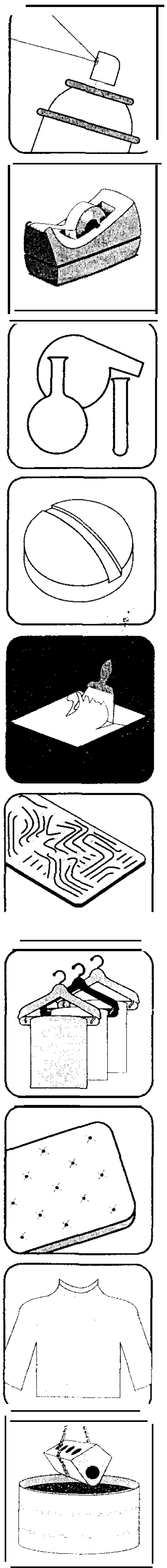
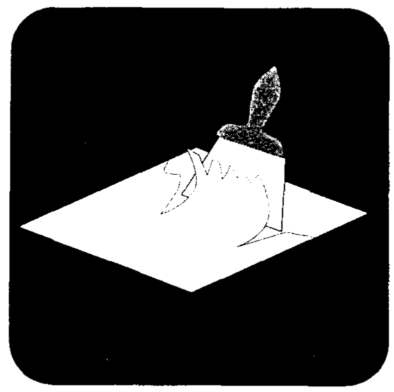
SOURCE REDUCTION RESEARCH PARTNERSHIP
Metropolitan Water District of Southern California
Environmental Defense Fund



SOURCE REDUCTION AND RECYCLING OF HALOGENATED SOLVENTS IN PAINT STRIPPING



TECHNICAL SUPPORT DOCUMENT

A REPORT ON RESEARCH PERFORMED BY THE
SOURCE REDUCTION RESEARCH PARTNERSHIP
FOR THE METROPOLITAN WATER DISTRICT AND
THE ENVIRONMENTAL DEFENSE FUND

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AND RECYCLING OF
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Prepared By

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Description of Project

This document is part of a 12-volume report on research performed by the Source Reduction Research Partnership (SRRP) over the past five years. The report as a whole, entitled ***Potential*** for ***Source Reduction and Recycling of Halogenated Solvents,*** covers a wide range of industries.

The Summary Report of this project, which is available separately, gives an overview and the results of the research as a whole. This is one of ten Technical Support Documents covering each of ten solvent-using industries and operations (listed below). The full report also includes a separate Lifecycle Inventory and Tradeoff Analysis, covering issues that arise in the comparison of existing halogenated solvent uses with potential alternatives. The ten categories of solvent-using industries and operations are:

- Adhesives
- Aerosols
- Chemical Intermediates
- Dry Cleaning
- Electronics
- Flexible Foam
- Paint Stripping
- Parts Cleaning
- Pharmaceuticals
- Textiles

The Source Reduction Research Partnership was formed and jointly managed by the Metropolitan Water District of Southern California (Metropolitan) and the Environmental Defense Fund (EDF). Metropolitan is a public agency, obtaining and supplying water for some 15 million consumers in Southern California. EDF is a national, not-for-profit, public interest organization with more than 200,000 members nationwide.

The research leading to this 12-volume report took place in two phases. The first phase consisted of multi-year field research, primarily in the Southern California area, involving on-site visits, site-specific data gathering, and research into individual processes for all of the affected industries, using a full-time staff employed directly by SRRP. Dr. Kathleen Wolf served as Project Manager during this phase, and staff included Richard Holland, Azita Yazdani, Pamela Yates, and Fidelia Fuhnore.

The second phase involved development of a methodology to quantify potential reductions, additional research and data assessment, analysis of lifecycle and tradeoff issues, derivation of results, and preparation of all report documents. Jacobs Engineering Group performed the work of this phase as consultants under contract. Michael Callahan served as Principal Investigator and Hector Ortiz served as Project Manager for Jacobs during this phase, assisted by Carl Fromm, Dr. Rajeev Sane, Harry Van Den Berg, David Shoemaker, Ross Teneyck, and Dr. Arthur Purcell.

Dr. Timothy Quinn of Metropolitan and David Roe of EDF served as co-administrators of the project throughout. A formal advisory committee, including over 40 representatives of solvent-using industries, industry associations, government agencies, and environmental groups, oversaw the design and development of the project.

Acknowledgments

Major funding for this project came from the Metropolitan Water District of Southern California, the Switzer Foundation, the U.S. Environmental Protection Agency, CAL/EPA (formerly the California Department of Health Services), and the City of Los Angeles through its Department of Water and Power. Both Metropolitan and EDF also contributed in-kind professional services, and EDF provided administrative and financial services for the project.

Additional funding to help set up the unusual partnership that made this project possible, and to help design the research format, came from the Michael J. Connell Foundation, the Andrew Norman Foundation, and Southern California Edison Company.

Metropolitan and EDF warmly thank all the sponsors of the Source Reduction Research Partnership for their support, patience, and faith in this unconventional and unprecedented research effort.

Even as originally conceived, this project's goals were ambitious; and while it was underway, unanticipated difficulties in meeting those goals regularly emerged. The results would not have been possible without the extraordinary effort of everyone involved in both phases of the project. Metropolitan and EDF gratefully acknowledge their special debt to the project's dedicated participants including staff, consultants, advisers, and supporters.

Disclaimer

Readers Note

Note on Terminology: The definition of key terms in this field, including the term "source reduction" itself, has been subject to rapid evolution and nearly continuous debate during the period in which this study was carried out.

In 1986, when SRRP was first taking shape, the sponsors chose to focus the SRRP study on "source reduction" defined to include recycling and recovery of solvents, as well as substitution of alternative materials, equipment and process modifications, housekeeping measures, and the like. In 1990, midway through the study, Congress passed the Pollution Prevention Act which defined "source reduction" to exclude recycling.

Although this report tries to use the terminology of the 1990 Act, the fact that the scope of this study is larger than the 1990 definition of "source reduction" might be confusing to the casual reader. Definitional issues and the reasons for choosing the scope of this study are discussed at greater length in the Summary Report.

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SOURCE REDUCTION AND RECYCLING OF HALOGENATED SOLVENTS IN PAINT STRIPPING

1.0 INTRODUCTION

The focus of this Technical Support Document is on the use of halogenated solvents (mainly METH) for paint stripping. Paint stripping activities can range from formulation of the paint stripper, use of stripper in the shop to remove old or defective coatings before repainting, use of stripper in the field for removing coatings from aircraft, vehicles, or any large structure that cannot be disassembled or moved into a shop for stripping, use by consumers for home painting, and use as a means of cleaning paint application equipment. Parts cleaning, a related activity, is discussed in its own Technical Support Document.

Usage of METH for paint stripping was estimated to be 66,000 metric tons (MT) in 1988. The original equipment manufacturing sector used 13,200 MT in the manufacture of automobiles and other items. The maintenance sector used 26,400 MT for stripping aircraft and other large vehicles and parts. Another 26,400 MT was used in the consumer sector, primarily for furniture stripping. The actual amount of stripper used is much greater since paint stripper is a formulated product. METH use for paint stripping has declined in recent years, and this decline is likely to continue because of increased regulatory scrutiny.

By employing the use of abrasive strippers such as plastic media, glass beads, high pressure water, and others, along with operational improvements to existing immersion stripping operations, it is estimated that METH use can be reduced by 14 to 37 percent in the short-term (0 to 5 years) and 32 to 57 percent in the long term (10 to 20 years). Many other options are also available for facilities to implement if these techniques are not feasible. Other options include use of thermal, cryogenic, and chemical (acid/alkali, non-METH solvent, and reduced METH content) strippers. With rising disposal costs for the continued use of METH-based strippers, many of these options are reported to yield sizable cost savings. With the listing of METH as an air toxic, other driving forces for the elimination of

METH use will come into play. Therefore, these reduction estimates are viewed as being conservative.

Section 2 of this document presents background information on halogenated solvent use in and releases from paint stripping activities. It also describes the characteristics of stripping processes in the three main sectors and presents the results of the field visits. The sites included five manufacturing facilities, six maintenance stripping facilities, and two contract stripping operations. Section 3 identifies and discusses source reduction options for each of the sectors. Section 4 analyzes several potential options. Finally, Section 5 presents an estimate of how much reduction is feasible and discusses the methodology employed to derive the estimate.

2.0 BACKGROUND

Methylene chloride (METH) has been the predominant chemical used for paint stripping in virtually all applications for many years. This section estimates the amount of METH used in each of the paint stripping markets and describes the stripping processes typically employed. The section then ends with a brief summary of regulatory and industry trends.

2.1 PAINT STRIPPING MARKETS

METH is the primary halogenated solvent used in paint stripping applications. It is generally assumed to be the chemical stripper that can effectively strip the widest range of cured coatings from the widest variety of substrates. The major markets for METH-based paint strippers include Original Equipment Manufacturing (OEM), field maintenance stripping, and home improvement/repair. Most of these markets purchase paint stripper from a formulator who mixes METH with other chemicals to achieve desired properties.

In the OEM sector, paint stripper is used to remove defective coatings from rejected parts. Stripper is also used for cleanup of the paint booths and paint application equipment. In maintenance stripping, parts may be stripped either in the field or in the shop. Stripping is performed to remove the old coating so that the parts or equipment can be inspected for damage, cracks, or corrosion and then be repainted. In the home market, stripping is mainly done on wooden building exteriors and on wooden household goods such as chairs, tables, and cabinets. The two types of strippers used are brush-on and immersion.

2.2 SOLVENT USAGE

Table 2.1 presents estimates of METH use in paint stripping by various industrial sectors in 1988. Major industrial sectors or markets include OEM, equipment maintenance, and home improvement/furniture restoration. The amounts shown in Table 2.1 are based on SRRP staff review of available literature and consultation with industry sources. The reader should be aware that estimates and market usage profiles presented in various references vary widely. METH usage in paint strippers has been placed at 70,200 MT (SRI, 1985), 63,500 MT (Radian, 1988) 51,800 MT (ICF, 1988), and 66,900 MT (CMR, 1989a). The total value shown in Table 2.1 includes the use of recycled METH that is assumed to be equal to 6,000 MT or 10 percent of virgin solvent usage. The market profile is based on data presented in ICF (1988) and adjusted to reflect reduced METH use in OEM operations.

Table 2.1

METH Usage by Various Paint Stripping Markets

Market	Usage (thousand MT)
OEM (20 percent)	
Automotive	5.3
Other	6.0
Subtotal	13.2
MAINTENANCE (40 percent)	
Military	16.6
Aircraft	4.2
Auto Repair	4.0
Other	1.6
Subtotal	26.4
CONSUMER USE (40 percent)	
Public	17.6
Contractors	8.8
Subtotal	26.4
TOTAL	66.0

Source: SRRP staff review of various information sources.

23 PROCESS DESCRIPTION

Paint stripping is commonly performed by one of three methods: physical, chemical, or thermal. Physical methods such as wire brushing or abrasive blasting rely on abrasion to remove the coating. Chemical paint stripping, which may involve the use of solvent, acids, and/or caustics, involves physical and chemical reactions. Solvents may be used to either dissolve or swell the coating so that it detaches from the substrate while acids and caustics may be used to react with and break down the coating. Thermal methods rely on heat to bum away the organic components of the coating. The inorganic components (i.e., pigments and ash) may then be removed by rinsing or abrasive blasting. In many applications, a combination of methods is used.

In selecting a method, many factors must be weighed. Important factors include type and condition of the existing coating, type and condition of the substrate, location of the paint stripping activity (i.e., shop or field), the size and configuration of the item being stripped, the availability of utilities such as heating, ventilation, and water supply, subsequent processing of the part, and means of waste disposal and wastewater handling. METH-based paint strippers have been widely used because they can remove a wide variety of coatings, seldom attack or damage the part, do not require heating, and typically require little maintenance (immersion strippers). Because of these properties, there has been little perceived incentive to investigate alternatives to METH-based strippers until recently. The major problems associated with their use are ones of worker exposure and environmental impact.

The following sections discuss the use of METH-based paint strippers. Major industrial uses include brush-on strippers or field stripping, immersion strippers or shop stripping, and cleanup of paint application equipment such as spray booths, spray guns, hoses, and racks. Brush-on and immersion techniques are also used by people involved in home repair and furniture restoration. Since most, if not all, paint stripper sold is a formulated product, a brief mention of the formulation process is included for completeness.

Formulation

Except for the direct use of METH in equipment cleanup, most paint strippers sold are formulated products. Substances such as METH and other chemicals used alone for stripping are not effective strippers. Solvent based strippers commonly have a number of components to accomplish the required functions of a viable stripper. The first component (usually METH), is a primary solvent that serves to penetrate the paint film and promote swelling. Cosolvents may also be used to increase the rate of penetration and to keep the various components from separating. Methanol and isopropyl alcohol are commonly used to promote mixing of METH with water soluble components.

Other ingredients include surface active agents, emulsifiers, thickeners, sealants, and corrosion inhibitors. Thickeners such as methyl cellulose derivatives are used to thicken the stripper so that it can be brushed onto vertical surfaces and remain where brushed. Sealants, such as crude or refined paraffin wax, act to retard evaporation of the METH so that the stripper remains effective over a long period of time. Other additives are often used depending on the specific application of the stripper.

Given the relatively high volatility of METH, most blending and formulation is performed in closed tanks. The proper sequencing of chemical additions to the mixing tanks is essential to ensure that adverse reactions do not take place. To promote the addition and mixing of the wax sealant into the formulation, the contents of the mixing tank may be mildly heated. Once mixed, the stripper can be pumped or transferred to the filling line where it is placed into appropriate containers for shipment.

Compared to the use of stripper, formulation is responsible for relatively minor emissions of METH. The use of closed mixing vessels and tanks minimizes losses. Other methods commonly employed include rigorous maintenance of the equipment to prevent leaks and spills, conservation vents on storage tanks, installation.of vapor recovery equipment, and recycling of solvent used for equipment cleaning. Given the relatively low level of emissions due to formulation, this operation is excluded from further study. However, it is important to recognize that paint stripper formulators act as a sink for some of the waste METH generated by other industries. While minimal information is available on the amount of recycled METH used, it has been reported that METH reclaimed from the leather, freeze-dried food, and other industries is used to formulate low cost paint strippers (Mallamee, 1979).

Field Stripping

The most common industrial applications of brush-on or field stripping is in maintenance of military and commercial aircraft, maintenance of other military equipment such as tanks, trucks, and ships, and automotive repair. This stripping is conducted at Department of Defense (DOD) facilities, at airports and commercial/private aircraft maintenance facilities, and at many automotive repair shops. Brush-on stripping may also be performed at small furniture restoration shops or at the home of the consumer. Much of this stripping is performed on wooden objects or items while most industrial stripping is performed on metal.

For many years, the DOD has employed METH-based strippers for stripping a variety of vehicles including planes, helicopters, jeeps, and tanks. These vehicles are maintained and stripped according to periodic schedules. In general, the stripper is sprayed onto the vehicle and allowed to stand until the paint blisters. The paint and stripper is then manually removed with a squeegee, a rubber edged scraping tool. Removed sludge is generally collected and put in drums for disposal. The remaining stripper and paint residue is then removed by flushing with water.

