtha, and terpenes. These chemicals have reduced VOC emissions due to their lower evaporation rate. Although toxicology information specific to these chemicals is relatively limited at this time, many researchers believe that the relative safety of similar chemicals indicate that they are a feasible alternative to organic solvents in certain applications (MnTAP, p. 5-6).¹

Recover and Reuse Spent Solvents

Onsite recycling of used solvent is another way to reduce waste and save money. Savings come from reducing the amount of solvent purchased and the volume of spent solvent that must be sent offsite for costly disposal. Two common methods of solvent recycling are settling and distilling (MnTAP, p. 5-6).

Settling involves putting used solvent in a container and letting the particulate matter settle out. The container should be designed to allow for removal of solvent without shaking up the sludge that has settled out (MnTAP, p. 5-6). Solvents can be used for gun cleaning and then can be placed back into the storage container for subsequent settling and reuse. Eventually, sludge will make up the majority of the container and offsite hazardous waste disposal will be necessary. At this point, the processes can be repeated using a different container. Solvent waste reduction of up to 33% can be accomplished with this simple method (IWRC, p. 15-17). Filtering equipment, which removes the particulate matter from solvents, also is available (MnTAP, p. 5-6).

Waste solvent also can be collected and processed through distillation equipment. Approximately 80%

CASE STUDY: Solvent Reclaimer

The Marmon Motor Company of Garland, Texas, spent \$10,000 to install a solvent still that reclaims thinners from paint-related wastes. By installing this standard technology, Marmon reduced its disposal of thinners from 34 drums to 3 drums and cut procurement of new thinner from 4,000 gallons to 2,000 gallons per year.

◆ Savings

As a result, waste disposal costs were reduced from \$6,200 to \$1,400 per year. Purchasing costs for new thinner decreased from \$9,500 to \$4,750 per year. Even with additional labor costs at about \$5,000 a year, the annual savings were approximately \$4,500 with a 2.2 year payback period (PPIFTI 1994).

¹ For more information on these alternative solvents, see *Project Summary: SAGE 2.1, Solvent Alternatives Guide: User's Guide*. Research Triangle Park, NC: Air and Energy Engineering Research Laboratory. EPA/600/SR-95/049.

CASE STUDY: Paint Gun Cleaning

Thermon is a electronics manufacturer in San Marcos, Texas, with 300 employees. To clean paint guns, the company traditionally soaked the guns in solvent. This method generated significant amounts of solvent waste and even clogged the guns when inexperienced personnel performed the cleaning.

To remedy this situation, Thermon purchased a spray gun cleaning system that circulates solvent through the gun. The cleaning solvent is filtered to remove particles that clog the paint gun, enabling the solvent to be reused several times before disposal. The system decreases solvent purchases and effectively cleans the paint spray gun even when inexperienced personnel perform the cleaning.

To prepare the paint guns for the cleaning system, the remaining paint is emptied from the canister and the canister is washed with a small amount of solvent (1/2 pint). The remaining solvent is poured out before the gun is loaded in the cleaning system. This extra rinsing step significantly reduces solvent use.

◆ Savings

With the new cleaning system and methods, Thermon reduced solvent use by 60%.

The cost of the spray gun system was \$700. The system was found to be very economical due to reduced solvent costs and, more importantly, improved spray gun performance due to increased cleaning effectiveness. Despite the fact that Thermon does a relatively small amount of painting, the cost of the unit was recovered in 6 to 8 months (PPIFTI 1994).

of the used solvent is recovered with basically the same cleaning properties as a new product. The remaining 20% sludge (still bottoms) must be collected for offsite hazardous waste disposal. To help maintain the cleaning properties of the recycled thinner, certain paint and solvent wastes should be segregated. Waste gun wash solvent and any waste lacquer paint and thinner mixtures can be included for recycling. All waste urethanes, enamels and enamel reducers should be placed in a separate container; enamel and urethane products will not clean as well as pure lacquer thinner. By segregating the two, the reclaimed solvent will possess cleaning properties like a virgin thinner. This waste management technique has the advantage of reducing the volume of virgin thinner purchased as well as the amount of waste thinner generated (IWRC, p. 15-17).

Onsite distillation equipment comes in a wide range of capacities, from 5 gallons per 8 hour shift batch operations to more than 100 gallons per hour flow-through units. Costs for 5 gallon batch units start at approximately \$1,500 with an average cost of \$3,000 (IWRC, p. 15-17).

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IHWRIcE. 1994. *Powder Coating*. Champaign, IL: Illinois Hazardous Waste and Information Center. (factsheet 1)

IHWRIcF. 1994. *Paint Removal Options*. Champaign, IL: Illinois Hazardous Waste and Information Center. (factsheet 7)

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Appendix A

Information Resources

Trade Journals

The following trade journals can provide up-to-date information on coating developments. Many of these journals have annual guidebooks and directories, issues with articles on coatings technologies, and vendor listings:

Journal of Coatings Technology
Surface Coatings International
American Paint and Coatings Journal
Modern Paints and Coatings
Metal Finishing
Chemicalweek
Chemical Marketing Reporter

Manufacturers' Literature

Binks Training Division (Franklin Park, IL) offers a variety of training materials on spray painting and related topics, including seminars, videotapes and literature. For more information, contact:
Binks Manufacturing Company
9201 W. Belmont Ave.
Franklin Park, IL 60103
Attn: Training Division

The following is a list of literature available from Binks:

Material Supply. TD2-1R-6.
Hose and Fittings. TD3-1R-2.
Compressed Air Supply. TD4-1R-6.
Automatic Spray Equipment. TD5-1R-4.
Spray Booths. TD6-1R-5.
Compressed Air Spray Gun Principles. TD10-1R-4.
High Volume Low Pressure-HVLP. TD10-4R.
Airless Spraying. TD11-1R-4.
Air Assisted Airless Spraying. TD11-3R-2.
Plural Component Spray Systems. TD16-1R-4.
Electrostatic Spraying. TD17-1R-4.
Electrostatics Safety Manual for Liquid and Powder Finishing Systems. TD17-2R.
Hot Spraying. TD42-1R-5.
Operator Techniques. TD49-1R-3.
Spray Application Processes. TD49-2R-4.

Paint Curing by Infrared Catalytic Thermoreactors. TD100-7.

Viscosity. TD100-1R-3.

Finish Problems-Solvent Base Coatings. TD100-2R-3.

Safety Considerations in Paint Applications. TD100-3R-5.

OSHA Safety and Health Standards. TD100-4R-4

Coating Materials. TD100-5R.

Surface Preparation. TD100-6.

Other equipment manufacturers that technical assistance providers should contact include:

DeVilbiss (800) 338-4448

Graco (800) 328-0211

Internet Links

The following Internet links can provide valuable information on coatings:

The ASTM Home Page

<http://www.astm.org/index.html>

ASTM has developed and published over 10,000 technical standards which are used by industries worldwide. ASTM members develop the standards within the ASTM consensus process. Technical publications, training courses, and Statistical Quality Assurance Programs are other ASTM products; ASTM services include The ASTM Institute for Standards Research.

CAGE

<http://cage.rti.org/>

CAGE (Coatings Alternative Guide) is a tool developed by the Research Triangle Institute to assist companies or technical assistance providers in selecting appropriate alternative coatings or coatings equipment.

Chemical Coaters Association International

<http://www.finishing.com/CCAI/index.html>

The Chemical Coaters Association International is the finishing industry's educational and networking association.

Corrosion Coatings & Linings Information Server

<http://www.corrosion.com/index.html>

Corrosion Coatings & Linings Information Server Protective Coatings, Linings and Related Resources is devoted to providing up to date, relevant information about products and services for the Protective Coatings, Linings, Painting and Corrosion Industry.

EnviroLink

<http://www.envirolink.org>

EnviroLink is an online environmental information resource. This non-profit organization unites hundreds of organizations and volunteers around the world and provides comprehensive, up-to-date environmental resources.

EPA's EnviroSense

<http://www.epa.gov/envirosense/index.html>

EnviroSense attempts to provide a single repository for pollution prevention, compliance assurance, and enforcement information and databases. Included are pollution prevention case studies, technologies, points of contact, environmental statutes, executive orders, regulations, and compliance and enforcement policies and guidelines. A major component of EnviroSense is the database for "solvent alternatives."

Federation of Societies for Coatings Technology

<http://www2.coatingstech.org/coatingstech/>

An individual member organization of over 7,200 international professionals in the coatings manufacturing industry.

Finishing

<http://www.finishing.com>

Finishing.com contains links to commerce, current events, and technical reference materials pertinent to anodizing, plating, powder coating, and surface finishing. Also located at this site is a link to a caller participation area where visitors can pose or respond to finishing industry questions.

The Golden Gate Society for Coatings Technology

<http://www.kudonet.com/~paintman/ggsct.htm>

The GGSCT site contains a comprehensive bibliography of coating industry issues.

National Paint & Coatings Association (NPCA)

<http://www.paint.org>

NPCA is the preeminent organization representing the paint and coatings industry in the United States. A voluntary, nonprofit trade association, NPCA represents some 500 paint and coatings manufacturers, raw material suppliers and distributors.

P2 Gems

<http://www.turi.org/P2GEMS>

P2Gems is a search tool for facility planners, engineers, managers, and technical assistance providers who are looking for technical process and materials management information. The site contains a database, searchable by keyword or by four categories: product or industry, chemical or waste, management tools, or process.

P2 Tech

<http://www.great-lakes.net/>

P2 Tech contains information on the economy, ecosystem, government, and environmental issues in the Great Lakes region.

The Paint/Coatings Net

<http://www.horizonweb.com/pcn/pcnmain.htm>

Paint/Coatings Net includes directories of manufacturers, distributors, contractors, and consultants as well as a collection of paint/coatings articles. The site also contains two discussion areas, a coatings clinic and an environmental clinic.

Pacific Northwest Pollution Prevention Research Center

<http://pprc.pnl.gov/pprc/p2tech/p2tech.html>

The Pacific Northwest PPRC provides technology reviews for manufacturers, researchers and others interested in the details of new cleaning technologies. Each review includes an overview of the technology as well as links to relevant Internet sites and bibliographies on each pollution prevention technology.

Paint Research Association (PRA) Home Page

<http://www.pra.org.uk>

PRA, the Paint Research Association was established at Teddington, Middlesex, UK in 1926 and is now the largest independent research center for the coatings industry worldwide. PRA is a mem-

ber based organization currently with over 200 members.

RadTech Ultraviolet (UV) and Electron (EB) Beam Curing Home Page

<http://www.radtech.com/>

RadTech International North America is a non-profit trade association with members from companies that supply UV/EB equipment, raw materials and formulated products, and other individuals interested in or involved in UV/EB curing technology.

SAE Home Page

<http://www.sae.org/>

The home page of the Society of Automotive Engineers is your one-stop resource for all aspects of vehicle design, engineering, safety, and manufacturing information. A non-profit, educational organization, SAE has nearly 70,000 members in over 80 countries.

Society of Manufacturing Engineers

<http://www.sme.org/>

SME is an international professional society dedicated to serving its members and the manufacturing community through the advancement of professionalism, knowledge, and learning. SME has more than 70,000 members in 70 countries. The society also sponsors some 300 chapters, districts, and regions, as well as 240 student chapters worldwide.

Trade Associations

The following trade associations can be contacted for more information:

Air & Waste Management Association
1 Gateway Center, 3rd Floor
Pittsury, PA 15222
(412) 232-3444

American Institute of Chemical Engineers
345 East 47th Street
New York, NY 10017
(212) 705-7338

The Association for Finishing Processes
One SME Drive
P.O. Box 930
Dearborne, MI 48121
(313) 271-1500

ASTM

100 Barr Harbor Drive
West Conshohocken, PA 19428
(610) 832-9500

Can Manufacturers Institute
1625 Massachusetts Ave. NW, 5th Floor
Washington, DC 20036
(202) 232-4677

Chemical Coaters Association International
PO Box 54316
Cincinnati, OH 45254
(513) 624-6767

Color Association of the United States
409 West 44th St.
New York, NY 10036
(212) 582-6884

Federation of Societies for Coatings Technology
492 Norris Town Road
Blue Bell, PA 19422
(610) 940-0777

National Association of Architectural Metal Manufacturers
8 South Michigan Street, Suite 100
Chicago, IL 60603
(312) 782-4951

National Coil Coaters Association
401 N. Michigan Ave.
Chicago, IL 60611-4267
(312) 321-6894

National Decorating Products Association
1050 N. Lindbergh Blvd.
St. Louis, MO 63132-2994
(314) 991-3470

National Paint and Coatings Association, Inc.
1500 Rhode Island Ave. NW
Washington, DC 2005
(202) 462-6272

Paint Research Association
8 Waldegrave Road
Teddington, Middlesex
TW11 8LD, UK
+44 (181) 977-4427

Powder Coating Institute
2121 Eisenhower Ave., Suite 401
Alexandria, VA 22314
(703) 684-1770

RadTech International-North America
60 Revere Drive, Suite 500
Northbrook, IL 60062
(708) 480-9576

Society of Manufacturing Engineers for Finishing
Processes
1 SME Dr., P.O. Box 930
Dearborn, MI 48121
(313) 271-1500 ext. 544

Steel Structures Painting Council
40 24th Street, 6th Floor
Pittsburgh, PA 15213
(412) 281-2331

Synthetic Organic Chemical Manufacturers
Association
1850 M Street NW
Washington, DC 20036-0700
(202) 296-8577

Clearinghouses

Center for Environmental Research Information
(CERI)
U.S. EPA
Cincinnati, OH 45268
(513) 569-7562

EPA's Pollution Prevention Information Clearing-
house
401 M Street, SW MC 7409
Washington, DC 20460
202 260-1023

Great Lakes P2 Information Clearinghouse
One East Hazelwood Drive
Champaign, Illinois 61820
217 333-8940

The Northeast Pollution Prevention Clearing-
house
129 Portland Street, 6th Floor
Boston, MA 02114
617 367-8558

Toxics Use Reduction Institute
One University Avenue
Lowell, MA 01854
(508) 934-3275

Waste Reduction Resource Center
3825 Barrett Drive, Suite 300
PO Box 27687
Raleigh, NC 27611-7687
(919) 715-6500

The Pacific Northwest Pollution Prevention
Research Center (PPRC)
1218 Third Ave., Ste. 1205
Seattle, WA 98101
206-223-11151

Technical Assistance Programs with Expertise in Metal Coating

Illinois Waste Management and Research Center
One East Hazelwood Drive
Champaign, Illinois 61820
(217) 333-8940

Maine Metal Products Association
190 Riverside Street
Portland, ME 04103-1073
(207) 871-8254

Massachusetts Office of Technical Assistance
100 Cambridge Street, Room 2019
Boston, MA 02202
(617) 727-3260

MnTAP
1315 5th Street SE, #207
Minneapolis, MN 55414
(612) 627-4646
<http://www.umn.edu/mntap>

North Carolina Division of Pollution Prevention
and Environmental Assistance
PO Box 29569
Raleigh, NC 27626-9569
(919) 715-6500
Great Lakes Pollution Prevention Centre
265 N. Front St., Suite 112
Sarnia, ON N7T 7X1 CANADA
Tel: (519) 337-3423

Toxics Use Reduction Institute
University of Massachusetts/Lowell
One University Place
Lowell, MA 01854

Appendix B

VOC/HAP Calculation

Air emissions that result from the evaporation of solvents such as those in paints can be calculated using a material balance approach. To calculate the pounds of HAPs or VOCs emitted, a firm needs to know:

- ◆ Quantity of product used annually
- ◆ Total density of the product
- ◆ Weight percent HAPs or VOCs

Calculating the Quantity of Product Used

The quantity of product used can be taken from purchasing records provided a company maintains an essentially constant inventory. If the firm is disposing of waste materials and has records to show the amount of HAPs or VOCs in the waste, that amount can be subtracted from the total used since it was not emitted into the air.

Calculating the Total Density

The total density of the product can be found on the Material Safety Data Sheet (MSDS). Sometimes it is listed as a specific gravity, calculated by using the ratio of product density/density of water. If specific gravity is given, multiply by 8.314 pounds per gallon (the density of water), to get the density of the product.

Calculating Weight Percent

The HAP content in the paint can be found on the MSDS. HAP content may be listed as a volume percent (vol %) or weight percent (wt %). VOC or solids content also may be listed. If the paint does not contain water or exempt VOCs, the VOC content can be calculated from the weight content using the following relationship:

$$\text{wt \% VOC} = 100 - \text{wt \% solids}$$

If the paint contains water or an exempt VOC, the amount of VOCs in the paint is calculated as follows:

$$\text{wt \% VOC} = 100 - \text{wt \% solids} - \text{wt \% water} - \text{wt \% exempt VOC}$$

Calculating HAPs and VOCs

Appendix C

Economic Analysis

Selection of a particular paint system (paint and application method) for a specific application depends primarily upon the products to be coated and production requirements. Before selecting a system, a comprehensive economic analysis considering the following items should be performed:

- ◆ Cost per volume of the nonvolatile fraction of the paint
- ◆ Transfer efficiency versus paint cost
- ◆ Relative costs of various coating process equipment
- ◆ Energy consumption

The following section provides one method for conducting a comprehensive economic analysis that considers all four factors. Technical assistance providers can help companies conduct this analysis to compare P2 options for painting operations.

Conventional liquid paints are comprised of both volatile and nonvolatile components. When paint is applied to the part, the volatile components evaporate, leaving the nonvolatile components to form the actual finish. In order to evaluate a coat of an applied finish, one must consider: 1) the nonvolatile fraction of the paint versus the product cost and 2) the efficiency of the paint application method (i.e., transfer efficiency).