Handling and disposal of this rinse water can be a major problem for many facilities. In the past, rinse water may have been sent to aeration and settling basins. With the concern for soil and groundwater contamination coupled with tougher air emission standards on wastewater treatment systems, aeration may no longer be a viable method. In addition to the METH, the presence of phenolic compounds in the stripper formulation has prevented some facilities from discharging their rinse water to a Publicly Owned Treatment Works (POTW) for treatment. These facilities must dispose of their rinse water as hazardous waste. It is for these reasons that the DOD is actively investigating the use of alternative stripping methods.

Another sizable use of brush-on strippers is in the consumer market. Items include doors, door frames, porches and decks, as well as pieces of furniture. One source estimates that 95 percent of all paint stripper used by the consumer is for stripping furniture (ICF, 1988). Stripper is generally applied with a brush and removed with a scraper. The furniture may then be rinsed off with water or cleaned with a solvent soaked rag. Use of water on wood would be followed by drying and sanding since water often results in the raising of the grain. Most consumers dispose of the stripped paint in the trash.

Immersion Stripping

Immersion stripping is often employed to remove paint from disassembled parts that require inspection and repair or from parts that have been improperly painted (i.e., rejects). Tanks used for immersion stripping are similar to cold cleaning tanks used for cleaning. Most tanks are equipped with manual or automatic parts handling systems so that the parts do not have to be touched after stripping and before they are rinsed. Unlike cold cleaning tanks, most immersion stripper tanks are followed by a rinse water tank or at least a manual hose flushing operation that is conducted on the shop floor.

Depending on the type of paint being stripped, immersion stripping may be performed with formulations of nearly 100 percent METH. To control emissions, a water blanket is used. This is a layer of water that floats on top of the METH formulation and suppresses emissions. A disadvantage of a water blanket is that it can remove stabilizer from the METH, become acidic due to decomposition of the METH and the presence of phenolic acid compounds in the stripper, and lead to etching of the metal parts being stripped. To avoid these problems, water blankets must be monitored and replaced on a routine basis. Problems associated with handling and disposal of this water, along with rinse water from the rinsing tank, are the same as mentioned above for field stripping.

Commercial furniture strippers practice a modified form of immersion stripping known as “flow over” stripping. Furniture is placed inside an empty tank and the operator hoses it down with stripper. The tank is designed to collect the stripper and pump it back through the hose. The operator directs the flow over the furniture, hence the term “flow over.” The flow is not strong enough to result in undue splashing or increased emissions, but aids in the removal of loosened paint. After draining, the piece is transferred to a separate area where the loosened paint is removed by hand scraping or water spraying. Brush-on stripper may be used to remove paint that remains in crevices or indentations. The stripped paint, along with waste stripper, is placed in drums for disposal.

Paint Application Equipment Clean-Up

Paint is commonly applied with spray guns; and these guns and the circulation lines are cleaned when a production run is completed or when the paint color is changed. Failure to properly clean the paint application equipment can lead to an increased reject rate and hence an increase in the need for part stripping (so that a new coating of paint can be applied). To clean the guns, lines, and hoses, paint stripper is circulated through the entire system and the equipment flushed and purged of paint. This operation may be performed with pure METH or if a formulated stripper is used, it may be followed by a flushing with solvent that is compatible with the paint formulation. METH or METH-based paint stripper may also be used to clean the outside of the hoses and spray equipment.

To clean paint booths, workers may spray the stripper or apply it with wax applicators to the inside walls and surfaces of the booth. The stripper is allowed to stand for 10 to 15 minutes and is then removed. Stripped paint may be scraped from the walls and placed in drums for disposal (dry filter booths) or flushed from the walls using high pressure hoses (water wash booth). When water is used inside a water wash booth, it will be collected in the spray booth water tank and will eventually be treated or discharged as paint booth water.

The frequency of booth cleaning depends on a variety of factors such as transfer efficiency of the paint application process and frequency of color change. Transfer efficiency is defined as the percentage of paint sprayed that actually reaches the item being painted. Obviously, the higher the transfer efficiency, the less paint there is to be cleaned from the walls of the booth. Color changes require booth stripping to avoid rejects due to paint flaking from the walls and spotting the just painted part. If production of a cosmetically perfect part is not critical, then some facilities can forego routine booth stripping. In many automotive painting facilities, booth cleaning must be performed every night.

Floors near the spray booth area are typically cleaned on an annual basis unless a spill of paint occurs. To clean the floors, workers pour the stripper onto the floors and spread it around using wax applicators. After several minutes, when the stripper has “lifted” the paint, absorbent material is used to pick up the residue. The absorbent, stripper, and stripped paint is then placed into drums and sent off site for disposal. Since floors are typically stripped once per year, the stripper used must be capable of removing cured paint. To avoid the use of chemical strippers, many facilities have switched to the use of high pressure water sprays.

Immersion cleaning of hooks, racks, and painting masks is also a common maintenance activity at most manufacturing facilities. Stripping tanks may contain pure METH or a METH-based stripping formulation. Parts to be cleaned may be placed in the tank for time periods of several minutes to several days. The length of time in the tank depends on the thickness of paint being removed from the part, the degree of cure that the paint has undergone, and the condition of the stripper in the tank Facilities that require the cleaning of a large number of hooks and racks on a constant basis often rely on high temperature burn-off ovens or high pressure water blasting systems.

Consumer Stripping

As indicated in Table 2.1, the consumer sector uses 40 percent of all METH used in paint stripping and consists of two major sub-sectors. The first is the do-it-yourself sub-sector where the consumer does the stripping at home. About two-thirds of the METH used in the consumer market is used by this sector. The second sub-sector consists of commercial firms that service consumers and businesses who need to strip goods for restoration or maintenance. In contrast to industrial paint stripping where the substrate is generally metal, consumer stripping generally involves wood. One source estimates that furniture stripping accounts for over 95 percent of the consumer paint stripping market (ICF, 1988). Other items stripped in the home include door frames and porch woodwork.

In the household sector, a variety of paints may be encountered. These include alkyd enamel, urethane alkyd, polyurethane varnish, epoxies, shellac, and acrylic latex. Paint and varnish cleaners commonly used contain 20 to 40 percent METH while paint and varnish removers typically contain 70 to 90 percent METH. The sale of paint and varnish removers heavily outweighs the sale of cleaners and the market is actually composed largely of removers (ICF, 1988).

Stripping of work in a commercial operation begins by disassembly of the furniture and removal of the upholstery. The furniture may then be stripped by use of brush-on strippers or be placed either in a soak tank or flow-over tank Soak tanks are used for stripping long items like doors. Flow-over tanks are used to strip most household, office, hotel, and restaurant furniture. In the flow-over system, the stripper is pumped through a hose that is fitted with a scrub brush. All work is done on a scrub table where the flowing stripper is collected and filtered for reuse. After it has been stripped, the furniture is rinsed with water and the effluent treated if necessary. The furniture is then taken to the drying area.

On an average work day, a commercial shop might use between 50 and 300 gallons of water in the rinse area (Kwick Kleen, 1987). Small amounts of METH will contaminate the rinse water. Some local sanitation districts may set limits on sewer releases as a matter of course. Often, the rinse water contains unacceptably high levels of METH and other contaminants and has to be disposed of as hazardous waste.

In addition to the rinse water, periodic disposal of the stripped paint is also required. In the soak tank, the METH continuously evaporates and make-up stripper must be added. Stripped paint rinsed from the furniture settles and accumulates at the bottom of the tank Operating manuals recommend that when the sludge level reaches 4 to 6 inches in the soak tank, it should be removed (Kwick Kleen, 1987). This sludge should be disposed of as hazardous waste regardless of the types of paint stripped.

Sources of Release

To develop the emission profile, METH use by each market segment (OEM, maintenance, and consumer) was segregated into the various types of stripping activities or operations commonly practiced (equipment cleaning, booth cleaning, field stripping, and immersion stripping). Emission profiles were then developed for each activity and the overall profile of use/loss developed. Given the highly diverse and wide-spread nature of paint stripping operations, the emission profiles presented in Table 2.2 are based mainly on SRRP staff experience except where noted in the discussion below.

In the OEM market, it was assumed that 20 percent of the stripper used is for equipment cleanup of spray guns and paint lines, 50 percent is for cleaning spray booths and floors, and 30 percent is for immersion stripping of hooks, racks, masks, and rejects. Data from several automobile manufacturing plants on their use of METH strippers in 1985 indicated that

Table 2.2

Solvent Use / Loss Profile for Paint Stripping

Industry and Operations	Media (a)	1988 Solvent Use (Thousand Metric Tons) TCE	PERC	METH	TCA	CFC-113	Total
OEM	Input	0.0	0.0	13.2	0.0	0.0	13.2
Spray Booth Cleaning	A(40%)	0.0	0.0	5.3	0.0	0.0	5.3
Spray Booth Cleaning	S(5%)	0.0	0.0	0.7	0.0	0.0	0.7
Spray Booth Cleaning	W(5%)	0.0	0.0	0.7	0.0	0.0	0.7
Immersion Stripping	A(24%)	0.0	0.0	3.2	0.0	0.0	3.2
Immersion Stripping	S(3%)	0.0	0.0	0.4	0.0	0.0	0.4
Immersion Stripping	W(3%)	0.0	0.0	0.4	0.0	0.0	0.4
Spray Equipment Cleaning	A(4%)	0.0	0.0	0.5	0.0	0.0	0.5
Spray Equipment Cleaning	S(16%)	0.0	0.0	2.1	0.0	0.0	2.1
Maintenance	Input	0.0	0.0	26.4	0.0	0.0	26.4
Field Stripping	A(56%)	0.0	0.0	14.8	0.0	0.0	14.8
Field Stripping	S(7%)	0.0	0.0	1.8	0.0	0.0	1.8
Field Stripping	W(7%)	0.0	0.0	1.8	0.0	0.0	1.8
Immersion Stripping	A(24%)	0.0	0.0	6.3	0.0	0.0	6.3
Immersion Stripping	S(3%)	0.0	0.0	0.8	0.0	0.0	0.8
Immersion Stripping	w(3%)	0.0	0.0	0.8	0.0	0.0	0.8
Consumer	Input	0.0	0.0	26.4	0.0	0.0	26.4
Field Stripping	A(67%)	0.0	0.0	17.7	0.0	0.0	17.7
Immersion Stripping	A(27%)	0.0	0.0	7.1	0.0	0.0	7.1
Immersion Stripping	S(3%)	0.0	0.0	0.8	0.0	0.0	0.8
Immersion Stripping	W(3%)	0.0	0.0	0.8	0.0	0.0	0.8
Total Use / Loss	Input	0.0	0.0	66.0	0.0	0.0	66.0
Emission	Air	0.0	0.0	54.9	0.0	0.0	54.9
Emission	Solid	0.0	0.0	6.6	0.0	0.0	6.6
Emission	Water	0.0	0.0	4.5	0.0	0.0	4.5

Source: SRRP staff estimates.

Notes: Percent shown represents amount of solvent used lost to air (A), water (W), or as solid (S) waste. Amount of recycled solvent used by formulators to produce low cost paint stripper is 10 percent of virgin use or 6,000 MT. See text for discussion of how the emission profile for each operation was derived.

cleaning of spray booths and floors accounted for 70 percent of use, immersion cleaning accounted for 20 percent, and line purging/gun cleaning accounted for 10 percent (ICF, 1988). In the last few years, METH use for booth cleaning is known to have declined and the percentage of METH allocated to this activity is considered to be lower. The same values are assumed to apply for the nonautomotive manufacturing sector.

In the maintenance market, a 70/30 percent split was. assumed for field stripping versus immersion stripping. In the consumer market, all home use was considered to be field stripping while all contract stripping was assumed to be immersion stripping. These distinctions are important, since the use of stripper either in the field or in an immersion tank can dictate the type of source reduction options available for use.

In 1987, the U.S. Environmental Protection Agency (USEPA) surveyed several major facilities that used METH strippers. Analysis of the questionnaires indicated that atmospheric emissions from automotive, other industrial, and military sources amounted to about 80 percent of use; air emissions from consumer sources were estimated at 100 percent (Radian, 1988). While the value for consumer use may be high (some waste would be solid and disposed of in the trash), the eventual release of METH into the air from this waste most likely does occur. The same can be said for most of the METH released to water.

To calculate amounts of release, it was assumed that 20 percent of the METH used for gun and line cleaning was emitted to the atmosphere and that 80 percent resulted in the generation of solid waste. Atmospheric emissions of METH used for spray booth cleanup, for field stripping by industry, and for all immersion stripping was considered to be 80 percent. Releases to water and as solid waste were both assumed to be 10 percent. For the portion of field stripping due to consumer use, all of the METH was considered to be emitted to the atmosphere. Overall, 83 percent of the METH used is lost to the atmosphere while 10 percent is disposed of as solid waste and 7 percent is released to water.

2.4 SITE SURVEYS

This section summarizes and discusses the results of the SRRP staff field visits to five original equipment manufacturing facilities, six maintenance operations, and two consumer contractors. Table 2.3 summarizes the major activities in the manufacturing, maintenance, and consumer facilities visited by SRRP staff.

Table 23

Summary of Facilities Surveyed

Plant No.	Products	Activity	Stripper	Comments
OEM				
1	Military Aircraft	Clean guns/lines	TCA	Will use gun cleaning station.
2	Cruise Missiles	Dip tank for reject parts	METH	Hot acid used for paint racks, peelable coatings inside booth.
3	Commercial Aircraft	Clean guns/lines	TCA	Booths cleaned manually.
4	Garbage Disposers	Clean guns/lines	TCA	Uses recycled solvent, booths cleaned manually. Some pre-painted parts are used.
5	Electromechanical Actuators	Dip tank for removing bake-on varnish	METH	Water blanket on tank
MAINTENANCE				
6	Military Aircraft	Strip primers/topcoats	METH	Converting to PMB for aircraft, now used on parts.
7	Commercial Aircraft	Strip paint	METH	
8	Private Aircraft	Strip polyurethanes/ epoxy	METH	
9	Commercial Aircraft	Strip polyurethanes/ epoxy	METH	Converting to PMB for aircraft.
10	Buses	Strip paint	**PMB**	Previously used METH.
11	Automobiles	Strip paint	Manual	Hand sand with pads. Touch-up removal with METH.
CONSUMER				
12	Contract Finishing	Refinish metal and wood furniture	METH	Mainly used on wood, metal is sanded and washed down.
13	Furniture Refinishing	Antique furniture	METH	Home operation.

Plant 1

In this operation, aluminum alloys and stainless steel aircraft parts are painted inside dry filter booths. Due to the low production volume at this site, booth stripping is not required or performed. The firm does, however, clean the paint supply lines and spray guns with TCA TCA is used because the plant is located in Southern California, and the firm must employ an exempt solvent. The firm purchased a drum mounted gun cleaning station to cut down on solvent use and control air emissions from the gun cleaning operation.

Plant 2

For stripping cured paint from parts, Plant 2 uses a METH-based stripper. The stripper consists of 65 to 70 percent METH, 10 to 15 percent phenol, and 10 to 15 percent formic acid. It is also used, to some extent, as a hand-wipe paint remover and a paint thinner. The firm uses about 95,000 pounds, or 9,500 gallons, of stripper and disposes of about 1,200 gallons annually. This waste is sent to an incinerator at a cost of $9,000.

The plant also has a hot acid strip tank for cleaning paint racks. The racks go through an automated line and the uncured paint is stripped in a hot solution of chromic and phosphoric acid. To reduce the need for solvents in booth cleaning, peelable coatings are used in the dry filter paint booths. Peelable coatings are painted onto the inside walls of the booth and when dirty, can be peeled off and disposed of as solid waste. A new coating is then applied. Paint supply lines and spray gun cleaning is performed with a hydrocarbon solvent.