Cost per Volume of the Nonvolatile Fraction of the Paint

The cost of a paint based on its nonvolatile (solid) fraction can be calculated from product information (generally the product Material Safety Data Sheets [MSDS]). For example, a paint that costs \$15 per gallon and contains 33% solids actually costs \$15 divided by 0.33 or \$45.45 per gallon of solids.

If a desired film thickness is known, this cost can be further broken down into a cost per applied surface area using the following equation:

Cost of paint solids per gallon x film thickness in mils x 0.0006233 = paint cost per square foot of applied finish (where 0.0006233 is a unit conversion factor)

Using the paint cost of \$45.45 per gallon of solids and a 2 mil (1 mil = 0.001 inch) finished film thickness, the paint cost per square foot of applied finish (assuming a 100% transfer efficiency) would be:

$$\$45.45 \times 2 \times 0.0006233 = \$0.057 \text{ per square foot (ideal)}$$

Transfer Efficiency Versus Paint Cost

The above calculation gives the minimum or ideal cost of paint per square foot of applied finish because it assumes that 100% of the paint product adheres to the part being painted. In order to get an actual cost, one must also include transfer efficiency. In most spray painting operations only a portion of the product reaches the part to be painted. The remainder (overspray) is collected in the paint booth filters or settles to the floor of the paint area. The amount of paint reaching the product versus the total amount of paint sprayed is referred to as transfer efficiency. A 50% transfer efficiency means half the paint adheres to the product and the other half is wasted. To calculate the actual cost of paint

per square foot of applied finish, one must include the estimated transfer efficiency of the paint operation into the above formula as follows:

$(\text{Ideal paint cost per square foot} \times 100) / \text{TE} = \text{Actual paint cost per square foot}$
 where: TE equals transfer efficiency

Using the previous example and a transfer efficiency of 50%, the actual paint cost would be:

$(\$0.057 \times 100) / 50 = \0.114 per square foot (actual) (IWRC, p. 10-12)

Example

A small manufacturer of metal cases for consumer electronics currently coats its products with conventional solvent-borne coatings. The firm is considering changing its current coating and application system to one containing lower VOC content and higher transfer efficiency, and they want to know what the coverage, total reduction in emissions and materials cost would be for the new system.

	Existing System	Proposed System
VOC Content (pounds per gallon)	3.5	2.5
Solids Content	35%	30%
Dry Film Thickness (mils)	0.8	<1.0
Equipment Transfer Efficiency	28% (air atomized)	65% (HVLP)
Cost (gallon)	\$15	\$20
Paint Use (gallons per year)	4,400	(to be determined)

Calculating Material Savings and Emission Reductions

$\text{Coverage} = (\text{paint volume} \times \% \text{ volume solids} \times \% \text{ transfer efficiency}) / \text{dry film thickness}$

If the surface to be covered is the same for both production scenarios, then:

$$(G_2 \text{ (gallons)} \times \% \text{VS}_2 \times \% \text{TE}_2) / \text{FT}_2 \text{ (mils)} = [(G_1 \text{ (gallons)} \times \% \text{VS}_1 \times \% \text{TE}_1) / \text{FT}_1 \text{ (mils)}] / \text{FT}_1 \text{ (mils)}$$

or

$$G_2 \text{ (gallons)} = (G_1 \text{ (gallons)} \times \text{FT}_2 \text{ (mils)} \% \text{VS}_1 \times \% \text{TE}_1) / (\text{FT}_2 \text{ (mils)} \times \% \text{VS}_2 \times \% \text{TE}_2)$$

Where:

G_1 = amount of coating currently used for a given application

G_2 = amount of coating used in new method for the same application

$\% \text{VS}_1$ = %volume solids of the original coating

$\% \text{VS}_2$ = %volume solids of coating used in new applications method

$\% \text{TE}_1$ = % transfer efficiency of existing applications method

$\% \text{TE}_2$ = % transfer efficiency of new applications method

FT_1 = film thickness achieved in existing applications method

FT_2 = film thickness achieved in new applications method

Emissions = paint volume used x VOC content of paint

or

$E \text{ (pounds)} = G \text{ (gallons)} \times \text{VOC (pounds per gallon)}$

$\text{Total materials cost} = \text{paint volume used} \times \text{cost per gallon of paint}$

$\text{TMC (\$)} = G \text{ (gallons)} \times C \text{ (\$ per gallon)}$

where:

c = cost per gallon of alternative coating

TMC = total paint materials cost of new application method

Substituting values, we get: $G_2 = 4400 \times 1 \times 35 \times 28/8 \times 30 \times 65 = 2764$ gallons

$\text{VOC emissions (E)} = G \text{ (gallons)} \times \text{VOC (pounds per gallon)}$

Current system: 4400 gallons x 3.5 pounds per gallon = 15,400 pounds per year VOC

Proposed system: 2764 gallons x 2.5 pounds per gallon = 6910 pounds per year VOC

Reduction in VOC: 8490 pounds per year VOC (NJTAP, p. 11)

Relative Costs of Various Coating Process Equipment

Because of the various painting requirements present in the broad category of metal manufacturers, providing a realistic cost comparison between one paint application method and another is nearly impossible. In order to provide some degree of comparative information the following table is offered.

Cost/Benefit Summary for Spray Application Methods

Method of Application	Capital Cost	Process Complexity	Waste and Emissions	Additional Considerations
HVLP Spray	Low	Low	Medium/High	
Air-Assisted Airless Spray	Low	Low	Medium/High	
Electrostatic Spray	Medium	Medium	Medium	Only conductive parts can be painted
Powder Coating	High	High	Low	Extensive parts washing and a curing oven are required

NOTE: Capital cost refers to the cost of the system in comparison to conventional air spray. The higher the process complexity, the higher the associated costs (i.e., training for employees and maintenance).

Energy Consumption

Energy consumption should also be a consideration when selecting a paint and application method.

Energy consuming operations include pretreatment (i.e., parts washing), ventilation, and makeup air/heat for curing. All three of these factors are directly related to the type of paint and application method selected. For comparative purposes, powder coating and waterborne paints might have higher energy requirements because of increased curing demands (IWRC, p. 10-12).

Appendix D

HVLP Spray Gun Purchasing Guidelines

The Wisconsin Department of Natural Resources developed the following list of purchasing considerations for HVLP guns to help Wisconsin businesses identify and evaluate current pollution prevention opportunities. Although this list does not cover every aspect of equipment selection, it includes some of the more important points and provides considerations for evaluating HVLP equipment.

- ◆ Would a cup-fed or a tank-fed sprayer be best for the applications?
- ◆ A cup-fed sprayer is an excellent choice for small jobs because it can be loaded with only the amount of paint that is needed.
- ◆ A tank-fed sprayer would be more effective for continuous, large volume operations in which the tank would need to provide a substantial supply of paint.
- ◆ Would the firm want to add an air heater to the HVLP system?
- ◆ Air heaters may decrease the drying time.
- ◆ Air heaters will increase the transfer efficiency of high solids coating material.
- ◆ Air heaters reduce the moisture condensation inside the system.
- ◆ Can the firm adapt any part of the existing system to the HVLP system or will they need to replace the system as a whole?
- ◆ Is the spray equipment warranted for use with the material that you want to apply?
- ◆ Are the electrical controls and components UL listed, and do they meet the firm's standards for safety at their facility?
- ◆ What is the weight of the spray gun?
- ◆ If the gun is used for an entire shift, the weight of the gun could affect the productivity of the worker using it.
- ◆ A spray gun made from composite materials may be lighter than a gun made from metal.
- ◆ What are the available sizes and shapes of the nozzles that can be used on the spray gun? Are the nozzles compatible with the material that must be applied?
- ◆ Is the equipment easy to disassemble (and reassemble) for the cleaning and maintenance of critical parts?
- ◆ Gun washers are considered by some to be an effective means of cleaning spray equipment. Some services rent these gun washers and sell the solvents that are used in them. When the washing solvent is dirty, the service will pick up the old solvent for recycling and drop off new cleaner.
- ◆ If you need to supply multiple HVLP spray guns simultaneously, will the operation of the spray equipment be affected significantly?
- ◆ Can an automatic positioner be added to the HVLP system?
- ◆ An automatic positioner holds the spray gun in the desired position while the material is applied. This reduces worker fatigue and improves reproducibility.
- ◆ Are there any local, state or federal health and safety or environmental quality regulations that apply to the use of this equipment?
- ◆ What are the electrical power requirements for the HVLP system? Is the system energy efficient? (MnTAPb, p. 1-3)

Appendix E

Testing

A variety of quality assurance tests are used on cured paints for characteristics including thickness, adhesion, chemical resistance, color match and cure. Companies generally select tests based on customer requirements. For example, applications that involve high exposure to water and/or weather require certain performance standards from the coating. Whether the coating supplier provides this information or the manufacturer does the tests at their facility, the customer must be assured that the coating can perform according to specifications. This appendix provides brief descriptions of tests that are commonly performed by coaters.

Thickness

The thickness of both wet and dry films are often measured.

Wet Films

The purpose of measuring wet films is to determine if they are sufficiently thick to develop the required thickness when dry. Gauges used to measure the thickness of wet coatings cut through the film. The two most extensively used gauges include a wheel gauge and a tooth gauge. Wheel gauges are rolled through the wet film to contact the base material. A tooth gauge is simply pressed into the wet coating to measure the thickness.

Dry Films

A wide variety of gauges are used to determine the thickness of dry films. Thickness measurements can be performed on substrates containing iron by using a magnetic "pull-off" type gauge. Magnetic attraction decreases in proportion to the coating thickness. Pencil and banana gauges are two types of pull-off gauges. For other substrates, micrometers can be used to measure coating thickness. Destructive thickness methods include placing a piece of tape on the substrate prior to painting, removing it, and measuring the difference between the tape thickness before and after painting.

Adhesion

Adhesion is defined in ASTM Designation D907 as the state in which two surfaces are held together by interfacial forces which consist of either valence forces or interlocking action, or both. It would be difficult or even impossible to measure these forces. Often it is difficult to determine the true adhesion of a coating due to issues such as voids in the surface profile, improper surface preparation and surface contamination. Many factors other than substrate and paint properties may influence adhesion. As a result, the type of test used should be selected according to the modes of failure observed in service. The most common adhesion tests include film removal and cross-hatch. Inertia tests that use vibration to lift the coating are rarely used.

Film removal

Tools used to test film removal vary from pocket knives to mechanically operated cutting edges, blades, or points. Gauges are used on some devices to measure the force needed to remove the coating.

Cross-Hatch

This test requires that two sets of parallel cuts are made at 90 degree angles to each other, forming a checker-board grid. The percent of paint remaining on the substrate is estimated. In some cases, additional 45-degree cuts are made.

Abrasion Resistance

Several properties are involved in the measurement of abrasion resistance. These include mar resistance, hardness, elasticity and tensile strength.

Flexibility

Flexibility (bend or impact) is usually measured by removing a piece of tape applied prior to painting. ASTM D-3359 provides details about this simple test, including a rating scale for evaluating results.

It is critical to perform this test consistently. The actual method may vary, but the procedure must be performed identically every time.

Hardness

A wide variety of devices are used to measure the hardness of paint films, including scratch or pendulum mechanisms.

Scratch

Scratch tests on paint films maybe performed using mechanically operated styli or knives. The pencil hardness test is also widely used. In this test, pencil lead with specified hardness is pushed against the paint. The hardest lead that does not mar the paint is considered the paint hardness. Pencils are available in 17 different grades of hardness ranging from 9H, the hardest, to 6B, the softest (SME, p. 30-3). As with other subjective tests, procedures must be followed consistently so test results are meaningful.

Extent of Cure (Solvent Resistance)

Extent of cure can be determined via hardness testing or a "solvent rub" test. The solvent rub test involves rubbing the cured coating a prescribed number of times with a cloth saturated with a specific solvent. If no color appears on the cloth, the paint is considered cured.

Weather Resistance

Water and weather resistance can be measured in a variety of ways. Immersion, humidity resistance, and accelerated weathering tests are typical methods. Accelerated weathering tests combine UV light exposure with elevated temperatures and humidity or salt sprays. In addition to predicting field performance, the accelerated weathering test used evaluates different coatings' performance. It is an effective screening tool for choosing alternate formulations.

Color Matching

Color matching is challenging because it requires the manipulation of many variables which contribute to the test's outcome. Reflected light is the basis for interpreting color. Light sources (sunlight or specific artificial sources) vary in intensity, thus

the amount of reflected light may vary. Conduct color matching, whether visual or instrumental, under several light sources. The Munsell system and the CIE systems are commonly used and employ three different light sources to determine color (KSBEAP, p. 26-27). For a summary of various tests, see the table below.

Summary of Paint Tests (KSBEAP, p. 27)

Attribute Measure	Test
Thickness	Pencil or banana gauge Micrometer Tape thickness
Flexibility	Bend or impact
Paint Adhesion	Tape adhesion
Hardness	Pencil hardness
Extent of Cure	Solvent rub
Water or Weather Resistance	Immersion Humidity resistance Accelerated weathering
Color Matching	Munsell or CIE

Appendix F

Glossary

Acrylic : A resin resulting from the polymerization of derivatives of acrylic acids, including esters of acrylic acid, methacrylic acid, acrylonitrile, and their copolymers. Acrylics are also used in powder coatings in their thermoplastic form.

Active solvent: A liquid which dissolves a binder.

Additives: Any substance added in small quantities to another substance, usually to improve properties. Examples of additives include plasticizers, fungicides, and dryers.

Adhesive: A substance capable of holding materials together by surface attachment. Various descriptive adjectives are used with the term adhesive to indicate certain characteristics: physical (liquid adhesive, tape adhesive), chemical type (silicate adhesive, resin adhesive), materials bonded (paper adhesive), and conditions of use (hot-set adhesive).

Air-assisted airless spray: Paint spray application system using fluid pressure to atomize the paint and low pressure air to adjust the shape of the fan pattern.

Air-bearings: A stream of air used to support a spinning shaft. Air bearings have limited load carrying capacity but require no lubricants.

Air-dried coatings: Coatings which are not heated above 194°F (90°C) for coating or drying. In the South Coast Air Quality Management District, curing also must be done below (rather than at or below) 194°F (90°C) to qualify as air dried. Air-dried coatings also include forced-air dried coatings.

Air-dryers: Used to remove moisture from compressed air. Dryers have three basic styles of operation: 1. deliquescent types have disposable drying agents and tend to be marginally effective for painting; 2. refrigerated dryers cool the air to

condense and remove the water. Most paint systems use this type; 3. desiccant types have a double bed dryer and are able to achieve the lowest dew point air. The beds are alternately on-stream and back-flushed to regenerate their moisture absorbing qualities. Some plants with critical finish requirements use this style of dryer to reach dew points of -40°F.

Air knife: A slotted jet of compressed air quickly blows superfluous water from parts, often before they enter a dryoff oven.

Airless spray: A paint spray application system using high fluid pressure to atomize paint by forcing it through a small orifice.

Air spray: A paint spray application system using air at high velocity and pressure to atomize the paint.

Air turbine: 1. Electric motor driven fans that create volumes of relatively low-pressure atomizing air for spraying. Their output is referred to as turbine air; 2. An air-driven precision fan that is used to spin a paint atomizing disk or bell head.

Aliphatic solvent: A solvent comprised primarily of straight chain hydrocarbons, including mineral spirits, kerosene, and hexane. These solvents are characterized as volatile organic compounds.

Alkali: Any substance that neutralizes acids. Alkalis are helpful in aqueous cleaning to speed soil removal and suspension. Alkali is synonymous with caustic.

Alkyd: A binder based on resins formed by the condensation of polyhydric alcohols with polybasic acids. They may be regarded as complex polyesters (Thermoset).

Amino resins: Resins used to crosslink polyesters, epoxies, acrylics, and alkyds to enhance their durability.

Amperes (AMPS): An electrodynamic unit of measure for the quantity of current in a steady electric flow.

Anode: The electrode at which chemical oxidation takes place. In electrodeposition (E-coating) the anode is indicated on diagrams by the positive (+) marking.

Anolyte: The water used to flush solubilizer molecules that form inside an electrocoating anode box. If used to flush a cathode box, it is termed catholyte.

Aromatic solvents: Hydrocarbon solvents which contain an unsaturated ring of carbon atoms, including benzene, naphthalene, anthracene and their derivatives. Toluene (toluol) and xylene (xylol) are commonly used aromatics. These solvents are characterized as volatile organic compounds.

Atomization: The formation of tiny liquid droplets during the spraying of coatings.

Autodeposition: Dip coating application method which depends on a chemical reaction to plate out the coating film.

Autodeposition (autophoretic): A precipitation reaction of an organic resin that occurs by the action of an acid etching a metallic substrate. The ions of the oxidized metal codeposit with the vinyl emulsion resin.

Azeotrope: A liquid mixture that distills with out change in composition. Azeotropes are characterized by a constant minimum or maximum boiling point which is lower or higher than any of the components.

Baked coatings: Coatings that are cured or dried at or above an oven air temperature of 194°F (90°C).

Barytes: Colorless crystalline solids, which are a form of barium sulfate (also called barite). Barytes are used as an extender pigment in primers and coatings.

Bells: A rotating head that is shaped to deliver paint forward in a circular pattern. The bell may be directed at any angle and be moved on robots or reciprocators, just as spray guns are.

Bentonite: A type of clay derived from volcanic ash, which is often used as a paint pigment.

Binder: The solid (non-volatile) material in a coating that binds the pigment and additive particles together to form a film. In general, binders are resins.

Biocide: A chemical agent capable of killing organisms responsible for microbial degradation. Biocides are sometimes added to waterborne coatings.

Bituminous coating: An asphalt or tar compound used to provide a protective finish for a surface.

Bleeding: Discoloration which occurs when colorants from a lower coat diffuse into a surface coat.

Blistering: The formation of hollow bubbles in the paint film caused by air, moisture, or solvents trapped under the film.