Plant 3

Plant 3 paints parts inside several paint booths, which they occasionally clean manually by chiseling the cured paint off with a hammer. Spray guns and paint supply lines are cleaned and purged with TCA because it is an exempt solvent under the rules of the South Coast Air Quality Management District. The firm plans to purchase a drum mounted gun cleaning system in the near future.

Plant 4

This operation employs water wash booths for painting plastic garbage disposal units. Some of the disposal units produced are fabricated with prepainted parts and hence do not require painting. Periodically, the water wash booths are shut down, and the walls of the booth are stripped manually by scraping. Recycled TCA is used to clean the spray guns and paint supply lines. Dirty TCA is sent to a off-site recycler for processing and the reconstituted TCA (a mixture of virgin and recycled solvent) is purchased back.

Plant 5

This firm manufactures actuators for the aerospace industry. Baked-on varnish is removed from electrical motors and tooling by dipping them into a stainless steel tank containing a formulation of 50 percent METH and about 20 percent cresylic acid. The parts are left in the tank overnight, removed, and allowed to drip over the tank, washed with water, and then dried with compressed air. The tank has a water blanket to suppress atmospheric emissions.

The firm purchases 200 gallons of the METH formulation each year. The tank is emptied twice a year for a net disposal of about 100 gallons or two drums of waste. The stripper is disposed of through a recycling firm. Annual disposal costs amount to $720 based on $240 per drum of liquid and $30 per inch for 4 inches of sludge per drum. The recycler sends this waste to a cement kiln.

Plant 6

Plant 6 performs depot maintenance on about 24 aircraft per year after they have flown 2,500 hours. The major aim of the maintenance operation is to examine the aircraft for structural integrity. When the aircraft are received, 10 percent of the primer and polyurethane topcoat is stripped. The aircraft are brought to the wash rack where stripper is applied using spray guns and, for small parts, by hand brush. After a time, the paint/METH mixture bubbles. Workers scrape the mixture off and rinse the aircraft with water, which goes into a drain connected to the wastewater treatment plant. The effluent is treated for heavy metals such as chromium, which comes from the zinc chromate primer.

The formulation that is used is a combination of METH and ammonium hydroxide. The firm purchases about 50 drums annually. Much of the METH is emitted to the atmosphere but a small amount is retained in the waste and rinse water. Presumably, some of the METH remains in the paint waste, which is sent off site for incineration. Dissolved metals in the rinse water are treated by pH adjustment and precipitation, followed by addition of flocculants to promote sludge separation. The rinse water is also air stripped to remove organics and the air stream is passed through a W/Ozone device to catalytically decompose the organics Formation of HCI, due to the decomposition of chlorinated organics such as METH, is controlled by scrubbing.

This firm also has a small plastic media blasting cabinet that is used for removing paint from small parts. The waste PMB and paint chips that contain chromium are sent to an incinerator because the firm does not want to incur the potential long-term liability associated with landfilling. The firm is planning to convert a hanger to PMB blasting for removal of paint from aircraft in the next few years.

Plant 7

This commercial airline strips 20 planes annually and employs the use of a non-phenolic METH-based stripping formulation. The planes are sprayed with the stripper and after a given period of time, the stripper is removed with squeegees. Paint sludge and stripper is collected on plastic sheets spread beneath the plane and then transferred into drums. The plane is then washed with water, which is routed to the pretreatment plant. The solid paint waste containing the stripper is sent back to the supplier. Purchases amount to three drums per week and the amount of waste generated is one drum per week. The firm will not consider converting to PMB because they do not want to assume the potential liability of damage to the aircraft.

Plant 8

This firm repairs, overhauls, and maintains corporate jet aircraft. The aircraft are completely stripped when the color scheme is changed, when the paint deteriorates, or when major maintenance is required. A METH/phenol based stripper is used to remove polyurethane and epoxies from all but the fiberglass parts and radomes, which are hand sanded. The stripper is sprayed on the plane with an air activated pump. After the METH has acted, the paint is taken off the planes with a brush or squeegee. This is followed by rinsing with water.

The stripped paint and stripper waste resulting from this operation is sent off site for incineration. Rinse water, which contains about 300 ppm METH, is also handled as a hazardous waste and sent off site for incineration. The cost for incinerating this aqueous stream is $1.30 per gallon. The firm is reluctant to convert to PMB because the presence of metals in the waste PMB would classify this waste as hazardous and there are potential long-term liabilities associated with land disposal.

Plant 9

This firm strips commercial aircraft of polyurethane and epoxy-based paint. The firm uses a 55 percent METH formulation. After application, the paint is wiped off the aircraft with rags, which are sent off site for incineration. The water used for rinsing is also collected and sent off site for incineration. The firm is converting to the use of PMB stripping.

Plant 10

Plant 10 strips 2,500 buses annually. The regular maintenance schedule requires stripping every 6 years but because of severe graffiti, the paint surface degrades more quickly. In such cases, stripping may be required every 4 years or sooner. Every 2 years, the topcoat is stripped off before painting but the primer is left on. Stripping is performed with PMB or by hand sanding. Seventy percent of the buses are fiberglass, which must be hand sanded.

After PMB stripping, the waste is vacuumed up and 70 percent of the plastic media is reused. The remainder is hauled away as hazardous waste since the paint waste contains chromium. For every five buses stripped, one 55-gallon drum of waste is generated. The facility purchases 8,000 pounds of PMB material annually and disposes of 20 drums per quarter. With PMB, the firm has experienced a 50 percent decrease in productivity (one bus per day versus two per day with METH).

Plant 11

This firm maintains and repairs 175 automobiles per month. Virtually all the stripping is performed by hand sanding the surface with scotch bright pads. The firm does purchase four l-gallon cans of stripper each year for touch-up stripping. In addition to METH, the formulation contains methanol, ammonia, sodium chromate, and lithium chromate.

Plant 12

This firm refinishes thousands of wood and metal items each year. It offers the full range of services including on-site and off-site furniture reupholstering, painting, and finishing. The facility has three paint spray booths and wood is painted in one of them, metal items in two. The booths are dry filter booths and they are not stripped.

The operation for refurbishing a metal cabinet might proceed as follows. First, the cabinet is hand sanded and an adhesive filler is used to fill in dents and cracks. The cabinet may then be washed down with soap and water and sometimes lacquer thinner or METH stripper is used. Once clean, the cabinet is repainted. METH-based formulations containing between 65 and 75 percent METH are used to strip wood items.

The firm combines all its liquid waste together, including the METH, and sends it off site for incineration. During a l-year period, the firm generated about 1,800 gallons of liquid waste. Disposal costs for incineration amounted to $7,500.

Plant 13

This operation is composed of one individual who operates out of his home on a part-time basis. He refinishes between 75 and 100 antique furniture items annually in his backyard and garage. He purchases the stripper in 20-gallon cans at a cost of $116. He places the item in a tank, pours the METH-based stripper into the tank, applies it to the item, and then scrapes the paint and METH into the basin. Eventually, the solid contaminants build up and the stripper can no longer be used. Over a 2-year period, 10 gallons of sludge were accumulated and disposed of in the garbage.

2.5 REGULATORY TRENDS

Several of the halogenated solvents have, for some time, been associated with human carcinogenesis. While a number of specific points of disagreement remain in regard to the health and environmental impacts of halogenated hydrocarbons, a consensus has emerged that these substances can pose major problems when they are released into the environment, and that significantly reducing their use can consequently reduce the health and environmental threats associated with them. Table 2.4 summarizes the health and environmental characteristics of the five halogenated solvents discussed in the SRRP project.

The 1990 amendments to the Federal Clean Air Act point toward strict regulations of METH, PERC, TCE, TCA, and other halogenated solvents identified as toxic air pollutants. In California, METH and PERC were recently identified as toxic air contaminants. As a

Table 2.4

Health and Environmental Characteristics of Halogenated Solvents

Solvent	OSHA PEL (ppm)	Known Carcinogen (California)	Photochemical Smog Precursor EPA	SCAQMD	Toxic Air Contaminant EPA	CARB	Ozone Depletion ODP Factor[c]	Montreal Protocol	Drinking Water RCRA Waste[d]	MCL (mgn) EPA	California
TCE	50	Yes[b]	Yes	Yes	Yes	Yes	-	NO	F00l/F002	-	0.005
PERC	25	Yes[b]	Yes	Yes	Yes	Yes	-	No	F001/F002	-	0.005
METH	500[a]	Yes[b]	Exempt	Exempt	Yes	Yes	-	No	F00l/F002	-	
TCA	350		Exempt	Exempt	Yes	Yes	0.1	Yes	F00l/F002	0.2	0.2
CFC-113	1,000		Exempt	Exempt	Yes	No	0.8	Yes	F001/F002	-	

Source:

SRRP staff review of various issues of the Federal Register and other regulatory documents.

Notes:

[a])California OSHA PEL for METH is SO.

[b])26 CCR Section 22-12000.

[c])The Ozone Depletion Factor (ODP) is a measure of the ozone depletion potential of a chemical that depends on its atmospheric lifetime and the amount of chlorine it contains. Values are relative to those of CFC-11 and CFC-12 which have defined ODPs of 1.0.

[d])The solvents are RCRA-listed hazardous waste (F001 through F002) which are banned from land disposal.

Abbreviations:

CARB - California Air Resources Board
MCL - Maximum Concentration Limit
OSHA - Occupational Safety and Health Administration
PEL - Permissible Exposure Level
RCRA - Resource Conservation and Recovery Act
SCAQMD - South Coast Air Quality Management District

result of this determination, METH and PERC use and emissions will be strictly controlled throughout the state. ARB is in the process of developing regulations that are likely to severely curtail METH use in California. Similar regulations for PERC are likely to follow.

METH, PERC, and TCE are listed by the State of California as known carcinogens. Under the state's landmark toxic control law, passed by the voters in 1986 and commonly known as Proposition 65, any business that exposes people to a listed chemical must give clear and reasonable warning to the individuals exposed. In addition, businesses may not discharge a listed chemical into any source or potential source of drinking water. Exceptions to both requirements exist if the business can show that the amount in question was within "no significant risk" levels (currently defined as 50 micrograms per day for METH, 14 micrograms per day for PERC, and 60 micrograms per day for TCE). Several manufacturers of METH-based paint strippers have been sued in California for failing to provide adequate warning to consumers under Proposition 65.

Provisions of Title III of the Super-fund Amendments and Reauthorization Act (SARA) have resulted in public pressure on users of air toxics including halogenated solvents. By mandating a national toxic chemical emissions inventory and delineating mechanisms for public disclosure of all toxic and hazardous chemicals in use by industry, SARA Title III is providing both a database on which to build source reduction programs and effective stimuli for generators to minimize their inclusion in this publicly scrutinized database.

The Food and Drug Administration (FDA) and EPA consider METH to be a suspect carcinogen based on the results of animal studies. The International Agency for Research on Cancer (IARC) classifies METH as "possibly carcinogenic to humans" and the National Toxicology Program (NTP) lists it as one of the substances that "may reasonably be anticipated to be carcinogens." While the workplace exposure level of METH has been set by the Occupational Safety and Health Administration (OSHA) at 500 parts per million (ppm), OSHA is expected to reduce this level significantly to 25 or 50 ppm. The Consumer Product Safety Commission (CPSC) now requires household products containing METH to be labelled as hazardous substances.

2.6 INDUSTRY TRENDS

Many automobile manufacturers are moving away from METH-based paint strippers for cleaning of spray booths. While it may no longer be widely used for booth cleaning ***or*** floor cleaning, it is still used for line purging and perhaps gun cleaning. In the industrial sectors, METH-based strippers are still widely used for all these activities.

In other OEM sectors, there is a trend to eliminate the need for painting by use of prepainted or powder coated metal sheets. By eliminating the need for painting, there will also no longer be a need to use chemical strippers for spray equipment and paint booth cleanup. The only painting that would be required would be for spot repair of damaged or scratched products. Another trend is to minimize the number of color changes and standardize the number of colors used. The major appliance industry has generally standardized on two colors (white and almond) for items such as refrigerators and washing machines. By reducing the number of colors, manufacturers are able to set up production lines for long runs and reduce the need for line purging and booth cleaning.

In the military and aircraft maintenance sectors, heavy emphasis has been placed on the use of abrasive strippers such as plastic media to replace METH-based strippers. Other materials and methods that are receiving active investigation include use of wheat starch, carbon dioxide pellets, sodium bicarbonate slurry, and high pressure water. Programs are also being established to assess the need for and degree of stripping required to achieve proper maintenance. Some airlines have also switched to the non-painted or polished metal look for their corporate image and identity.

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3.0 SOURCE REDUCTION OPPORTUNITIES

This section discusses the source reduction options that might be effective in reducing or eliminating the use of METH in paint stripping applications. The discussion is presented in the order of field stripping, immersion or shop stripping, paint application equipment cleaning, and consumer stripping. While many of the options discussed apply to all four activities, differences in operating conditions affect the implementation potential of each.

In field and immersion stripping, the types of paint to be stripped vary widely and are most often fully cured. This requires the use of a highly effective general purpose stripper. When stripper is used to clean paint application equipment, the type of paint typically does not vary and the paint may be uncured. This allows for the use of a more selective stripper. In addition to paint type and degree of cure, the ways in which the stripper is applied and removed play a role in the implementation potential for each option.

One activity not included in this discussion is paint stripper formulation. Formulation is not included since the level of emissions, and hence, effect of control, is relatively minor compared to the use of stripper. For information on options that could be employed by a formulator, refer to the companion Technical Support Document on aerosol products. A summary of the options investigated in this section is presented in Table 3.1.

3.1 FIELD STRIPPING

Field stripping is performed mainly by the military and aircraft manufacturing and service industries (field stripping by the consumer sector is discussed in Section 3.4). The standard stripper used consists mainly of METH and phenols or cresylic acids. While the USEPA has discouraged the use of these compounds because of their toxicity and deleterious effects on wastewater treatment plants, the high performance paints often used on military equipment cannot be effectively removed by the nonphenolic alternatives. Alternative strippers often rely on formic acid for the replacement of phenols and cresylic acid but still employ METH as the primary solvent. Both industries tend to use the alternative strippers whenever feasible but there are many applications in which the standard formulation must be used.

Both the military and aerospace sectors have pioneered abrasive paint stripping techniques that may be viable substitutes for chemical based stripping. The use of alternative chemical strippers in the field is difficult not only due to the types of paint encountered but also due to

Table 3.1

Summary of Source Reduction Options Investigated

Option	Advantages	Disadvantages
Field Stripping		
1. Use of Non-Painted Surface Materials	Eliminates need for painting and subsequent stripping.	Applications are very case-specific. Maintenance may require increased labor for polishing and buffing.
2. Use of Abrasive Techniques	Eliminates use of METH and results in less waste generation. PMB is in wide use in some applications. Other techniques are actively being investigated.	Can result in physical amage to substrate, highly dependent on skill of operator. Solid abrasives can intrude and foul hydraulic fluids if equipment is not properly masked.
3. Use of Thermal Techniques	Uses light energy to pyrolize paint and does not damage substrate. Coating layers can be selectively stripped.	Highly experimental technique limited to flat surfaces. Very slow stripping rate. Concern over toxicity of break-down products.
Immersion Stripping		
1. Strip Parts Only When Required	Eliminates needless generation of waste both due to stripping and repriming. Reduces need for operator labor.	May lead to early failure of new coating. Some parts must be stripped to be properly inspected.
2. Train Painters and Establish Application Standards	Reduce generation of rejects and hence the need for stripping. Results in higher quality product.	Requires time and budget for training. Data monitoring and tracking may increase workload beyond capability of current staff levels.
3. Use of Abrasive Techniques	See Option 2, Field Stripping	See Option 2, Field Stripping.
4. Use of Thermal Techniques	Bum-off ovens and molten salt baths widely used for cleaning hooks and racks. Can remove heavy deposits rapidly.	Leaves ash and heat scale on parts which may then require cleaning with abrasive methods. Heat can distort and ruin part.