Blocked isocyanates (blocking agent): Isocyanates, normally extremely reactive with water, can only be used in waterborne coatings if they can be prevented from reacting before the water is baked out of the paint film. This is done by capping or blocking the isocyanate group with a thermally decomposable chemical. In a bake oven, the water evaporates, the chemical cap decomposes and the isocyanate crosslinks the paint. Blocked isocyanates are often employed for E-coat curing.

Blocking: Undesirable sticking together of painted surfaces when pressed together under normal conditions. Sticking or blocking can be reduced by anti-block paint additives.

Blooming: Powder-like deposit forming on the surface of the film often resulting from partial dissolving and redepositing of pigment by a solvent component.

Blushing: Whitish, milky area which develops on the film and may be caused by absorption of water vapor by the drying film.

Bounce-off, bounceback: Paint droplets from air-atomized application that rebound or bounce away from the surface due to the blasting effect of the air.

Brush coating: Manual application of coatings using brushes and rollers.

Bulk coating: The painting of large masses of small unchangeable parts by a variety of possible techniques such as dip-spin and dipping.

Burn-off ovens: A paint stripping method accomplished by combustion of the coating in gas-fired, burn-off ovens in which high temperatures are controlled by injecting of water spray into the oven.

CARC: Chemical Agent Resistant Coatings. The polyurethane-based coatings are highly crosslinked to resist chemical attack. CARC is often used on military equipment that might become contaminated by nuclear, biological, or chemical substances.

Cathode: The cathode is defined as the electrode at which chemical reduction takes place. In electrodeposition (E-Coating) the cathode is indicated on diagrams by the negative (-) marking.

Caustic: A substance that neutralizes acids. Caustics are used in aqueous cleaning to speed soil removal and increase soil suspension. Caustic is synonymous with alkali.

Cellosolve: The generic term for the solvent family of mono-alkyl ethers of ethylene glycol. For example, a widely-used solvent is butyl cellosolve, which chemically is ethylene glycol monobutyl ether.

Centrifugal coater: see dip-spin coater

Chalking: The degradation of a paint film by gradual erosion of the binder, usually due to weathering.

Checking: Slight breaks in the film that do not penetrate to the substrate surface. If the substrate surface is exposed it is called cracking.

Chipping: Total or partial removal of a dried paint film in flakes by damage or wear during service.

Chlorinated solvents: Organic solvents that contain chlorine. Examples include 1,1,1-trichloroethane and methylene-chloride. These solvents are characterized as volatile organic compounds. Their use is regulated and heavily restricted.

Coating: A liquid or mastic composition which is converted to a solid protective, decorative, or functional adherent film. The South Coast Air Quality Management District defines coatings as materials which are applied to a surface and which form a continuous film in order to beautify and/or protect the surface.

Coating line: Coating lines are all operations involved in the application, and/or drying of surface coatings. However, this definition does not specifically delineate what separates coating lines in a source, especially when a single oven may cure parts from multiple spray booths. For most rules, where the exemption level of the rule is not related to the volume of coating applied per coating line, this definition does not apply.

Cobwebbing: The tendency of spray paint to form strands rather than droplets as it leaves the spray gun. Cobwebbing may be caused by too volatile a solvent or too little air pressure.

Continuous coater: An enclosed automatic spray booth that recovers and reuses oversprayed paint. A continuous coater is suitable for coating large volumes of similarly-sized parts.

Conversion coating: A chemical or electrochemical treatment of a metal surface to convert it to another form, which provides an insulating barrier of exceedingly low solubility between the metal and its environment, and is an integral part of the metallic substrate. Examples are phosphate coating of steel and zinc and chromate anodizing of aluminum.

Cosolvents: Water-miscible organic solvents. Waterborne paints frequently require cosolvents in addition to water for easier manufacturing and improved application properties.

Cracking: The splitting of a dry paint film, usually the result of aging. This includes: hair cracking, checking, crazing, and alligatoring (crocodiling).

Cratering: Small round depressions in a paint film which may or may not expose the underlying surface.

Crawling: A defect in wet paint or varnish film where it recedes from small areas of the surface, leaving them apparently uncoated. Crawling is caused by an incompatible film on the surface.

Crazing: The formation of fine surface cracks, often as a network, which do not penetrate to the underlying surface.

Crosslinking: The setting up of chemical links between the molecular chains of a resin to form a three-dimensional network polymer system. Crosslinking generally toughens and stiffens coatings.

Cup gun: A spray gun used with a siphon cup.

Cure: Using heat, radiation, or reaction with chemical additives to change the properties of a polymeric system into a more stable, usable condition. For liquid coatings, it is the process by which the liquid is converted into a solid film.

Current density: A measure of the total electrical flow across a given area, frequently expressed in units of amps/square foot.

Cyclone separator: A funnel-bottomed enclosure that rapidly moves particulate-laden streams of air in a circular path. As the relatively high mass of particles are thrown to the sides of the enclosure, they slide down through the funnel into a container for reuse. Cyclone separators are commonly used for powder coating applications.

Deionized water: Water resulting from the removal of contaminants by a double-bed ion exchanger. The ion exchanger replaces positive

impurity ions with H^+ (hydrogen) ions and negative impurity ions and OH^- (hydroxide) ions. The hydrogen ions and hydroxide ions then combine to form H_2O (H_2O). Deionized water is comparable in purity to distilled water but is much less costly to produce.

Diluent: Liquids which increase the capacity of a solvent for the binder. Diluents cannot dissolve the binder themselves, but are used to control viscosity, flash time, or cost. While true solvents can be added in unlimited amounts to lower paint viscosity, it may be more economical to lower viscosity with less costly diluent solvents. When added to a prepared paint, a diluent will lower the viscosity just as effectively as a true solvent. However, if too much diluent is added, the resin will separate out of solution and the paint becomes unusable.

Dip coating: The process in which a substrate is immersed in a solution (or dispersion) containing the coating material and withdrawn.

Dip-spin coater: Bulk painting of small and unchangeable parts accomplished by dipping a mesh basket of parts, followed by rapid rotation of the basket to remove excess paint. Parts from the dip-spin coater are dumped onto a belt for curing.

Disks (discs): Rotating heads that deliver paint using a horizontal 360 degrees motion and an omega loop conveyer line. A disk is usually mounted horizontally on a vertical reciprocator.

Dispersion coating: A type of coating in which the binder molecules are present as colloidal particles and spread uniformly throughout the formulation as a stable mixture.

Doctor blade: Device used to prepare paint and varnish films of even and predetermined thicknesses.

Drier: An additive which accelerates the drying of coatings.

E-coating (electrodeposition): A dip coating application method where the paint solids are given an electrical charge opposite to the part being coated. In this method, which closely parallels electroplating, paint is deposited using

direct electrical current. The electrochemical reactions that occur cause water-soluble resins to become insolubilized onto parts which are electrodes in the E-coating paint tank. Subsequent resin curing is required.

Eductor: Nozzles located along E-coat return headers and spaced laterally at intervals across the tank. These nozzles help to agitate the paint and prevent settling of pigments, which results in cleaner film deposits.

Electrostatic spray: Method of spray application of coating where an electrostatic potential is created between the part to be coated and the paint particles.

Emulsion: A two-phase liquid system in which small droplets of one liquid (the internal phase) are immiscible in, and are dispersed uniformly throughout, a second continuous liquid phase (the external phase). This contrasts with latex, which consists of solids dispersed in a liquid.

Emulsion paint: A coating comprised of an emulsion of a resin binder in water.

Enamels: Topcoats which are characterized by their ability to form a smooth surface; originally associated with a high gloss, but may also include a lower degree of gloss. Also a class of substances having similar composition to glass with the addition of stannic oxide, or other infusible substances to render the enamel opaque. Can be used to describe a coating which forms a film through chemical union of its component molecules during curing. In shop terminology can be used to describe paint which is no longer a lacquer. All paints, powder or liquid, that form crosslinking chemical bonds during curing are considered enamels. The majority of industrial finishes fall into this category.

Epoxies: Binders based on epoxy resins. Epoxy crosslinking is based on the reaction of the epoxide groups with other materials such as amines, alcohols, phenols, carboxylic acids, and unsaturated compounds. Also used as a thermoset powder coating.

Etching: A chemical solution used to remove a layer of base metal to prepare a surface for coating or binding.

Etching filler: Coatings that contain less than 23% solids by weight, and at least 0.5% acid by weight, and are used instead of applying a pre-treatment coating followed by a primer.

Exempt compounds: Hydrocarbon compounds excluded from the definition of volatile organic compound, as defined by the U. S. Environmental Protection Agency, on the basis that these compounds have negligible contribution to tropospheric ozone formation. Acetone is an exempt compound.

Extender (pigments): White powders used to give body to the coating.

Fading: The loss of color in a pigmented coating film, over time, following exposure to light, heat, etc.

Faraday cage: Electrostatic application causes paint particles to be attracted to the nearest grounded object. This attraction force is often strong enough to pull paint particles out of their intended flight direction. Recessed areas on parts often receive insufficient paint coverage since they require a slightly longer path for paint particles. As a result, these Faraday Cage areas may need touch-up painting with non-electrostatic spray.