Table 3.1

Summary of Source Reduction Options Investigated (continued)

Option	Advantages	Disadvantages
5. Use of Cryogenic Techniques	Sometimes used to remove heavy deposits of paint from hooks, racks, and fixtures. Only waste generated is stripped paint or paint and PMB.	Extreme cold can distort and damage part. Method is not effective at removing thin coatings. Limited to stripping small to medium sired items.
6. Use of Biodegradation	Natural method relies on effect of enzymes to attack and degrade paint.	Experimental method that is very slow acting. Would require reformulation of paint which could lead to reduced service life.
7. Use of Alkaline or Acidic Strippers	Caustic is widely used to strip paint from steel parts. Emission controls, other than venting, typically not required. Waste can often be handled by sites wastewater treatment plant.	Heated tanks require energy and make-up water. Some parts may be attacked by stripper. Inhibited strippers difficult to rinse off parts and may cause problems during repainting.
8. Use of Alternative Solvents	Eliminates use of METH, and METH health risks.	No substitute is as universally effective as METH. Health risks are not fully known.
9. Use of Reduced METH Content Strippers	Reduces use of METH while still allowing for the use of METH strippers. May be drop-in option.	Extent of reduction must be determined experimentally. Lifetime of stripper not established.
10. Operational Improvement to Stripping Operation	Many low cost options can be implemented to reduce loss of stripper. Options include use of water blanket, improved racking, improved drainage, monitoring of water blanket, and conversion of free-running rinses to still rinses. Reductions of 50 percent or more can be achieved.	Requires active employee and management participation. May decrease through-put since operators must take more time in racking and removing parts from stripper tank.

Table 3.1

Summary of Source Reduction Options Investigated (continued)

Option	Advantages	Disadvantages
11. Filter Stripping Solution	Can extend life of stripper bath and reduce amount of sludge requiring disposal.	May increase employee contact with waste during filtering.
12. Recycle Spent Stripper	Reduces overall use of METH.	Most spent stripper contains low concentration of METH. Presence of other components in formulation makes recovery and reuse very difficult.
<u>Paint Application Equipment</u>		
1. Use of Alternative Solvents	Just as effective as METH on uncured paint.	Health risks are not fully known for several of the new solvents being proposed.
2. Use of Strippable Coatings on Booth Walls	Eliminates use of METH and results in a dry solid waste instead of a wet sludge.	Coatings emit VOC's during application and must be properly applied to be effective.
3. Use of High Pressure Water Sprays	Eliminates use of METH.	Only useful for cleaning water wash booths. Potential for worker injury from spray.
4. Rigid Inventory Control of Solvent	Reductions of 50 to 75 percent are feasible by restricting access to solvent. Discourages wasteful use.	May slow down production while worker obtains solvent. May increase reject rate if workers forego cleaning equipment.
5. Use of Easy-to-Clean Equipment	Reduces need for METH and the generation of dirty clean-up waste.	May result in generation of disposable paint cups or liners.
6. Use of an Enclosed Cleaning Station	Reduces air emissions of METH and allows for its decanting and reuse. Units can be purchased or leased.	Requires source of compressed air.

Table 3.1

Summary of Source Reduction Options Investigated (continued)

Option	Advantages	Disadvantages
7. Install On-Site Recycling Equipment	Maintains solvent purity and minimizes waste generation.	Only practical for use of pure METH in clean-up applications.
<u>Consumer</u>		
1. Use of Alternative Solvents	Can effectively strip paint and coatings from many wood items.	Health risks are not fully known for several of the alternative solvents.
2. Use of Thermal and Abrasive Technologies	Eliminates use of METH. Paint removed in large pieces, making collection and disposal easier.	Thermal methods may volatize lead pigments in old paint while abrasive methods can generate dust. Problems with potential damage to substrate and fire hazard when thermal stripping dry wood.

the variable environmental conditions at the point of use. Field strippers cannot be heated or agitated, and they must stay where brushed-on until removed. Release of these strippers into the environment at their point of ***use*** is a major issue that needs to be addressed. For these reasons, their use in maintenance field stripping is not considered to be viable.

1) Use of Non-Painted Surface Materials

In the airline industry, several companies have changed to minimal paint designs on their aircraft. Commercial aircraft are painted every 4 years on the average and often require complete stripping before repainting. While some believe that paint protects the aircraft surfaces from salt water, oxidation, and jet fuel spills, the largest producer of fuselage skin material in the U.S. (Alcoa) recommends against painting for safety, cost, and environmental reasons (AWST, 1989). American Airlines has not painted its aircraft since the 1950s and US Air recently decided to do the same. Both airlines use only decals for ornamentation and identification.

For airlines that do not paint, there are savings in fuel due to lower weight, reduced aircraft downtime, in labor, in waste disposal, and in stripper and paint purchases. To prevent corrosion of unpainted surfaces, however, the aircraft must be washed and buffed more frequently. US Air, for example, washes each of its aircraft every 90 to 120 days and buffs the exterior skin panels two to three times a year (AWST, 1989). While detailed cost information is not available, one industry source reported to SRRP staff that the total cost for frequent buffing and polishing was about equal to the cost of stripping and repainting.

Field stripping is also performed on buildings and other structures that must be stripped in place. One way to avoid the need for stripping is to design the structure so that it does not require painting. Examples would be the use of vinyl siding in home construction and the use of pre-colored concrete in building construction. To promote the development of surface-coating-free materials, the USEPA conducted a recent workshop and is planning a conference to address this issue in early 1993 (Kosusko, 1991).

2) Use of Abrasives Techniques

Abrasive media that have been used in stripping include local sand, silica sand, copper slag, walnut shells, rice hulls, aluminum oxide pellets, peridot and starolite, steel grit or shot, glass beads, aluminum oxide, garnet, and plastic beads. These media have varying levels of hardness that make each appropriate for a particular application. The hard media are often used to produce a rough, textured surface or for removing corrosion from steel. Since the main advantage of chemical based strippers is that they do not damage the substrate, most abrasives looked at as viable substitutes for METH are relatively soft materials. Five abrasive removal techniques are actively being investigated in the area of field stripping: plastic media blasting (PMB), carbon dioxide pellet blasting, sodium carbonate slurry blasting, wheat starch blasting, and high pressure water blasting. These are discussed below.

Plastic Media Blasting

U.S. Technology Corporation was the first firm to introduce plastic media into the market. Three grades are available. The first is Polyextra(R) with a Mohs hardness of 3, which is a thermoset polyester resin. The second is Polyplus(R) with a hardness of 3.5, which is based on a urea formaldehyde resin. The third is Type III(R) a melamine formaldehyde resin with a hardness of 4. Other manufacturers provide the media as well. DuPont manufactures two types, Type L(R) and Type C(R), with hardness of greater than 3.5 and 4 respectively. Other suppliers include MCP Industries, Aerolyte, and Tierco; these latter two manufacturers also make plastic media blasting equipment.

In plastic media blasting, the air-entrained plastic beads are forced at high velocity through a nozzle at the painted surface. The beads impact the painted surface and the rough edges of the beads abrade the paint. When plastic media was first introduced, equipment manufacturers tried to adapt traditional sand blasting equipment. It was soon realized that PMB had different characteristics that made it necessary to redesign all modules of the equipment. Today, some firms that offer traditional blasting equipment also offer a separate line for PMB while there are new market entrants who only offer PMB equipment.

PMB used for field stripping is often used in an open area or in an enclosed blast booth or room that is designed to house large vehicles or aircraft. To protect the operators from dust, they must often wear self contained breathing equipment to work inside the room. PMB systems, regardless of their size, always consist of certain fundamental components that include the blasting machine, a source of clean, dry, and oil-free compressed air, a system for recovering and recycling the PMB material, and some means of dust suppression or control. Two types of blasting machines are typically encountered: direct pressure and suction.

In the media recycling system, the spent media and dry stripped paint must be collected, transferred to the recycling system for separation of reusable media from paint and media fines, make additions of fresh media as required, and return the recovered media to the blasting equipment. In blast rooms and booths, pneumatic floor recovery systems collect the spent media. In the field, PMB may be collected manually with shovels or vacuum hoses. Some blasting systems are equipped with a collection pick-up hose that is mounted near the discharge nozzle. With these systems, blasting and media recovery occur almost simultaneously. Manufacturers claim that 90 to 95 percent of the media can be reclaimed after each blast cycle (NCEL, 1986).

Plastic media blasting has been pioneered by the military and it has been used with success at a number of military facilities. Corpus Christi Army Depot (CCAD) has been examining PMB since 1983 (CCAD, undated). CCAD is responsible for overhauling various types of helicopters, which are stripped every 5 to 8 years on average. One impetus in investigating PMB was the new requirement to switch to chemical agent resistant coating (CARC), which was projected to increase stripper requirements to three times the previous level. Since the facility was having a difficult time meeting its USEPA NPDES permit limitations, increased use of METH-based strippers was not viable. The depot’s investigation of PMB showed that the technique would be more cost-effective than use of METH stripper. Projected savings associated with labor, materials, and waste disposal were estimated to be $1 million annually for conversion to PMB.

Hill Air Force Base has also investigated and pioneered the use of PMB for stripping aircraft (HAFB, 1986). The aircraft stripped (several F-4s) were coated with multiple coats of epoxy, enamel, lacquer, and polyurethane, which had been applied on top of one another. Because the weight of the coatings were impacting on aircraft performance, it was decided to strip the aircraft down to bare metal and repaint with a standard polyurethane. PMB was investigated and projections were that the technique would save about $2.8 million annually and reduce the time for stripping by 50 percent (one F-4 aircraft requires 364 hours to strip by means of METH-based strippers).

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and the USEPA jointly investigated PMB for stripping U.S. Army communications shelters at McClellan Air Force Base. The PMB process was judged to be superior to chemical stripping and also resulted in sizable cost savings. Costs were reduced from $4,856 per square meter stripped using chemical stripping to $634 per square meter stripped with PMB (Wolbach and McDonald, 1987).

In a Boeing Vertol program, stripping of exterior paint from the fuselage and interior areas of 436 CH-47 helicopters will be required over the next decade. PMB was investigated and found to be a viable alternative. In August 1985, a temporary facility for testing PMB was designed. A permanent facility put in place later has been used to strip 20 of the helicopters without damage to the substrate (Bilbak et al., 1986).

The first commercial airline to use PMB was Republic Airlines, now part of Northwest Airlines. It began the operation in May of 1985. Between May 1985 and March 1986, the process was used to strip more than 50 aircraft. Republic began experimenting with many kinds of media and ultimately chose PMB as the best technique. Savings were estimated at $60,000 to $70,000 for each aircraft stripped. These savings resulted from reduced turnaround time; chemical stripping required 7 days, whereas PMB required only 5 (AWST, 1986). Use of an aircraft has been estimated at $30,000 per day indicating that a two day reduction in downtime saves $60,000 per plane stripped. These savings are augmented by an average savings of $4,000 per plane in labor and other expenses (AWST, 1987).

At the Republic Airlines facility, plastic media collects on the hanger floor as aircraft are stripped. Each aircraft generates about 30,000 pounds of used media and it is cleaned up using a motorized floor sweeper that returns the media to the classifier provided with the blasting machine. The classifier separates the residue and dust from the reusable media (AMJ, 1986). Republic is able to recycle 90 to 95 percent of the media and the waste passes the EP toxicity test for metal leaching. The waste is disposed of in a sanitary landfill.

While many facilities have had success with PMB, there are several disadvantages or points of contention against its use. First, there is a concern that the dust generated during the blasting operation creates an unsafe working environment. The dust load due to breakdown of the plastic media and stripped paint in a blasting operation can be significant. This dust may be explosive and the probability that the dust will ignite depends on a variety of factors including the concentration of the dust, particle size, and presence of ignition source.

Another danger is worker’s exposure to dust. Workers must wear protective equipment inside blast rooms and booths and when working in the field. Equipment for working inside a booth includes a helmet air filter, a climate control tube to allow the operator to heat or air condition the air, hearing protection, leather gloves, and a leather faced cotton-backed blast suit (NCEL, 1986).

Additional concern arises over the issue of substrate damage. There is considerable controversy over this issue and it is an extremely important one because of safety, reliability, and liability concerns. Major issue areas include the potential for removal of protective cladding, reduction in the fatigue life of the vehicle, covering of fatigue cracks that would prevent their detection, and the promotion of stress cracks by the PMB itself.

Most military aircraft have aluminum cladding over metal to protect it from oxidation, which would lead to corrosion. If this protective coating were removed, the aircraft could be subject to increased corrosion. Tests conducted at Corpus Christi Army Depot indicated that walnut shells, which require three times the blast pressure of plastic media, removed more of the aluminum clad than did PMB (NCEL, 1986). Other studies suggest that PMB does remove some clad but that even after numerous cycles, the clad is degraded by only 25 to 50 percent. Hand sanding, which is sometimes done after chemical stripping, may actually remove more of the cladding than PMB (ADL, 1987).

Tests sponsored by the Corrosion Office at Warner Robins Air Force Base were designed to determine whether PMB shortened the fatigue life of aircraft. The tests showed that with aluminum sheet of 0.065-inch thickness, the fatigue life is reduced by less than 25 percent. With aluminum sheet of 0.030-inch thickness or less, significant fatigue life reduction of up to 90 percent can occur (ADL, 1987). Other tests showed fatigue life loss in thin aluminum sheet of 0.016- to 0.032-inch thickness; less damage was observed with increasing thickness (Battelle, 1987). Tests conducted at the North Island Materials Engineering Lab concluded that PMB did not damage low-alloy steels, corrosion resistant steels, or titanium (NCEL, 1986).

Tests conducted at Hill Air Force Base indicated that covering over of existing stress or fatigue cracks is not a problem except at very high blast pressures. However, tests conducted by the Materials Engineering Division at NARF Pensacola and NARF Jacksonville did lead to some crack closure on certain aluminum alloys (NCEL, 1986). As to the generation of stress cracks by PMB, tests performed at Warner Robins Air Force Base found that surface pits containing foreign metals or silica were produced after blasting with plastic media. The pits containing foreign matter can act as so-called stress risers, which can initiate cracks. Even when using virgin media, foreign contamination was found. Results of testing suggested that fatigue cracks were initiated at small surface craters, which were believed to be produced by contaminants in the media. The findings also indicated that PMB created stress that caused crack growth (Batelle, 1987). Proponents of PMB indicate that more serious stress risers are created with hand sanding (ADL, 1987).

Another major problem with PMB is dust intrusion into the aircraft interiors. In particular, intrusion into surface panel overlapping areas can cause stress, especially around rivets where fatigue cracks can propagate (Parrish, 1987). In the small aircraft commercial sector, several refinishers have reported serious dust intrusion into engine compartments and landing gear. To some extent, these problems can be solved by better masking of potential entry points. However, given the added risk of critical component failure (e.g., engine failure due to PMB pellet intrusion), most refinishers will probably continue to rely on chemical paint strippers.