Faraday cage effect: The phenomenon by which charged particles are prevented from entering recessed areas during the electrostatic application of coatings.

Fatty edge: An excess bead of paint that forms on the bottom edges of parts when they are in the drippage zone following dip or flow coating.

Film: One or more layers of coating covering an object or surface.

Fisheye: A paint defect resulting in a pattern of small surface depressions or craters in the wet film, often caused by surface contamination such as oil or silicone materials.

Flash point: The lowest temperature of a liquid at which it gives off sufficient vapor to form an ignitable mixture with air.

Flash-off time: The time required between application of wet-on-wet coatings or between application and baking to allow the bulk of the solvents to evaporate. In baked coatings, the flash-off time helps to prevent solvent boil off and film blistering.

Flat coatings: Coatings with a gloss reading of less than 15 on an 85-degree meter or less than 5 on a 60-degree meter. This definition is usually found in architectural coating rules.

Flocculation: The formation of loose clusters of dispersed pigment particles in liquid coatings.

Flooding, floating, or mottle: Tendency of pigment particles to separate and concentrate in an area such as the surface.

Flow coating: A coating application system where paint flows over the part and the excess coating drains back into a collection system.

Fluidized bed: Finely divided powders can be made into a fluid-like state by passing air through the porous plate bottom of a powder hopper. This permits powder particles to be used in dip tanks and to be transported in a manner similar to liquids.

Flushable electrode: An anode in cathodic E-coating placed inside a semi-permeable membrane enclosure. Excess solubilizer generated at the anode can be continuously removed by water pumped into the bottom of the enclosure. Flushable electrodes in anodic E-coating can also be used (but rarely are needed) for the cathode.

Free radical polymerization: Reactive electrons that chemically bond to adjacent molecules and produce a cured paint film. Certain organic compounds will form highly reactive electron configurations by the action of UV light (or other activation sources). These reactive species are called free radicals because, to an extent, 'free' electrons are available for bonding.

Fusion: The melting of a powder coating into a solid film.

Grain refiners: Agents used in water rinses prior to zinc phosphating or in the zinc phosphatizing bath itself to produce smaller crystals. Finer grain zinc phosphate crystals provide superior corrosion resistance and paint adhesion.

Ground (electrical ground): An object so massive that it can lose or gain overwhelmingly large numbers of electrons without becoming perceptibly charged.

Halogenated hydrocarbons (halogenated solvents): Formed by substituting one of the halogen elements (chlorine, bromine, or fluorine) into a chemical compound to change both the physical and chemical nature of the compound.

Heat-resistant coatings: Designed to resist degradation upon continuous or intermittent exposures to a predetermined elevated temperature. A San Diego Air Pollution Control District rule stipulates that the coating must withstand temperatures of 400°F during normal use as determined by ASTM Method D-2485.

High boilers: Solvents with a boiling point above 212°F (tail-end solvents). These solvents usually evaporate during baking.

High-solids: Solvent-borne coatings that contain greater than 50% solids by volume or greater than 62% (69% for baked coatings) solids by weight.

High temperature coatings: Coatings certified to withstand a temperature of 1000°F for 24 hours.

High volume low pressure spray: Spray equipment used to apply coating by means of a gun which operates between 0.1 and 10.0 psig air pressure. The high volume of air is produced by a turbine.

Hot water curing: A curing procedure which involves immersing parts in 180°F water. Hot water curing is faster than oven curing for parts that act as a large heat sink, but is normally not used since it results in reduced corrosion resistance.

Hydrocarbon solvent: An organic compound consisting exclusively of the elements carbon and hydrogen. They are principally derived from petroleum and coal tar, and include aliphatic, aromatic, and naphthenic solvents.

Hydroxides: The chemical opposites of acids. Also known as caustics and alkalis. Examples are sodium hydroxide and potassium hydroxide.

Hygroscopic: A material property defined by the ability of a substance to readily absorb moisture from the air. Hygroscopic materials, such as silica gel and calcium chloride, are used as desiccants. Thinly spread deposits of hygroscopic materials can absorb enough water to completely dissolve.

Inhibitor: A chemical additive that retards undesired chemical reactions such as corrosion, oxidation, drying, and skinning.

Initiator: A chemical used to help start a chemical reaction such as polymerization. Its action is similar to that of a catalyst, except that it is usually consumed in the reaction.

Inorganic polymers: Substances whose principal structural features are made up of homopolar interlinkages between multivalent elements other than carbon. This does not preclude the presence of carbon-containing groups in the side branches, or in interlinkages between principal structural members. Examples of such polymers are ethyl and butyl silicates, mica, clays, and talc.

Ionized air cloud: A cloud of air molecules that have picked up excess electrons around the tip of an operating electrostatic spray gun. The electrons from the power pack flow off the end of the needle electrode at the gun tip. When paint droplets pass through the ionized air cloud they accumulate electrons that enable electrostatic attraction of the droplets to parts being coated.

Isocyanate: A compound containing the functional group $-N=C=O$. Isocyanates are crosslinked with hydroxyls to form polyurethanes.

Kick-out: The portion of binder that comes out of solution as small lumps.

Lacquer: Coating composition based on synthetic thermoplastic film-forming material dissolved in organic solvent and dried primarily by solvent evaporation. Typical lacquers include those based on nitrocellulose, other cellulose derivatives, vinyl resins, and acrylic resins.

Latent solvent: A liquid which cannot itself dissolve a binder but which increases the tolerance of the coating for a diluent.

Latex: Stable dispersion of polymeric solids in an aqueous medium.

MEQ (milliequivalents): The concentration of E-coat solubilizer in the bath.

MHO: Unit of conductance equal to the reciprocal of the ohm.

Molecule: The smallest particle of a substance that retains all the properties of that substance and is composed of one or more atoms. Water, for example, consists of molecules having 2 hydrogen atoms and 1 oxygen atom. The chemical formula, H_2O , indicates the composition of a water molecule. Organic polymers often have many thousands of atoms per molecule.

Molten salt bath: A mixture of inorganic salts melted at temperatures between 650° and $900^\circ F$. Painted items immersed in these are rapidly stripped by combustion of the paint.

Nitrocellulose: A binder (resin) based on a polymer from cotton cellulose. Nitrocelluloses were primarily used in lacquers, and were widely used from the 1920's to the 50's on automobiles.

OHM: A standard unit of resistance to electrical flow.

Ohmeter: A device that measures (in units of ohms) electrical resistance in a circuit.

Oil base: Coatings which form films through crosslinking of unsaturated plant oil (drying oils) in the presence of oxygen.

Omega loop: The conveyor for rotating disk paint applicators that is shaped to produce a

circular path around the vertically oriented disk to deliver paint from all 360 degrees of its circumference. The term was derived because the shape of the conveyor resembles the capitalized form of the Greek letter.

Orange peel: An irregularity in the surface of a paint film resulting from the inability of the wet film to level out after being applied.

Overbake or overcure: Exposure of the coating to a temperature higher or for a longer period of time, or both, than recommended for optimal curing; the condition may adversely affect the appearance and properties of the coating.

Overspray: Any portion of a spray-applied coating which does not land on a part.

Oxygenated solvents: Volatile organic compounds which contain oxygen in addition to carbon and hydrogen. Includes alcohols, esters, ketones, and ether-alcohols.

Peeling: Failure of a coating film to maintain adhesion with its substrate. Sheets or ribbons of the film detach from the substrate. The condition results from contaminated surfaces or excessive differences in polarity and thermal expansion characteristics between the surface and the film.

Permeate: The output from ultrafiltration, also called ultrafiltrate.

pH: The measure of the acidity or alkalinity of a solution and defined as the logarithm of the reciprocal of the hydrogen-ion concentration of a solution. The scale ranges from 2 for highly acidic solutions to 14 for highly basic or alkaline solutions. Neutral solutions have a pH of 7. Because the scale is logarithmic, the intervals are exponential.

Phenolic resins: Resins formed by condensation of phenols and aldehydes.

Phosphating: A pretreatment for steel or certain other metal surfaces by chemical solutions containing metal phosphates and phosphoric acid as the main ingredients. A thin, inert adherent,

corrosion-inhibiting phosphate layer forms which serves as a good base for subsequent paint coats.

Pigment: Finely ground insoluble particles dispersed in coatings to influence properties such as color, corrosion resistance, mechanical strength, hardness, durability, etc. Particles may be natural or synthetic, and inorganic or organic.

Polar: Descriptive of molecules where the atoms and their electrons and nuclei are so arranged that one end of the molecule has a positive electrical charge and the other end of the molecule has a negative electrical charge. The greater the distance between the two charged ends, the higher the polarity. Polar molecules ionize in solution and impart electrical conductivity.

Polyester: A polymer in which the monomer units are linked by the functional group -COO- . Polyester has been used as thermoplastic powder coating, and in the following thermosetting powder coatings: epoxy polyester hybrid powder, urethane polyester powder, and polyester TGIC powder.