The level of waste that is generated in the PMB process depends on several factors including the number of stripping operations, the amount of media used, the degree of recycling that is possible, the number of paint coats requiring removal, and the composition of the paint. At Hill Air Force Base, PMB stripping of each F-4 aircraft yielded 1,500 pounds of waste. On an annual basis, the stripping of 205 aircraft resulted in 307,500 pounds or about 140 MT of waste (NCEL, 1986). Although much of the media is recycled, this still represents a large amount of waste requiring disposal. This waste may be classified as hazardous if the stripped paint contains lead, chromium, and cadmium, which is often the case with paints used by the military and in transportation services.

With this in mind, the Air Force commissioned a study on ways to render hazardous PMB waste non-hazardous (Tapscott et al., 1988). The research involved collecting and analyzing PMB samples from various Air Force bases and then investigating different treatment methods. The findings suggested that incineration was possible but that siting was likely to be a barrier. Chemical treatment based on extraction was effective for chromium removal but not for cadmium or lead. Based on test work by Wolbach and McDonald (1987), concentrations of chromium, cadmium, and lead in PMB floor dust was 72 ppm, 16 ppm, and 64 ppm respectively. Initial levels in the virgin PMB were 5 ppm, 5 ppm, and less than 1 ppm.

Aqueous extraction to remove chromium would have the disadvantage of generating a liquid waste and the remaining PMB dust would still be classified as hazardous. Heating the PMB to high temperature to break-down and volatize the polymer would require an afterburner and additional air pollution controls. Encapsulation might require a permit and would increase the volume of waste. The study did not identify any especially promising techniques for reducing or eliminating the PMB waste. For facilities stripping paint that did not contain heavy metals, the waste could be disposed of as nonhazardous.

Sodium Bicarbonate

Sodium bicarbonate slurry blasting is an experimental technique that utilizes sodium bicarbonate as the abrasive media. Kelly Air Force Base has tried the technique for stripping paint from aircraft. The Base has put in a new PMB operation, but wanted to have an alternative process available for use. According to this user, the operating costs for PMB and the bicarbonate process are about the same. The PMB process requires 800 pounds per hour of abrasive whereas the bicarbonate process requires 150 to 200 pounds per hour. The total cost of the bicarbonate process tends to be lower because the process does not generate a large volume of hazardous waste. Stripped paint can be filtered from the slurry and the slurry can then be used to neutralize any acid waste generated elsewhere at the facility.

Although carbonate blasting is not as likely as PMB to mechanically damage the substrate, it does introduce the potential for long-term corrosion damage. Alkaline compounds left on the metal can cause corrosion or lead to failure of the adhesive bond between the metal and the paint. To overcome these problems, some firms are performing tests on the use of corrosion inhibitors added to the slurry. Depending on the corrosion inhibitors employed, the resulting slurry waste may then be classified as hazardous. To reduce or avoid potential problems associated with corrosion, one researcher is investigating the use of magnesium carbonate (Doscher, 1989).

Carbon Dioxide Pellets

Blasting of surfaces with carbon dioxide pellets was first proposed at Lockheed in California in 1969. In most of the systems, liquid carbon dioxide is maintained under pressure in a reservoir and is used to produce the pellets. The pellets of dry ice are then conveyed through the blasting nozzle using compressed air. Several firms (such as Del Crane Cryogenics, Alpheus, and Cold-Jet) are currently marketing carbon dioxide pellet blasting systems.

The use of carbon dioxide pellets to remove paint has several environmental advantages in that the stripping media is relatively safe, the only waste produced is the stripped paint, and the carbon dioxide used is mainly recovered from waste gas (hence emissions of carbon dioxide do not result in a net increase of global warming gases). On the negative side however, test work conducted by McDonnell Douglas has shown that the process suffers from slow stripping rates and that it can cause damage to aircraft skins and composite structures (Schmitz, 1991). Douglas is no longer considering the technology for paint removal from aircraft but is investigating its use as a cleaning method.

Wheat Starch Blasting

Work conducted by the Boeing Defense and Space Group has found that wheat starch blasting is effective at removing most organic coatings, produces no macroscopic damage to metal, and is more effective and forgiving than plastic media, sodium bicarbonate slurry, carbon dioxide pellets, or ice crystal blasting (Larson, 1991). The process has been used at several sites to remove Tedlar adhesively bonded to aluminum panels. Cleaning of the stripped aluminum prior to repainting can be performed with warm water plus surfactant. Alodined surfaces require reactivation prior to repainting. Boeing is currently working with United Airlines to determine the effect of the process on composite materials.

High Pressure Water Blasting

The Air Force Wright Laboratory and the Oklahoma City Air Logistics Center are investigating the use of an automated high pressure water system for stripping B-lB, B-52, C-135, and E-3 aircraft (See and Bennett, 1991). If successful, the system will reduce the need for METH-based strippers by 90 percent and reduce labor costs by 53 percent, material costs by 50 percent, and waste treatment and disposal costs by 75 percent. The process has been in use since 1986 on NASA’s Space Shuttle Program and has been demonstrated at several naval facilities for stripping paint from ships. Process validation work and refinement of the blasting nozzle design is currently underway.

3) Use of Thermal Technologies

Thermal methods such as flame burn-off are sometimes used to strip paint from large metal structures such as bridges. The method is highly labor intensive, results in emissions of burned paint that cannot be easily controlled, and typically results in a metal surface fouled by heat scale. This heat scale must subsequently be removed by abrasive methods such as sanding, wire or power brushing. Most thermal methods are limited to metal parts that will not distort or warp due to the heat. New thermal methods such as laser or flash lamp stripping avoid these problems by rapidly heating the surface layer of the coating only. These two methods are discussed below.

Laser Paint Stripping

The use of lasers for ablative material removal was first proposed in 1987. Although the removal mechanism is not known with certainty, it is postulated that removal is due to the breaking of the chemical bonds in the paint resin. This causes an instantaneous increase in the volume of the resin, which then causes the inorganic solids to be blown away from the surface (Allison and Rudness, 1987). An advantage of the laser system is that an adsorption frequency could be chosen to maximize paint removal and minimize substrate damage.

One group has performed research to determine the feasibility of using a pulsed laser for removing the polyurethane topcoat and the epoxy primer from a carbon fiber-epoxy composite. Four frequencies were tested: one was ineffective, two appeared to cause fiber damage, and the fourth one gave slow but adequate results (Allison and Rudness, 1987). Compared with PMB, laser stripping resulted in a cleaner surface.

Another group is investigating the use of a pulsed carbon dioxide laser for paint removal from aircraft (Lovoi, 1989). Laser pulsing is controlled by a computerized system that monitors color variation of the stripped surface. The technique has been successfully applied to a variety of coatings (polyurethane, epoxy primer, chemical agent resistance coatings, and polysulfide sealant) on a range of substrates (anodized aluminum, graphite epoxy composite, and glass reinforced plastic). As the coating material is removed, it is vacuumed up in a collection system and sent to a two stage waste processor. The waste processor separates the waste into particulate material and vapors. The particulates are filtered out and placed in a waste receptacle while the vapors are thermally oxidized.

High Intensity Light

This system utilizes a tubular quartz flash lamp filled with xenon gas at low pressure. A pulse of light is absorbed by the surface material, which may then sublime, pyrolyze, or chemically dissociate. A shock wave is caused by the reaction at the surface and a loud report occurs with each pulse of the flash lamp (Surfprep, undated). Residue left after stripping is a fine, black dust that can be wiped away with a rag. Because of the presence of heavy metals in the paint, this dust may be listed as hazardous.

Laboratory investigation of the technique was performed at McClellan Air Force Base using a 9-inch xenon arc flash lamp. Tests were conducted on an F-111 aircraft wing with an epoxy primer and an acrylic topcoat and on composites of graphite epoxy with a fiberglass outer layer coated with an epoxy primer and a polyurethane topcoat. The flash lamp was able to selectively strip 1 mil of paint at a time.

The group concluded that the flash lamp has the potential for field use. One problem that remains to be investigated is how the system can be used to strip coating from comers and other complex geometries. One solution would involve the use of a mobile arm fitted with quick disconnect adapters that could handle flash lamps of various shapes. The Base anticipates a 5-year savings of $1,660,000 from use of the flash lamp compared to use of chemical-based strippers.

3.2 IMMERSION STRIPPING

There are many source reduction options available for facilities engaged in immersion stripping. Immersion stripping may be performed on disassembled parts during maintenance, on rejected parts after painting, and on hooks, racks, and fixtures used during painting operations. A form of immersion stripping may also be performed on wooden furniture stripped by commercial refinishers. Since the use of an immersion stripper typically takes place in a shop, control of environmental factors is often more viable than in field stripping. The following options are investigated: use of alternative strippers such as abrasives or alternative chemicals, thermal burn-off methods, and improvement to the operations employing METH-based strippers.

Options not discussed include the recovery of METH from air streams and the recovery of METH from wastewater streams. The concentrations of METH in these streams vary widely which makes the design of reliable systems difficult. When comparing the cost of such systems to the amount of METH that could be recovered, it is very doubtful that METH recovery can be justified on economic grounds alone.

1) Strip Parts Only When Required

Several military facilities are adopting Inspect and Repair Only as Needed (IROAN) policies to cut down on waste generation. In the past, vehicles would be routinely disassembled, stripped, inspected, repaired (if necessary), repainted, and reassembled. The new policy now calls for disassembly and inspection followed by stripping only if the part shows signs of damage or corrosion. One facility reported that 90 percent of the parts being stripped did not actually require stripping. In the case of stripping to salvage a part that is improperly painted, this option would not apply.

2) **Train Painters and Establish Application Standards**

By reducing the number of rejects from a paint application line, the need for and use of paint stripper will also be reduced. Viable ways include training of painters, setting of proper quality standards in terms of applied coating thickness and cure times, maintenance of paint spray equipment, et cetera. While the major benefit of this option will be in reduced paint consumption and labor for rework, it will also result in reduced paint stripping waste. This option would not apply to maintenance stripping.

3) **Use of Abrasive Techniques**

Many military facilities have reduced their reliance on METH-based immersion strippers by using plastic media blasting (PMB) systems. Blast cabinets or so-called glove boxes can be used to remove paint from small parts. Larger components may be stripped inside an automated blasting chamber. In both systems, safety equipment is not required because the operator remains outside the cabinet. The media is fed into the cabinet or chamber and directed against the part being stripped. Used media and paint waste are then pneumatically conveyed from the blast area to the reclaimer. Reusable media is separated from the waste and fines are collected in a dust collector. Other abrasive materials such as glass beads, sand, and steel shot are also in use.

4) **Use of Thermal Techniques**

Bum-off ovens and molten salt baths are often 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 with water. Use of thermal technologies has been limited in the area of parts stripping due to the high temperatures involved, which often lead to distortion of the part and formation of heat scale. However, thermal technologies are finding use in some part stripping applications. Two technologies, fluidized bed stripping and molten salt bath stripping, are discussed below.

Fluidized Bed Stripping

This method employs a heated fluidized bed to remove coating systems and is available from such companies as Dinamec, under the name “Fluid Clean.” The Dinamec system consists of a tank containing quartz sand or aluminum oxide. An air stream is blown into the tank to fluidize the sand mass. Natural gas is mixed with the primary air stream and ignited above the surface of the bed. The normal operating temperature. is approximately 800^0F, but can be adjusted for specific applications via a temperature controller.

Plastic or paint coated components are lowered into the bed in a basket. Organic materials on the parts are vaporized in the fluidized sand mass. The resulting gases and uncombusted gas/air mixture are burned in a post-combustion chamber, located above the surface of the fluidized bed, by an after-burner system. The exhaust from the after-burner passes through a wet scrubber to remove solids prior to discharge to atmosphere. The Red River Army facility in Texas is currently testing a fluidized bed stripping system. This method has proved successful for steel parts, but cannot be used on aluminum due to the high temperatures involved (Jackson, 1991).

Molten Salt Bath

Molten salt baths operating at 900°F have been used for many years to strip heavy accumulations of paint. However, the high temperature involved precludes the stripping of many components, such as sheet metal stampings, because of potential heat distortion. When new salt baths with lower melting points, lower viscosities, and operating ranges between 500°F and 700°F were developed, problems with warpage and distortion were significantly reduced. The lower temperature process was first applied to steel components, but use in stripping organic coatings from aluminum substrates quickly followed.

Typical process equipment for molten salt stripping consists of a salt bath furnace, water rinse tank, acid tank, second water rinse tank, and a sludge receiving station. All of these items are enclosed in a protective steel enclosure. There are entry and exit doors at each end and operator viewing windows at each station. A slot down the center of the enclosure allows for overhead hoist access.

The work load is engaged by an overhead hoist, moved through the entrance door of the unit and lowered into the salt bath. On completion of the stripping process, the components are raised from the bath, allowed to drain, and then transferred to the first rinse tank, where they are immediately immersed in water at ambient temperature. Here the part cools and the salt on the surface is dissolved. The actual procedure for stripping aluminum parts will then usually include immersion in a dilute organic acid solution for neutralization, prior to final rinsing. Reaction between organic coatings and molten salts creates a residue or sludge consisting of paint pigments and fillers along with used or reacted salt. This residue has a higher density than the salt, and settles to the bottom of the bath.

There are two potential disadvantages in using molten salt baths for stripping aluminum components. First, when aluminum stampings are run through a salt bath at 600^0F, a degree of metallurgical change takes place. This is primarily in the form of relieving stresses created in forming the part. If the stripping time exceeds 60 seconds, parts may be softened or distorted sufficiently to affect end use. Second, a potential problem may arise if salt becomes trapped or has solidified in an area that allows only limited or no entry of rinsewater. This salt can result in later “bleed-out” and corrosion.

5) Use of Cryogenic Techniques

Cryogenic techniques have been used to remove paint from body carriers, hooks, fixtures, and racks. Such items are placed in a specially designed cryogenic chamber and either sprayed with liquid nitrogen or immersed in a nitrogen bath for several minutes. The cryogenic temperatures create large stresses between the substrate and the coating due to differences in the degree of contraction. Steel contracts about 1 percent when its temperature is reduced from 293 degrees K to 173 degrees K while a powder coating will contract by 6 percent (IF, 1986). The difference in contraction between the substrate and coating causes hairline fractures in the coating.

To subsequently remove still cold, brittle and highly stressed coating, it is bombarded with high-velocity plastic media which causes cracking and debonding. In another system, the parts are placed in a vibratory trough after immersion in the nitrogen. The parts knock into each other and the coating flakes off. The plastic media method is best suited for large parts whereas smaller parts can be effectively stripped in the vibratory trough.

Cryogenic stripping of paint hangers and racks coated with baked on acrylic is performed at a Whirlpool plant in Ohio. This plant produces 1,200 ranges and 2,000 dishwashers a day and has an inventory of 13,000 racks and hangers. Based on this workload, 375 racks and hangers require stripping each day. The chamber is operated at -130 degrees F. The media used for abrasion is recycled and the paint chips are drummed and disposed of (presumably as hazardous waste). The nitrogen gas is exhausted to the atmosphere. The cost of the stripping operation is reported to be $0.54 per hanger stripped (IF, 1985).

For small sized units, an installed cost for a 6-cubic-foot tumbler is estimated to be $30,000 while a 25-cubic-foot tumbler would cost $50,000. For a cryogenic chamber capable of handling large parts, the total cost would range from $250,000 to $300,000. These costs do not include the cost for nitrogen storage. Nitrogen is currently priced at 6 cents per pound and typical consumption rates are one-half pound of nitrogen per pound of parts. The cost for media is $3.00 to $3.50 per pound.

While this method appears viable, there are some limitations to its widespread use. Auryd, acrylic, polyester, vinyl, and lacquer coatings have been removed successfully, but epoxy and urethane coats are difficult to remove. For these coatings, lower nitrogen temperatures in the -250 degrees F range are required. Furthermore, coatings thicker than 0.01 inches are effectively removed whereas thicknesses less than 0.01 inches are not (IF, 1984). This means that the method is best suited for stripping heavy accumulations of paint from items such as hooks and racks as opposed to thin coatings on finished goods.

In addition to paint type and coating thickness limitations, large bulky parts cannot be stripped. The weight of parts in the chamber is limited to 400 pounds per cycle. There are also two safety concerns with this process: the inert character of the nitrogen and the extremely low temperatures. To prevent oxygen depletion, the spent nitrogen must be exhausted from the chamber and be safely vented outside. Workers must wear protective gloves when unloading the parts though the parts can be safely handled several minutes after removal from the chamber.

6) **Use of Biodegradation**

This technique is still in the research phase and is being investigated at Hill Air Force Base (Hedberg, 1989). The Base has completed two preliminary studies of the applicability of the method. In the first approach, microorganisms were grown, which were able to use polyurethane based paint as a nutrient. While the organisms could degrade the paint, the rate of degradation was very slow; the organisms required 4 to 5 weeks. Work is in progress to isolate the enzyme responsible for degradation with the hopes that use of the enzyme will significantly speed up the process.

The second approach to this project is to reformulate the paint so that it is more readily biodegradable. One way to achieve this is to add cellulose and elastin to the paint. A disadvantage of this approach would be that the use of biodegradable paints may increase the need for stripping and repainting due to their reduced effectiveness of protecting vehicles in the field. Both approaches, however, are still in the research phase and are unlikely to have practical application for some years.

7) **Use of Alkaline or Acidic Strippers**

Alkaline strippers based on caustic have been used for many years and are common in industry. They are typically heated and maintained at a caustic concentration of 1 to 3 pounds per gallon. Generally, the alkaline strippers cannot remove pigments completely and a residue is left on the parts. Alkaline strippers can attack some metals such as aluminum but they are commonly used on steel.

In the case of oil-based paints or alkyds, stripping is effected by the saponification of the fatty acid component of the vehicle. With cellulosics, stripping is due to the breakage of the ester linkages (Sizelove, 1972). Alkaline strippers are also effective on gum varnishes and phenolics (Mallarnee, undated), but they are not effective on epoxies. Additives such as sequestering agents, surfactants, and activators are included in most stripper formulations to improve their effectiveness.

Acidic strippers are less commonly used and they tend to attack metal. They should not be allowed to contact high-strength steel (Hans, 1980). These strippers work by oxidizing or dehydrating the paint vehicle and inhibitors must be used to prevent metal attack. Solvents such as alcohols and glycol ethers are sometimes added to the formulation to make the strippers easier to work with and more easily inhibited for metal attack (Sizelove, 1972). Nitric acid can be used to strip off tough, hard coatings and it can effectively remove epoxy coatings. Heated phosphoric acid can be used to strip aluminum and zinc based parts.

Both alkaline and acidic strippers are most appropriate for immersion type applications because they must be heated to be effective. They are not appropriate for paint booth cleaning, line and gun cleaning, or floor cleaning, though they could be used for stripping rejected parts and paint hooks. Alkaline strippers have been used to clean the grates from paint booths in automobile plants (ICF, 1988).

8) **Use of Alternative Solvents**

Many new strippers based on N-methyl-2-pyrollidone (NMP) and dibasic esters (DBE) have come onto the market in recent years. These strippers have found use in the areas of paint application equipment cleanup and the consumer market. They have not found wide-spread use in the area of immersion stripping because they are less effective in removing fully cured high performance paints than the METH formulations currently in use. Many of the substitutes also suffer from one or more of the following disadvantages:

- increased stripping time required
- flammable or combustible
- require elevated temperature to be effective
- contain compounds with unknown long term health and environmental effects
- photochemically reactive.

Therefore, direct substitution for METH-based stripping agents is not a clear cut issue. Due to the interest in finding a substitute for METH, several test programs have been initiated. The conchtsions and test results of three such programs are described below.

Carltech Associates, Inc.

In 1986, Carltech Associates Inc. conducted a study for the USEPA to survey commercially available paint stripping formulations and to identify those whose use would result in lower toxic organic loading (as defined by 40 CFR 413) on wastewater treatment systems while not decreasing the effectiveness or efficiency of the stripping operation (Carltech, 1986). Testing was performed on two substrates (aluminum and steel), three primers (zinc chromate, epoxy, and water reducible), and three top coats (enamel, epoxy, and polyamide).

Following testing, Carltech concluded that of all the commercially available strippers tested, only those based on METH, phenol, and an organic acid effectively removed the top coat from each paint system within a submersion time of 20 minutes. However, it was concluded that NMP exhibited some potential as a basic ingredient for new formulations. NMP was found to be effective in removing enamel paint from an aluminum substrate but was generally ineffective on polyamides.

U.S. Army Toxic and Hazardous Material Agency

The U.S. Army Toxic and Hazardous Material Agency (USATHAMA) is in the process of completing a three-phase study of METH substitutes for paint stripping. The study includes laboratory scale testing, pilot scale testing, and production line testing. Prior to the first phase, 30 commercially available, non-METH-based strippers were identified. Each stripper was then immersion tested in a laboratory environment using test coupons coated with a variety of typical paint systems. Strippers were considered successful if they could remove the coating within 2 hours.

Six of the strippers tested were successful and they were advanced on to the second phase of testing. Tests on a pilot scale using actual parts were conducted at the Sacramento Army Depot. Three strippers were successful in these tests and are currently being evaluated in production line stripping tanks. In the production tests, Oakite ALM became ineffective after six months and did not remove Chemical Agent Resistant Coating (CARC). Fine Organic 606 and Turco 5668 could not remove epoxy paint. All three strippers suffered from high evaporation rates and no clear conclusions emerged from this study (Jackson, 1991).

Idaho National Engineering Laboratory

The Idaho National Engineering Laboratory (INEL) is currently investigating the use of alternative paint strippers for the U.S. Department of Defense and the Department of Energy. Eleven commercial strippers are being tested on seven different paint systems. Corrosion testing is also being performed on seven different metal substrates. Typical constituents of these new strippers include ethanolamine, NMP, glycol phenyl ethers, and various hydrocarbons. Preliminary conclusions are that none of the brush-on strippers have passed screening, corrosion rates are comparable to controls, biodegradation of spent products has not been established, and all alternative strippers contain components with some level of toxicity (Propp, 1991).

9) Use of Reduced METH Content Strippers

In the Carltech study mentioned above, it was reported that the total toxic organic loading in the wastewater from stripping operations could be lowered significantly by reducing the METH content of the stripper. Of the METH-based strippers tested, Enthone S-26 was specifically formulated to be diluted with water. Enthone S-26 contains a small amount of proprietary emulsifying agent to facilitate the mixing of water with METH. Recommended dilution ratios range from 1 part stripper to 4 parts water up to 20 parts water. Varying the dilution rate controls the aggressiveness of the stripping action and is determined by trial and error in the shop. While use of this option may reduce METH loss due to drag-out and rinsing of the parts, it is not known what effect this option would have on longevity of the stripping bath and on subsequent wastewater treatment and stripper disposal due to the presence of surfactant.

10) Operational Improvements to Stripping Operation

Minor, low-cost operational improvements can do much to reduce the generation of METH-based stripper waste and the loss of stripper to the environment. Viable methods include maintaining a water blanket on top of the stripper at all times, improving the methods of racking to increase drainage, increasing drainage times, installing drainage collectors, monitoring the condition of the water blanket for acid formation, and converting free running rinses to still or fog spray rinses. Each of these options is discussed below.

Maintain Water Blanket and Cover

Immersion stripping is often performed in tanks that are identical to tanks used for cold cleaning. To prevent excessive evaporation of the METH, the stripper is often covered with a layer of water or water blanket. The use of water as a floating cover is feasible since the water is relatively insoluble in METH and is less dense. This water blanket also serves as an initial rinse, reducing the drag-out of stripper. Since METH will diffuse through the water blanket and evaporate, a solid cover should be placed over the tank when not in use. In addition to suppressing emissions, the cover prevents parts from accidentally falling into the tank and reduces contamination of the bath due to airborne dust and dirt.

Improve Racking Practice

For parts with complex shapes, a significant quantity of stripping solution can be dragged out from the stripping tank in recesses and cavities. Parts should be racked or placed in the basket in such a manner to promote drainage. By following proper racking practices, drag-out can be reduced by 50 to 90 percent (Dumey, 1984). The position of any object that will minimize drag-out is best determined by experiment, although the following guidelines have been found effective:

- Orient surfaces as close to vertical as possible
- Do not rack parts directly over one another
- Rack parts with their lower edge tilted from the horizontal, so that the run-off is from a corner rather than an entire edge
- Ensure that all cavities and recessed pockets are oriented downward

The design of the baskets used for holding the components can be reviewed, with the objective of minimizing wetted surface area. It may also be possible ***to*** modify existing baskets by adding internal supports that facilitate good drainage.

Using the correct size of basket for the required parts load is also important at minimizing drag-out. Using partially filled baskets needlessly increases the surface area that must drain. For this reason, small baskets of parts should be stripped individually, and not be placed into a larger basket for handling. Other opportunities to reduce drag-out include plugging the ends of tubing or hollow parts with suitable caps, and not using porous materials such as multifilament ropes to hold parts.

Increase Part Drainage Time

By increasing the amount of drainage time over the stripping tank, drag-out can be further reduced. Increased holding times over the stripping tank should be specified in Standard Operating Procedures, and all operators should be trained to follow these instructions during the chemical stripping operation. One study reports that drag-out can be reduced by over 60 percent by allowing a minimum of 10 seconds drainage time (Meltzer, 1989). Increasing the drainage time from 5 to 15 seconds can result in a 50 percent reduction in the volume of solution carried out of the tank on flat vertical surfaces.

Therefore, if improvedracking methods, described above, produce a 50 percent reduction in drag-out, and increased drainage time reduces the dragged-out material by 50 percent, then the total reduction in drag-out will be 75 percent. However, if the drainage time is extended to an overly long time period, then the residual material clinging to the substrate becomes more difficult to remove as methylene chloride evaporates and solution viscosity increases. Also, it may be difficult for large items such as electronic equipment housings to drain properly, consequently reducing the potential benefit.

Install Drainage Collectors

In order to collect dripping stripper liquid as the parts are transferred to the rinse tank, a drag-out drainage collector could be positioned between the stripping tank and the rinse tank. This drainage collector would consist of a plate connecting the two tanks, and be sloped to drain back into the stripping tank Drag-out from the stripping tank, which otherwise would drip onto the floor during transfer, would be collected on the drainage collector, and recycled back to the stripping tank.

Control pH of Water Blanket

This option addresses the potential problem of methylene chloride break-down to hydrochloric acid. This can result in increased etching and corrosion of some parts, and hence, the increased need for water blanket change-out. Controlling the pH allows the continued use of blanket water for a longer period of time. Buffer salts, such as disodium phosphate (Na^2HP0^4), can be employed to maintain the pH. Strong alkalies, such as sodium hydroxide (NaOH), should not be used since this would lead to degradation of the METH. Before implementing pH control, tests should be performed to determine the allowable level of salt build-up in the water.

Convert Rinse Tanks to Still or Fog Spray Station

The effluent produced in the rinse tank consists of METH and phenols dragged out of the stripping tank, paint residue, and rinse water. One method to reduce the amount of waste rinsewater generated is to convert free running rinses to still rinses. Additional reductions can be achieved by converting still rinses to fog spray stations. Stripped parts, after draining, would be placed over the empty still rinse tank and sprayed clean with fog nozzles. Fog nozzles produce a very fine spray of water and are very efficient at rinsing with a minimum volume of water. Since the parts are always sprayed with clean water, the need for floor flushing could be reduced or eliminated.

Spray rinsing typically uses from one-eighth to one-fourth the amount of water required for immersion rinsing. Typically, in such systems, spray or fog nozzles are mounted around the perimeter of the rinse tank, at various orientations, to direct the spray on to the components. The spray water would be continuously removed from the tank for treatment either on site or off site. A manual fog rinsing lance could be utilized only for areas not cleaned by the fixed spray system (i.e., recesses and cavities). The disadvantages of manual spray rinsing include increased labor cost and increased potential of worker exposure. Protective clothing and a respirator may be required.

11) **Filter Stripping Solution**

METH-based strippers work by breaking the adhesive- bond between paint and substrate without the use of heat. An advantage of using a cold stripper is that it remains active regardless of the volume of paint stripped. Slow-down in stripping rate is usually due to a build-up of solids, which reduces the degree of contact between the stripper and the paint. When the decrease in stripping rate indicates the need for replacement, many industrial facilities reclaim the stripper by straining it through a screen or filter. Removal of paint sludge can be accomplished by adding a small pump and bag filter to the stripping tank in order to clean the stripper bath, either continuously or on an intermittent basis. This would result in maintaining the stripper performance at the maximum possible level, and would also reduce the amount of sludge requiring disposal. Paint remaining in the tank slowly absorbs stripper and therefore increases in volume. The disadvantage of a filtering system is the potential for operator exposure to METH and paint sludge during clean-out.

12) **Recycling of Spent Stripper**

Other than the filtration of stripper to prolong its use, recycling of spent stripper by means of distillation or other technology is seldom practiced. Most formulated strippers are a complex mixture of METH and acids that do not lend themselves to easy separation, recovery, and reuse. Even if the METH was recoverable, it would still have to be formulated back into a viable product and all of the non-recoverable components disposed of as hazardous waste. The only way recycling of paint stripper would be readily viable would be if the facility was using pure METH for stripping. This practice is not common for immersion stripping but is common in the area of paint application equipment cleanup.

3.3 PAINT APPLICATION EQUIPMENT CLEAN-UP

While many of the options discussed for reducing the use of METH-based stripper in field and immersion stripping apply to cleanup of paint application equipment, there are some differences in these operations. First, the type of paint being stripped is more consistent than in maintenance operations where a wide variety of coatings might be encountered. Next, the paint being stripped or removed is often uncured. This allows for a wider variety of effective stripping agents to be used. The following options discuss the use of alternative solvents, non-chemical based stripping technologies, and ways to reduce the need for stripper.

1) **Use of Alternative Solvents**

There is a range of solvent-based paint strippers on the market today or in the research phase that could serve as alternatives to METH. Several of these are discussed in the following sections and include N-Methyl-2-Pyrrolidone (NMP), Dibasic Ester (DBE), Furfuryl Alcohol, Alkyl Acetates, and conventional paint thinners. These are described below.

N-Methyl-2-Pyrrolidone

NMP is manufactured by GAF Chemicals Corporation and BASF Chemicals Corporation. Compared to METH, it is slower acting but is also less volatile. The low volatility results in low levels of air emissions and allows more of the stripper to remain on the substrate than with METH. Industry sources claim that 1 gallon of stripper containing 70 to 90 percent METH can be replaced with half a gallon of stripper containing 25 to 40 percent NMP. Therefore, four to six times as much METH must be used to strip the same amount of surface as with NMP.