Polyethylenes: Thermoplastic resins composed of polymers of ethylene (CH_2CH_2). Polyethylenes are normally translucent, tough, waxy solids that are unaffected by water and a large range of chemicals. Frequently used in powder coatings.

Polymers: A high molecular weight organic compound, natural or synthetic, with a structure that can be represented by a repeated small unit, or mer.

Polypropylenes: Tough lightweight thermoplastic resins composed of polymers of propylene (CH_3CHCH_2). They are commonly used in powder coating.

Popping: Eruptions in a coating film after it has become partially set, causing craters to remain in the film.

Pot life: The length of time a coating material is useable after the original package is opened or after a catalyst or other ingredient is added.

Powder coatings: Any coating applied as a dry (without solvent or other carrier), finely divided

solid which adheres to the substrate as a continuous film when melted and fused.

Power-and-free conveyor: A separate pusher chain unattached to paint hooks and riding freely on a separate support beam (as distinguished from a continuous power conveyor). This conveyor allows parts spacing to vary and parts to be held stationary even when the pusher chain is moving.

Power conveyor (continuous): Electrically driven cables or chains mechanically attached to hoods which are used to hang parts to be painted. The conveyor is used to carry parts through the painting process. When the line is operating, all individual hooks on the line will continue to move and maintain their spacing.

Precursor: A chemical compound which is released into the atmosphere, undergoes a chemical change, and leads to a new (secondary) pollutant. Volatile organic compounds are precursors to ozone.

Pressure pot: Various-sized paint tanks containing delivery tubes which extend to the bottom of the tank. These tanks are pressurized with compressed air to force paint to the application device.

Primers: Coatings which are designed for application to a surface to provide a firm bond between the substrate and subsequent coatings.

Reactive diluent: A liquid which is a VOC during application, and through chemical reaction, such as polymerization, 20% or more of the VOC becomes an integral part of the finished coating.

Reciprocator: An automated device which moves a paint-applying tool in alternating directions along a straight or slightly curved horizontal or vertical path.

Resin: The polymer (plastic) component of a paint that cures to form a paint film. Also known as binder or vehicle.

Retarders: Solvents added to a coating to slow down a chemical or physical change, such as the rate of evaporation.

Reverse osmosis: In reverse osmosis, high pressures are applied to force water out of the concentrated solution, often to obtain pure (or purer) water. Solvent is driven through a semi-permeable membrane separating solutions of different concentrations.

Ringling: The occurrence of circular spots in a sprayed repair area (spotting).

Roll coating: Process by which a film is applied mechanically to sheet or strip material.

Rusting (face and/or scratch): The appearance of metal oxidation (corrosion) on the surface of damaged paint.

Sagging: The downward flow of a coating film as a result of the film being applied too heavily or fluid-like.

Sandscratch swelling: A paint defect where solvent from a repair coat soaks into scratches in the initial coat and causes paint swelling.

Sealers: A liquid coat applied to a porous substrate such as wood or plaster, to prevent the substrate from absorbing subsequent coatings.

Shelf life: The length of time a coating may normally be stored without losing any chemical/physical properties. Manufacturers typically specify the shelf life.

Silicone release: A coating which contains silicone resins and is intended to prevent food from sticking to metal surfaces such as baking pans.

Silicones: Resins consisting of silicon-oxygen linkages, unlike organic resins which contain carbon.

Silking: A surface defect which results in parallel flow lines in the paint film.

Siphon cup (suction cup): When a special air spray tip is employed, a partial vacuum is created by the atomizing air just outside the fluid orifice. As a result, atmospheric pressure on the paint in a container connected to the fluid line (such as a

siphon cup) will force paint out of the container into the fluid line. The term siphon is actually a misnomer; suction is a more accurate description of the action.

Skinning: The formation of a surface skin on coating liquids formed by the coating reacting with air or rapidly losing solvent.

Slitting: Cutting wide coils of roll-coated materials into narrower widths.

Solubilizer: Compound that forms polar polymer ions when mixed with water-insoluble resins. Since water is a polar solvent and resins are usually non-polar, the resins must be treated to increase their polarity if they are to be used in waterborne paints.

Solution paint: Resin molecules fully dissolved by solvents in the paint.

Solvency: The degree to which a solvent holds a resin or other paint binder in solution.

Solvent: The liquid or blend of liquids used to dissolve or disperse the film forming particles in a coating which evaporate during drying. A true solvent is a single liquid which can dissolve the coating. The term solvent is often used to describe terpenes, hydrocarbons, oxygenated, furans, nitroparaffins, and chlorinated solvents.

Solvent-borne: Coatings in which volatile organic compounds are the major solvent or dispersant.

Specific gravity: Weight of a given volume of any substance compared with the weight of an equal volume of water. Also known as relative density.

Static electricity (electrostatics): Electrons temporarily removed from various items can cause static charges. Whatever has excess electrons has a negative charge; the object from which electrons have been taken will be positively charged. Electrons will tend to jump from a negatively charged object to a positively charged object.

Stencil coating: Ink or other coating which is rolled or brushed onto a template or stamp

in order to add identifying letters and/or numbers to metal parts and products.

Surface tension: The energy required to expand a liquid surface by one unit area. Liquids reduce their surface area to bring intermolecular attractive forces into equilibrium. A low degree of surface tension is preferred for liquid coatings to maximize minimize wetting and spreading and minimize edge-pull and fish-eye effects.

Surfacer: Easily sanded coating used to fill surface irregularities.

Terpene solvents: Volatile organic compounds obtained from pine trees and are the oldest solvents used in coatings. Includes turpentine, dipentene, and pine oil.

TGIC (triglycidyl isocyanurate): A complex chemical used to crosslink paint, especially polyester powders, to increase exterior durability.

Thermoplastic: Resin capable of being repeatedly softened by heat and hardened by cooling. These materials, when heated, undergo a substantial physical, rather than chemical, change. Thermoplastic resins can be completely dissolved with appropriate solvents.

Thermoset: Resin that, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble material. Thermosetting resins will soften but will not dissolve in any solvent.

Thinning: The process of adding volatile liquid to a coating to reduce its viscosity. This liquid may be a solvent, diluent or a mixture of both. Thinning may also be called reducing or "adding make-up solvent".

Thixotrope: Substance that temporarily causes high paint viscosities by forming loosely-held three-dimensional particle networks within paint fluids. Agitation of the paint by stirring, pumping, spraying, etc., quickly destroys the networks and viscosity drops sharply. When agitation is halted, the networks rapidly reform and paint viscosity rises again.

Thixotropy: The tendency for the viscosity of a liquid to be shear-rate dependent. When a liquid is rapidly shaken, brushed, or otherwise mechanically disturbed the viscosity decreases rapidly.

Throwing power: The ability of electro-deposited coatings to cover interior surfaces.

Topcoat: The final coating film or multiple layers of the same coating film applied to the surface.

Touch-up: The portion of the coating which is incidental to the main coating process but is necessary to cover minor imperfections.

Transfer efficiency: The ratio of solids adhering to a surface to the total amount of coating solids used in the application process, expressed as a percentage.

Underbake or undercure: Exposure of the coating to a temperature lower or for a shorter period of time, or both, than recommended for optimal curing; the condition may cause tackiness, softness, and inferior film durability.

Ultrafiltration: Ultrafiltration uses low-pressure membrane filtration to separate small molecules from large molecules and fine particulates. For example, E-coat rinse water is extracted from the paint bath by ultrafiltration.

Ultrafiltrate: The output from an ultrafiltration unit; also called permeate.

Ultrasonic cleaning: Vibrational frequencies slightly higher than those audible used to agitate immersion cleaning tanks. Microbubble formation in the liquid accelerates dislodgement of soils.

Undercoats: Coatings formulated and applied to substrates to provide a smooth surface for subsequent coats.

Urethanes: Materials based on resins made by the condensation of organic isocyanates with compounds or resins containing hydroxyl groups. Categories of polyurethane coatings include: single component prereacted-urethane coatings; single component moisture-cured urethane coatings; single component heat-cured urethane coatings;

two component catalyst-urethane coatings; two component polyurethane coatings; and one component nonreactive lacquer-urethane solution coatings.

Vacuum metallizing: Process in which surfaces are thinly coated by exposing them to metal vapor under a vacuum.

Varnish: Clear or pigmented coatings formulated with various resins and designed to dry by chemical reaction on exposure to air. These coatings are intended to provide a durable transparent or translucent solid protective film.

Vehicle: The liquid portion of a coating in which the pigment is dispersed; it is composed of binder, solvent and diluent.

Vinyl chloride polymers: Polymers formed by the polymerization of vinyl chloride or copolymerization of vinyl chloride with other unsaturated compounds, the vinyl chloride being in greatest amount by weight. Can be used in thermoplastic powder coatings.

Vinyl resins: Resins which contain the unsaturated vinyl group, ($\text{CH}_2 = \text{CH}-$) including polyvinyl acetate, polyvinyl chloride, copolymers of these, the acrylic and methacrylic resins, the polystyrene resins, etc.