For stripping uncured paint, manufacturers of NMP claim that stripping times are equivalent to those for METH. For the stripping of paint booth walls, NMP formulations can remove paint in 20 minutes; it takes only 3 to 5 minutes to remove paint from spray guns. Responses to the USEPA questionnaires by the auto industry indicate that stripping of booth walls with METH-based formulations requires 10 minutes to 1 hour. Therefore, use of NMP stripper should be viable.

For stripping cured paint, NMP-based formulations take much longer to work. In tests conducted by one manufacturer, it took 24 minutes for three applications of a METH-based stripper to remove four coats of alkyd paint. It took 66 minutes for two applications of NMP stripper to remove the same four coats. Cured paint is commonly encountered in floor stripping and immersion stripping of rejected parts. The longer stripping time for NMP may not present a problem for most facilities because stripping of floors and rejected parts is commonly done overnight when the production line is shut down.

NMP-based formulations are about five times the cost of a METH formulation, about $40 per gallon. Since less NMP is required, however, the net cost of using NMP strippers may be roughly the same. While NMP could be recycled to reduce costs, very few recyclers presently have this capability. To recover the NMP, vacuum distillation equipment would be required.

NMP is combustible; it has a closed cup flash point of 199 degrees F. In terms of worker exposure, NMP manufacturers recommend an internal Threshold Limit Value (TLV) of 100 ppm. This is lower than the current workplace exposure level of 500 ppm for METH set by OSHA. However, OSHA is expected to lower the level for METH to 50 or 25 ppm in the near future. While NMP is biodegradable, it has not been tested for chronic toxicity.

Dibasic Esters

The dibasic esters (DBE) are a mixture of methyl esters of adipic, glutaric, and succinic acid produced by DuPont (DuPont, undated). It is typically composed of 17 percent dimethyl adipate, 66 percent dimethyl glutarate, and 17 percent dimethyl succinate. Unlike METH, which swells the coating and lifts it from the surface by bubbling, DBE strippers only soften the coating and do not cause it to lift or bubble.

For spray booth cleaning, one recommended formulation consists of 40 weight percent DBE, 15 percent NMP, 35 to 38 percent aromatic 150 solvent, 2 percent monoethanolamine, 4 percent potassium oleate, and 1 to 4 percent thickener (Lucas, 1988). The mixture of DBE and NMP allows the stripper to remove a wider variety of paints than either solvent could alone. Immersion stripper formulation includes 100 percent DBE; 60 percent DBE and 40 percent NMP; and 60 percent DBE and 40 percent ethyl 3-ethoxypropionate (EEP). As with most strippers, these formulations give better results with increased temperature; 95 to 100°F appears to be optimum. Line purging and gun cleaning can best be accomplished with 100 percent DBE (Lucas, 1988). Compared to METH, DBE formulations take two to three times longer to perform an equivalent amount of stripping (ICF, 1988).

Like NMP, DBE is not exempt from VOC regulations. Because it is not especially volatile, however, air emissions are likely to be low and its low volatility allows more of it to remain on the surface longer than does METH. This results in less stripper being required for a particular operation. DBE is also biodegradable and like NMP, could be recycled using a vacuum still. DBE has not been tested for chronic toxicity.

Furfuryl Alcohol

Furfuryl alcohol based formulations are blended by CLM Company, Nalco, and Charles J. Haas. One source estimates that it is used to perform 20 to 30 percent of all booth stripping today in the automotive industry but it is not used for line purging. Furfuryl alcohol formulations have relatively low flash points ranging from 105 degrees F to 150 degrees F making them a fire hazard. This is probably not a problem at most automotive plants since they are generally equipped with explosion proof equipment.

The Short-Term Exposure Level (STEL) to furfuryl alcohol for skin is 15 ppm and the Time Weighted Average (TWA) is 10 ppm. It is an eye sensitizer but generally because of the high ventilation rates inside the spray booths, concentrations tend to be low. The substance is considered to be a contributor to photochemical smog formation.

Furfuryl alcohol formulations generally contain 20 to 30 percent of the chemical, naphtha or petroleum solvents, and various other ingredients (ICF, 1988). The cost of these formulations ranges between $7.50 and $10 per gallon, which can be compared with an NMP price of $40 per gallon. One plant using the formulation indicates that about 20 percent more furfuryl alcohol formulation is required than METH-based formulations.

Alkyl Acetates

The primary market for alkyl acetates is as solvents in paint but they are also being marketed for paint stripping, paint booth cleaning, line purging, and gun cleaning. Alkyl acetates are slower acting than METH-based strippers and their flash points range from 134 to 200°F. Exxon, the manufacturer of alkyl acetates, has internally set a worker exposure level of 50 ppm. Like the other heavy hydrocarbons, they are not exempt as smog contributors and they have not been tested for chronic toxicity.

Paint Thinners

Many of the auto plants have switched their booth, gun, and line cleaning operations from METH to paint thinners such as methyl ethyl ketone (MEK), acetone, methyl alcohol, ethyl alcohol, toluene, xylene, or mineral spirits. While baked phenolic paints such as acrylics and alkyd epoxy are not soluble in these thinners, most cleaning involves the removal of uncured paint. In addition to uncured acrylics and epoxies, paint thinner can be used to cleanup air dried paints and lacquers.

2) Use of Strippable Coatings or Covers for Booth Walls

Coatings that can be stripped or peeled from the walls of booths are available. The coatings are sprayed on surfaces and when the over-spray is accumulated, they are stripped or peeled off and replaced. The frequency of disposal depends on the over-spray accumulation and can vary from once a month to once every 6 months. Such coatings are not especially applicable to the automobile industry because the booths must be stripped once a day and it would be impractical to apply and strip off the coatings so frequently. They are widely used in other industrial sectors or where cleaning requirements are not so frequent. Alternatively, a number of spray booth operators have started using disposable paper or plastic covers which are replaced after each painting campaign, dried, and disposed of as either hazardous or non-hazardous waste depending on the presence of heavy metals in the paint pigment.

3) Use of High Pressure Water Sprays

Water blasting by means of high pressure hoses can be employed to remove uncured paint from the walls and grates of paint booths. One automobile plant in California uses this technique. While this method eliminates all use of chemicals for stripping and reduces worker exposure to METH, it does introduce a new hazard into the paint booth. High pressure water sprays can seriously injure a worker if all of the proper precautions are not taken. A safer, highly automated blasting system can be used to strip paint from paint hooks and removable floor grates.

4) Rigid Inventory Control of Cleaning Solvent

There are many ways in which the indiscriminate use of solvent can be reduced. Interviews with paint spray booth operators indicate that many operators are not watchful of the amount of solvent they use for cleaning. Studies in the automotive refinishing industry have shown that rigid inventory control can reduce solvent waste generation rates by 50 to 75 percent (CDHS 1987). Control measures included sign-out for supplies, use of low volume cleaning techniques and equipment such as enclosed cleaning stations, and reuse of decanted thinner.

One way operators can reduce their solvent use is by not using the fill and dump method for cleaning spray cups and pressure pots. This practice involves filling the cup or pot with solvent, stirring until the paint dissolves, and then dumping the waste into a dirty thinner container. Depending on the care taken to stir and mix the contents of the cup or pot, repeated cleanings are often necessary.

To reduce solvent use, paint cups should first be drained and then wiped or scraped free of residual paint by using a soft wood or plastic spatula. The cup should then be rinsed with a small amount of solvent and wiped clean with a lint-free rag. To promote the reuse of thinner, paint sludge initially removed from the cup should be placed in a waste drum for sludge and the thinner rinse stored in a separate container. By not loading the thinner with solids, it can be decanted and reused for cleaning several times.

5) Use of Easy to Clean Equipment

To reduce solvent used for cleaning, the use of non-stick Teflon-lined spray cups may be a viable option- Teflon linings promote drainage and hence reduce the amount of paint remaining inside the drained cup. The cost for a standard l-quart suction cup runs about $34 compared to $43 for a Teflon-lined cup. Test work would need to be performed to calculate the potential savings and cost-effectiveness of this option.

The use of disposable paint spray cups might be another option for reducing the amount of solvent cleaning waste generated. These cups are made of translucent, 100-mil polyethylene and cost less than $3 each. When new, very little paint sticks to the inside of the cup. Cleaning can be performed by draining and wiping. As the cup gets more difficult to clean (i.e., each cleaning requires the use of more solvent), it can instead be disposed of. For the cleaning of pressure pots, use of disposable polyethylene bags or liners is an option.

6) Use of an Enclosed Cleaning Station

To cut down on air emissions and promote recycling, the use of an enclosed cleaning station is often required by local regulations. These units are designed to mount on top of a 55-gallon drum and they contain an air-driven, solvent condensing unit. To use the unit, the operator pours some clean solvent into the spray cup or pressure pot, locks the spray gun into the receiving hole of the unit, and then triggers the gun on. Solvent vapors enter the condensing unit where they are condensed and returned to the drum. Provided that operators are careful not to introduce too much paint sludge into the drum (sludge should be stored in another drum), relatively clean solvent can be decanted from the drum for reuse.

Several companies, such as Safety Kleen and Safeway Chemicals, offer the equipment and solvent recycling service. Both cleaning solvent and enclosed gun cleaning station are leased to the facility for use. When dirty, the solvent is picked up for processing and the system refilled with fresh or recycled solvent. Several paint supply companies also offer this service.

7) Install On-Site Recycling Equipment

For facilities using pure METH to clean their paint application equipment, on-site recycling may be a viable option. Depending on the quantity of waste generated, small batch units may be practical. Units capable of processing 5 to 15 gallons per batch tend to cost less than $5,000. For a larger system capable of processing 55 gallons per batch, the total installed cost would be on the order of $35,000 to $40,000. Depending on where the facility is located, permits may be required. This cost has not been included.

3.4 CONSUMER STRIPPING

The source reduction options that apply to field stripping by the consumer sector are primarily limited to chemical substitutes. Abrasive stripping and thermal stripping have limited applicability for widely replacing the use of chemical based strippers. The major concerns over increased use of these methods are potential damage to the wood items being stripped and consumer safety. Options that apply to immersion or shop stripping of furniture by commercial refinishers were discussed in the previous section.

1) Use of Alternative Solvents

A new product containing DBE, called Safest Stripper, has recently been put on the market (3M, 1988). It is a water-based product and is used in paste form. Because Safest Stripper is water-based, some raising of the wood grain may occur during stripping. To restore a smooth surface, the wood must be sanded. Clean-up of the work area and stripping tools can be accomplished by rinsing off with water. Clean-up of equipment used in METH-based stripping often requires the use of solvent.

An advantage of DBE-based strippers over METH-based strippers is that DBE is less volatile and the stripper therefore retains its effectiveness for a longer period of time. Safest Stripper maintains its paste form for at least 10 hours. The disadvantage to DBE-based strippers is that they work more slowly. Depending on the thickness of paint being removed, several applications of stripper may be required. This would increase the amount of stripper used and increase stripping costs since the price for DBE-based strippers and METH-based strippers are equivalent on a per gallon basis.

Strippers based on acetone, methanol, methyl ethyl ketone, or other hydrocarbon solvents have a small share of the market today. The primary application of such strippers is for removing clear coatings such as shellacs, varnishes, or lacquers from flat surfaces. One source claims that these strippers can be used to remove polyurethane and some alkyd coatings (ICF, 1988). Given the limited range of application and the potential hazard of using these flammable solvents, it is likely that their market share will remain small.

2) Use of Thermal and Abrasive Technologies

In the consumer market, thermal and abrasive methods are often used to remove the heavy build-up of paint on building exteriors. Blow torches are sometimes used to heat and blister the paint. This would then be followed by scraping, wire brushing, and sanding. Compared to chemical based stripping, thermal methods tend to be more hazardous since workers may be exposed to volatized paint pigments (which may contain lead if the building is old). Another hazard is the potential for wall fires, which sometimes occur if the flames shoot under the siding. Given these potential hazards, the increased use of these methods to replace METH-based stripper use is unlikely.

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4.0 ANALYSIS OF SOURCE REDUCTION OPTIONS

It is difficult to present an analysis of a source reduction option that would have wide ranging application to the industry as a whole. Paint stripping activities can be classified into one of three industrial sectors (OEM, Maintenance, and Consumer) and each sector can be further divided into two or more subsectors. Each sector consumes ***a*** sizable portion of the METH used, and no one sector dominates. Therefore, the usefulness in developing and presenting a detailed analysis for a given option would only be of interest to a limited few. Therefore, detailed economic analysis for one or two representative options is not provided.

Instead, some of the issues affecting the development of a complete and valid analysis are presented. SRRP staff review of available reference sources indicates that many of the economic evaluations presented to date are not definitive and cannot be used to assess the true and total cost of implementing an option. Quite often, the requirements for ancillary facilities are either overlooked or taken for granted to be existing. An example would be the use of cryogenic stripping, which requires the use of liquid nitrogen. For facilities without liquid nitrogen storage, the costs associated with a storage and handling system must be included for the analysis to be representative.

In the military and commercial aviation sector, the use of plastic media blasting has been touted as a cost effective substitute for chemical based stripping. While many articles have been written about the economic benefits of this process, other articles regarding the other abrasive techniques such as sodium carbonate, wheat starch, carbon dioxide pellets, and high pressure water blasting have pointed out that these estimates were optimistic. Electrical power required to operate the media recovery system and the cost for disposing of the spent media as hazardous were often excluded. In PMB’s defense, many of the cost estimates presented for these other techniques were equally lacking in scope and definition.

There are several reasons why the presented economic analyses tend to exclude or overlook certain costs. With any new technology, one tends to focus on the cost of the major items and generalize the cost of any ancillary support services. Initial cost estimates tend to be order of magnitude (i.e., with accuracy of 30 to 50 percent) and subject to revision. Until several systems have been built and operated, many of the assumptions regarding conditions that will be encountered in the field have to be based on little or no available information. For most state-of-the-art technologies, development of reasonable installation and start-up costs tend to be more art than science.

Another reason for certain cost exclusions may be due to the way in which military budgets are developed (capital and operating costs often come from several different budgets or sources of funding). If so, then the reported costs may be valid for the host facilities but would be incomplete for someone operating in the private sector. Costs other than power and waste disposable that are sometimes ignored include ancillary material handling equipment, worker training, equipment maintenance, and permitting.

In the area of cost savings, most analyses account for savings in METH-based stripper purchases and disposal of drummed METH waste, but fail to account for potential air emission fees. Most cost analyses were performed before METH came under heavy regulation as an air toxic. In California, the Air Resources Board has declared METH to be an air toxic and will promulgate stringent emission standards over the next few years. The South Coast Air Quality Management District has proposed a fee on METH emissions of $1.20 per pound. This will effectively double the cost of using METH-based strippers.

Depending on the nature of the operations conducted at the facility, another cost savings for eliminating the use of METH-based strippers may be in the area of wastewater pretreatment. Quite often, wastewater containing METH is air stripped before entering the treatment system. Operation and maintenance costs for air stripping systems can be quite high depending on the design and age of the system. If eliminating the use of METH allows the air stripper to be shut-down and by-passed, additional cost savings will result. Saving will be even greater if the continued use of METH forces the facility to install air emission controls on the air stripper.

5.0 ESTIMATION OF SOURCE REDUCTION POTENTIAL

A standardized methodology was devised to determine ranges of source reduction potential for each option and industry. The use of ranges, as opposed to fixed values, was deemed more appropriate since the surveys conducted in this study, and from which the range estimates are derived, were limited, both in geographic range and number (a fuller discussion of limitations is presented in the Summary Report for these Technical Support Documents). The results of this exercise are presented in Section 5.1 followed by discussion of methodology in Section 5.2.