Viscosity: The property of a fluid whereby it tends to resist relative motion within itself. A thick liquid such as syrup has a high viscosity. Viscosity is often measured using an efflux type cup which gives the time required for a given quantity of paint to flow through a hole in the bottom of the metal cup at a given temperature (See Zahn Cup).

Volatile organic compound (VOC): Any organic compound, not specifically exempted by the U.S. EPA, that participates in atmospheric photochemical reactions. VOCs may be emitted during the application and/or drying of coatings. In calculating the VOC content of the coating, exempt compounds and water are excluded. Exempt compounds are acetone, ethane, methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, metallic carbonates, ammonium carbonate, methylene chloride, 1,1,1

trichloroethane (methyl chloroform), 1,1,2 trichlorotrifluoroethane (CFC-113), trichlorofluoromethane (CFC-11), dichlorodifluoromethane (CFC-12), dichlorotetrafluoroethane (CFC-114), chloropentafluoroethane (CFC-115), trifluoromethane (CFC-23), and chlorodifluoromethane (CFC-22). Although many of these compounds are exempt under the VOC rule, they may contribute to upper atmosphere ozone destruction:

Volatility: The tendency of a liquid to evaporate. Liquids with high boiling points have low volatility and vice versa.

Voltage: measure of the potential difference (force or pressure) in electrical systems.

Waterborne coatings: Coatings in which water is the major solvent or dispersant. Solvents or dispersants include water soluble polymers (water reducible), water soluble colloidal dispersions, and emulsions (including latex).

Water-reducible coatings: see waterborne coatings.

Weir: The (often adjustable) barrier that controls the paint depth in an E-coat tank over which the paint flows to the circulation pump to be filtered.

Wet-on-wet finishing: Applying a new coat over an earlier applied coat which has been allowed to flash-off but not cure.

Wrap around: Electrostatic effect where charged coating particles curve around the part and are deposited onto the rear side of the part.

Wrinkling: Distortion in a paint film appearing as ripples.

Zahn cup: Commonly used efflux cup used for measuring the viscosity of coatings. Other widely used viscosity cups are the Fischer cup and the Ford cup. These instruments measure the time required for a given quantity of paint to flow through a hole in the bottom of a metal cup at a given temperature.

Appendix G

Measuring Transfer Efficiency

Before conducting any transfer efficiency test, several parameters need to be established:

- ◆ What part will the test focus on?
- ◆ Which coatings and spray guns will the test use?
- ◆ Who will apply the coatings?
- ◆ How will the test simulate day-to-day production conditions?

After identifying the basic parameters, the paint operator must establish a fluid flow rate that is representative of day-to-day production. The operator needs to set the optimum air pressure for coating atomization and to adjust the coating viscosity and temperature to be representative of typical operating conditions. If the operator is using electrostatic equipment, they must confirm that the parts are properly grounded, the coating is adjusted so that resistivity meets manufacturers recommendations, and the air velocity through the spray booth is neither too high nor too low. A decision also needs to be made in selecting the proper transfer efficiency test.

Guidelines for Choosing Transfer Efficiency Methods

- ◆ If workpieces are small and lightweight (less than 70 pounds each), use the weight (mass) method.
- ◆ If workpieces are small and heavy (greater than 70 pounds each) with simple geometry, use the weight method by "wallpapering" with aluminum foil.
- ◆ If workpieces are small with complex geometry but the surface area can still be calculated, use the volume method.
- ◆ If workpieces are small with a complex geometry where the surface area cannot be calculated, a special protocol may need to be designed.
- ◆ If workpieces are too large to fit onto a balance and have a simple geometry, use the weight method by "wallpapering" with aluminum foil.
- ◆ If workpieces are too large to fit onto a balance and have a complex geometry, but the surface area can still be calculated, use the volume method.
- ◆ If workpieces are large with a complex geometry where the surface area cannot be calculated, a special protocol may need to be designed.

The Weight (Mass) Method

Determining transfer efficiency on a weight or mass basis, as is usually the case, requires purchasing or renting an electronic balance capable of measuring within 0.5 grams. There are balances available that can weigh parts up to 70 pounds (154 kilograms) with this accuracy. The balance must sit on a hard surface, such as a metal table, concrete floor, or cement slab. Operators should never place a piece of cardboard under the balance, as this will lead to inaccurate results.

In addition, the operator must shield the balance from all drafts that occur on a factory floor (this can be accomplished by surrounding the balance with cardboard walls). The operator must also ensure that the pressure pot or coating reservoir is not too heavy for the balance and that the part to be coated falls within the acceptable limits of the balance.

The balance should be set so that the air bubble in the bubble glass falls within the center of the glass. In addition, all four feet of the balance must be in firm contact with the ground or surface. Finally, the operator must calibrate the balance using standard weights, which are often supplied by the balance manufacturer.

The paint operator should follow the steps below to determine the weight of coating used during the operation. This process begins by measuring the liquid coating, then calculating the weight of the solid coating.

1. Before beginning the test, appropriately label each part and then accurately weigh the parts on the balance. Record the weights.
2. Place the pressure pot or coating reservoir on the balance and slowly fill it with coating, ensuring not to exceed the limit of the balance even after tightening the pressure pot cover.
3. Before commencing the actual test, apply the coating to several dummy parts to ensure that the coating process is representative of actual operating conditions.
4. To begin the test, disconnect the fluid and air hoses from the pressure pot. Do not allow any paint to drip to the floor, as it is imperative that the coating fills the line all the way up to the spray gun. Record the coating weight and then replace the air and fluid hoses and begin the spraying operation.
5. For accurate results continue spraying until at least one quart of paint has been used (approximately 2.2 pounds or 1 kg). After applying the coating to the selected parts, immediately disconnect the fluid and air hoses from the pressure pot, weigh the pot and record the second reading. Repeating this entire procedure three times will help determine an average transfer efficiency.

At any time during the test, the operator should take a small grab sample (approximately one pint of the coating) from the pressure pot. The operator should be sure to close the container to prevent solvent evaporation. The facility should send the sample to an analytical laboratory that will conduct a percent weight solids test in accordance with ASTM D2369 (this is the standard test method for volatile coatings).

The company should not bypass the sampling procedure by simply calling the coating manufacturer to request information on the percent weight solids or referring to the MSDS. Even a small discrepancy between the manufacturer's value and

the actual value obtained from the pressure pot sample will make a large difference in the transfer efficiency calculations.

The weight of solids used is calculated by following this equation:

$$\text{Wt of Solids Used} = \frac{\text{Wt of Liquid Coating} \times \% \text{ Wt. Solids}}{100}$$

As noted earlier, before starting the transfer efficiency test, each part must be labeled and weighed. After applying the coating, the operator should allow thorough curing before weighing the part again. If the coating is normally air or force-dried, allow extra time for all of the solvent to evaporate. Curing the parts in an oven set at 230°F will result in a more accurate transfer efficiency reading, even if this is not the normal method for curing. This oven curing schedule is identical to what a laboratory will use to determine the percent weight solids of the one pint sample taken earlier.

After the coating has thoroughly cured, the operator should weigh the parts. The difference between the weights of coated and uncoated parts represents the weight of solid coating deposited. Knowing the weight of solid coating used, and the weight of solid coating deposited, the operator can calculate the transfer efficiency as follows:

$$\text{Transfer efficiency} = \frac{\text{Mass of solid coating deposited}}{\text{Mass of solid coating used}}$$

The credibility of the results depends entirely on the accuracy of the weighing. If the factory has drafts or vibrations that could affect the balance, the operator may wish to take two or three readings before recording any one weight. In addition, the laboratory determination of percent weight solids must be accurate. Finally, the accuracy of the results will increase if a number of parts are coated during any one test.

When using this method for a large part with a relatively simple geometry the operator can still use the weight method by "wallpapering" the surface with pre-weighed aluminum foil. At the conclusion of the test, the operator should weigh the dried coating on the foil to complete the calculations.

Costs

The cost to conduct a transfer efficiency test can be minimal. Companies can usually rent an electronic balance for less than \$300/week. A laboratory charge might be \$150/ sample. The other "in-house" expense is labor. If a consultant is retained costs might range from \$3,000 to \$5,000, depending on the complexity of the operation.

The Volume Method

The volume method is not as accurate as the weight method. To measure transfer efficiency using the volume method, a laboratory must determine the percent solids of the coating as applied, as described in the weight method. To determine the volume of solid coating deposited, a lab measures the average film thickness of the deposited coating; as well as the total surface area of the coated parts.

Reader Response Survey

Pollution Prevention for the Metal Coating and Painting Operations Manual - Reader Response Survey

This manual has been published as a pilot project to develop a comprehensive pollution prevention manual for technical assistance programs for the metal coating and painting operations industry sector. In order to determine the utility and make improvements in future editions, we would like to hear from you. Your comments will enable us to increase the value of this document. Please take a few moments to answer some questions. When completed, simply fold in half, staple and mail the survey back. We appreciate your comments and suggestions.

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For the following questions, please circle the number that best describes your level of agreement with each statement.

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3

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3

2

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