5.1 QUANTIFICATION

To quantify potential source reduction, each option discussed in Section 3 was assigned a range of effectiveness and implementation potential in accordance with the methodology discussed in Section 5.2. The top one or two methods for each impacted medium were then combined and the medium reductions combined to yield reductions for a given operation. Operation reductions were then combined to yield an overall reduction for the industry or activity as a whole. Since only the top one or two options for an impacted medium were selected, as opposed to selecting all options, the estimated reductions are viewed as conservative. The results of this exercise are presented in Table 5.1.

Paint stripping offers relatively high source reduction potential given the many non-chemical methods that have been developed and are currently in use. Potential methods include abrasive, thermal, and cryogenic techniques. Moreover, there is a developing trend to examine more closely the need for painting and paint stripping. For example, the “Inspect and Repair Only as Necessary” (IROAN) guidelines for military vehicle maintenance substantially reduces routine stripping with the objective of avoiding unnecessary, and potentially polluting, efforts. For facilities using METH-based immersion strippers, improved operating practices and filtration of spent stripper can reduce waste generation. Unlike other solvent using operations, installation of air emission controls and solvent recycling equipment has relatively low implementation potential.

Overall short-term reductions from paint stripping are estimated to be 14 to 37 percent. This reduction can primarily be achieved by increased use of abrasive techniques in place of field and immersion stripping and by improvements to existing immersion stripping operations. In

Table 5.1

Source Reduction Potentials for Paint Stripping Operations

	Source Reduction Method	Media	Effectiveness (%)		Implementation Potential						Source Reduction Potential					
					Short(%)		Medium(%)		Long(%)		Short(%)		Medium(%)		Long(%)	
			Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
	Spray Booth Cleaning (OEM)															
	1. Use of Alternative Solvents	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
	2. Use of Strippable Coatings on Walls	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
>	3. Use of High Pressure Water Sprays	A/S/W	100	100	20	40	40	60	40	60	20	40	40	60	40	60
	Reduction Potential for Method 3	A/S/W									20	40	40	60	40	60
	Immersion Stripping (OEM)															
	1. Train Painters and Establish Standards	A/S/W	0	20	20	40	40	60	60	80	0	8	0	12	0	16
>	2. Use of Abrasive Techniques	A/S/W	100	100	20	40	40	60	40	60	20	40	40	60	40	60
	3. Use of Thermal Technologies	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
	4. Use of Cryogenic Techniques	A/S/W	100	100	0	20	0	20	20	40	0	20	0	20	20	40
	5. Use of Biodegradation	A/S/W	100	100	0	0	0	0	0	20	0	0	0	0	0	20
	6. Use of Alkaline or Acidic Strippers	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
	7. Use of Alternative Solvents	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
	8. Use of Reduced METH Content Strippers	A/S/W	40	60	20	40	20	40	20	40	8	24	8	24	8	24
>	9. Operational Improvements to Stripping	A/S/W	40	60	20	40	40	60	60	80	8	24	16	36	24	48
	10. Filter Spent Stripping Solution	Solid	40	60	20	40	40	60	40	60	8	24	16	36	16	36
	11. Recycle Spent Stripper	Solid	0	20	0	0	0	20	0	20	0	0	0	4	0	4
	Reduction Potential for Methods 2 & 9	A/S/W									26	54	50	74	54	79
	Paint Equipment Clean-Up (OEM)															
	1. Use of Alternative Solvents	A/S	100	100	20	40	20	40	40	60	20	40	20	40	40	60
>	2. Rigid Inventory Control of Solvent	A/S	60	80	20	40	40	60	60	80	12	32	24	48	36	64
>	3. Use of Easy to Clean Equipment	A/S	40	60	0	20	20	40	40	60	0	12	8	24	16	36
>	4. Use of Enclosed Cleaning Station	Air	60	80	40	60	60	80	60	80	24	48	36	64	36	64
	5. Recycle METH On-Site	Solid	40	60	20	40	20	40	40	60	0	24	8	24	16	36
	Reduction Potential for Methods 2 & 4	Air									33	65	51	81	59	87
	Reduction Potential for Methods 2 & 3	Solid									12	40	30	60	46	77
	Reduction Potential for Paint Application		Weighing factors = 0.2 (A) and 0.8 (S).								16	45	34	65	49	79
	Field Stripping (Maintenance)															
	1. Use of Non-Painted Surface Materials	A/S/W	100	100	0	0	0	20	0	20	0	0	0	20	0	20
>	2. Use of Abrasive Techniques	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
>	3. Use of Thermal Technologies	A/S/W	100	100	0	0	0	0	0	20	0	0	0	0	0	20
	Reduction Potential for Methods 2 & 3	A/S/W									20	40	20	40	40	68
	(continued)															

Table 5.1

Source Reduction Potentials for Paint Stripping Operations (continued)

	Source Reduction Method	Media	Effectiveness (%)		Implementation Potential						Source Reduction Potential					
					Short(%)		Medium(%)		Long(%)		Short(%)		Medium(%)		Long(%)	
			Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
	Immersion Stripping (Maintenance)															
	1. Strip Parts Only When Required	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
>	2. Use of Abrasive Techniques	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
	3. Use of Thermal Technologies	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
	4. Use of Cryogenic Techniques	A/S/W	100	100	0	0	0	20	0	20	0	0	0	20	0	20
	5. Use of Biodegradation	A/S/W	100	100	0	0	0	0	0	20	0	0	0	0	0	20
	6. Use of Alkaline or Acidic Strippers	A/S/W	100	100	20	40	20	40	40	60	20	40	20	40	40	60
	7. Use of Alternative Solvents	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
	8. Use of Reduced METH Content Strippers	A/S/W	40	60	20	40	20	40	20	40	8	24	8	24	8	24
>	9. Operational Improvements to Stripping	A/S/W	40	60	20	40	40	60	60	80	8	24	16	36	24	48
	10. Filter Spent Stripping Solution	Solid	40	60	20	40	40	60	40	60	8	24	16	36	16	36
	11. Recycle Spent Stripper	Solid	0	20	0	0	0	20	0	20	0	0	0	4	0	4
	Reduction Potential for Methods 2 & 9	A/S/W									26	54	33	62	54	79
	Field Stripping (Consumer)															
	1. Use of Alternative Solvents	Air	100	100	40	60	40	60	60	80	40	60	40	60	60	80
>	2. Use of Thermal/Abrasive Techniques	Air	100	100	0	20	0	20	0	20	0	20	0	20	0	20
	Reduction Potential for Method 2	Air									0	20	0	20	0	20
	Immersion Stripping (Consumer)															
>	1. Use of Abrasive Techniques	A/S/W	100	100	0	20	0	20	20	40	0	20	0	20	20	40
	2. Use of Alkaline or Acidic Strippers	A/S/W	100	100	0	20	20	40	20	40	0	20	20	40	20	40
	3. Use of Alternative Solvents	A/S/W	100	100	40	60	40	60	60	80	40	60	40	60	60	80
	4. Use of Reduced METH Content Strippers	A/S/W	40	60	20	40	20	40	20	40	8	24	8	24	8	24
>	5. Operational Improvements to Stripping	A/S/W	40	60	20	40	40	60	60	80	8	24	16	36	24	48
	6. Filter Spent Stripping Solution	Solid	40	60	20	40	40	60	40	60	8	24	16	36	16	36
	Reduction Potential for Methods 1 & 5	A/S/W									8	39	16	49	39	69
	Paint Stripping Overall Reduction Potential		Weighing factors (see note below).								14	37	20	43	32	57

Note: Weighing factors for overall reduction are 6.6/66.0 (spray booth cleaning), 4.0/66.0 (immersion stripping), and 2.6/66.0 (spray equipment cleaning) for OEM, 18.5/66.0 (field stripping) and 7.9/66.0 (immersion stripping) for the maintenance sector, and 17.7/66.0 (field stripping) and 8.7/66.0 (immersion stripping) for the consumer sector.

the area of equipment cleanup, use of high-pressure water sprays for booth cleaning and rigid inventory control of solvent, use of easy to clean equipment, and use of enclosed cleaning stations could substantially reduce METH use in this activity. Based on total METH usage of 66,000 MT, short-term reductions of 9,300 to 24,600 MT are projected. Medium-term reductions are projected to be 20 to 43 percent, or 13,200 to 28,700 MT and long-term reductions are projected to be 32 to 57 percent or 21,200 to 37,500 MT.

5.2 METHODOLOGY

The methodology used to estimate nationwide source reduction potential is comprised of the following major steps: assign source reduction effectiveness ranges to each option, assign implementation potential ranges to each option, compute the range of source reduction potential for each impacted media and then compute the range of source reduction potential for the industry. Definitions and examples are provided in the following sections.

Source Reduction Effectiveness

Source Reduction Effectiveness (SRE) measures the pure technical effectiveness of a source reduction option for a unit operation, for example, the extent to which the use of the target substance can be reduced by application of a given source reduction option in an industrial process or operation at a typical facility. The ranges of SRE used in this study were:

Reduction	Range (percent)
None	0
Small	0-20
Moderate	20-40
Medium	40-60
High	60-80
Very High	80-100
Full Elimination	100

For example, the use of abrasives in place of METH would be assigned an SRE of 100 percent since halogenated solvent use is fully eliminated. Likewise, the substitution of one halogenated solvent with another (e.g., TCA for METH) would be assigned an SRE of 0 percent because the option does not reduce solvent use. The assignment of SRE ranges ignored the effect of non-technical constraints on reducing source reduction potential.

Implementation Potential

The Implementation Potential (IP) is a percentage range estimate of the extent to which a particular source reduction option could be implemented on an industrywide scale, taking into consideration many technical and nontechnical constraints. The ranges used for IP were identical to those used for SRE above. To account for time effects, IP ranges were determined for short-term (0 to 5 years), mid-term (5 to 10 years), and long-term (10 to 20 years) periods of time.

Estimating the IP for each source reduction option is a complex task, involving the meshing of environmental, technical, and socioeconomic variables into workable scenarios. Since this study has generally looked at source reduction technologies that have been demonstrated to work in the field, then from a technical standpoint alone the IP of most options studied is relatively high. Technology, however, is only one component. Other environmental and socioeconomic variables prominent in determining IP are:

- extent of current use
- economic considerations
- time
- customer attitudes
- regulatory compliance
- management capabilities and commitment
- information and training resources
- monitoring and maintenance capabilities

Extent of Current Use

Implementation potential for a given source reduction alternative depends on the extent to which this alternative has been implemented in the studied industry. For example, easy and accessible techniques such as improved maintenance or operator training have largely been implemented by the larger, more sophisticated firms. Hence, the implementation potential ratings for these alternatives must be rated downward to account for the fraction of facilities where they have already been applied.

Economic Considerations

A contemplated source reduction project often finds itself as only one of many competitors for available capital. As with other activities requiring capital expenditures, two basic economic considerations govern source reduction: availability of capital, and the potential return on investment. Capital availability varies considerably among halogenated solvent users, with smaller operations generally at a disadvantage. To account for this effect, low cost measures were rated higher than high cost measures.

Time

Time can markedly change feasibility and potential of source reduction measures. Technologies can move from novel to standard; what may be considered economically infeasible today may be judged cost-effective tomorrow. Generally, well established technologies have been given a higher short-term IP rating than the emerging ones.

Customer Attitudes

If a service or a product developed through source reduction methods is less marketable than one from standard practices, the source reduction option will likely fail. Customer attitudes are an important influence in source reduction. SRRP staff research found that rigid customer specifications, particularly military specifications, pose significant source reduction barriers in many industries. These barriers tend to keep the IP rating for measures involving material or process changes low.

Regulatory Compliance

Complexities in meeting regulatory requirements for end-of-pipe pollution control generally spur source reduction. Both technological complexities in achieving specific emission reductions, and administrative complexities in obtaining required permits and approvals (e.g., obtaining of wastewater discharge and air permits) influence the rating of the implementation potential of source reduction measures.

Management Capabilities and Commitment

Successful implementation of source reduction depends on: a) the management level at which it is actively endorsed, and b) the technical. and administrative capability of that management in regard to implementation. Source reduction usually requires a reorientation of management perceptions and priorities away from traditional environmental management approaches, and toward pollution prevention. Some of the common barriers to such reorientation can be expressed by the following viewpoints:

- We already invested in an expensive treatment system. Why reduce?
- We will not be the first to try this out. Let others do it, then we will see.
- Product quality will definitely be affected by substitutions. We will not do anything until we have to.

The rating of IP must consider resistance to change of management's perceptions. In deriving the rating, higher scores were assigned to industries where process and product changes are frequent rather than to more static industries.

Information and Training Resources

The best source reduction technologies available, supported by top management, can fail if sufficient information and training for effective implementation, running, and monitoring are not available to managers who must direct source reduction efforts and to line employees who must make them work and adapt them to changing conditions.' Information and training needs in the constantly evolving source reduction field are many. They range from simple instruction manuals to sophisticated databases. In general, the greater the requirement for information and training resources, the lower the IP rating.

Monitoring and Maintenance Capabilities

Unless source reduction programs are carefully monitored, they can rapidly become suboptimal, posing a number of technical, economic, and other problems. Similarly, without proper maintenance geared specifically to source reduction goals, source reduction measures can falter. For small firms, the need for extensive monitoring and maintenance will lower an option's IP rating.

Source Reduction Potential

The Source Reduction Potential (SRP) for each implementation time frame was calculated as the product of Source Reduction Effectiveness and Implementation Potential. As an example, an SRE of 20 to 40 percent and an IP of 60 to 80 percent, would yield an SRP of 12 to 32 percent. The assignment of short-term, medium-term, and long-term IPs was done to account for reductions in constraints over time. While it could be argued that short-term, medium-term, and long-term SRE values should have been assigned to account for technical improvements, over time, the added complexity and the movement away from a conservative stance did not appear warranted.

After calculation of individual SRPs, the top one or two options for each impacted medium were selected from among the non-solvent based alternatives. While the use of hydrocarbon solvents in place of halogenated solvents could achieve sizable reductions in halogenated solvent use, these options were not viewed as true source reduction since the overall environmental benefit is unclear. Also excluded were options that could pose major impacts on other media (i.e., air versus water). In general, most selected options dealt with use of similar products with less solvent content, more efficient use of products, and recycling/reuse of solvent vapors and waste. The SRP for an impacted medium was calculated as follows:

$$SRPmedium = SRP_1 + SRP_2(100 - SRP_1/l00$$

where $SRP_{1,2}$ are the two leading calculated source reduction potentials for each medium. SRPmedium is the combined range of source reduction.

It should be noted that selection of one or two top ranking options in calculating an SRP for an impacted medium is arbitrary. If there are 10 source reduction methods available, and there are appropriate driving forces, then it is likely that more than two will be implemented, in which case the reduction in halogenated solvent use will exceed the estimate. Therefore, this technique provides a conservative estimation of SRP.

Overall Source Reduction Potential

Once the SRPs for each impacted medium have been determined, the overall SRP for each industrial sector (e.g., formulator and user) and the industry as a whole is determined. The SRP for each industrial sector is determined by the equation:

$$SRPsector = (Wair/Wtotal) X SRPair + (Wsolid/\backslash Wtotal) X SRPsolid + (Wwater/Wtotal) X SRPwater$$

where Wair, Wsolid, and Wwater is the weight of halogenated solvent released into the environment from an environmental sector. The industry-wide SRP is then determined by weighing each SRP sector by the ratio of solvent released from that sector by the total amount of solvent used by the industry.

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