Source Reduction Research Partnership
Metropolitan Water District of Southern California
Environmental Defense Fund

Source Reduction of Chlorinated Solvents

Paint Removal

Prepared for

Alternative Technology Division
Toxic Substances Control Program
California Department of
Toxic Substances Control

and

Pollution Prevention Research Branch
Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency

June 1991

Source Reduction Research Partnership
Metropolitan Water District of Southern California
Environmental Defense Fund

Source Reduction of Chlorinated Solvents

PAINT REMOVAL

Prepared for

Alternative Technology Division
California Department of
Toxic Substances Control
P.O. Box 806
Sacramento, CA 95812-0806

Pollution Prevention Research Branch
Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

June, 1991

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (cont'd)

ACKNOWLEDGMENT

The principal sponsors of this project, The Metropolitan Water District of Southern California and the Environmental Defense Fund gratefully acknowledge major support from the Switzer Foundation and from the U.S. Environmental Protection Agency, The California Department of Health Services, and the City of Los Angeles, (Los Angeles Department of Water and Power). Additional support was received from Southern California Edison Company.

The Environmental Defense Fund also gratefully acknowledges the support of the Andrew Norman Foundation an the Michael J. Connell Foundation for the exploratory phase that led to the formation of the Source Reduction Research Partnership and the development of the research plan.

The principal project sponsors recognize the effort and contributions of many people from industry and government who helped in preparation of these reports. These efforts and contributions are being gratefully acknowledged.

DISCLAIMER

PREFACE

This report is one of twelve reports that evaluate the opportunities for source reduction of chlorinated solvents in twelve specific industries. The twelve reports are part of a large-scale study sponsored by the Source Reduction research Partnership (SRRP), a joint venture by the Metropolitan Water District of Southern California and the Environmental Defense Fund. The reports cover the following industries and industrial practices:

1. Aerosols Manufacture
2. Adhesives Manufacture
3. Chemical Intermediates Manufacture
4. Dry Cleaning of Fabrics
5. Electronic Products Manufacture
6. Flexible Foam Manufacture
7. Food Products Manufacture
8. Paint Removal
9. Pesticides Formulating
10. Pharmaceuticals Manufacture
11. Solvent Cleaning
12. Textiles Manufacture

The objectives of the SRRP study include a survey and evaluation of existing and potential techniques for reducing the generation of halogenated solvent wastes, and thus their potential release into the environment, across a wide range of the industrial users of these solvents.

Each of the industry-specific reports begins with a description of the industry and processes where halogenated and solvents are used. Sources and causes of releases are described and regulatory regime discussed for waste streams of concern.

Subsequent sections focus on source reduction opportunities through chemical substitution, process modification, product substitution and recovery/reuse. For major solvent using industries, select source reduction options were analyzed for their economic feasibility.

The information in the reports was compiled and analyzed by the SRRP project staff, employed by the Partnership to carry out the project research. Each report was reviewed by industry representatives and/or other experts familiar with the specific industry and the relevant technologies and issues, and then reviewed and edited by an additional expert consultant.

The intent of the sponsors is to provide all interested parties with useful information on available and potentially available methods for source reduction of halogenated solvents, in the context of specific industries and processes, and an evaluation in context of the various source reduction options.

I. INTRODUCTION

The five major chlorinated solvents most widely used in commerce today include trichloroethylene (TCE), perchloroethylene (PERC), l,l,l-trichloroethane (TCA), methylene chloride (METH) and 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113). The primary solvent used in paint stripping is METH.

This report is one of several companion reports that focus on source reduction of chlorinated solvents in the major industries where they are used. This particular document identifies and examines the potential of a variety of source reduction options for reducing or eliminating the use of METH in paint stripping.

Three paint stripping sectors are investigated in this document. In the first--original equipment manufacturing--METH is used for paint stripping activities in automobile assembly plants and in the production of other industrial goods. The second sector is maintenance where the METH is used periodically to strip military vehicles and equipment, commercial aircraft, automobiles and other industrial equipment. In the third sector, consumer applications, METH is used directly by consumers or by commercial stripping firms to remove coatings, largely from furniture.

The use of METH for paint stripping in 1989 is estimated at 50 thousand metric tons (mt). One-fifth or 10 thousand mt was used in the original equipment manufacturing sector in the manufacture of automobiles and other items. Two-fifths or 20 thousand mt was used in the maintenance sector for stripping aircraft and other large vehicles and parts.

Another 20 thousand mt was used in the consumer sector, primarily for furniture stripping. METH use for paint stripping has declined in recent years, particularly in automotive assembly plants. This decline is likely to continue over the next few years because of the increased regulatory scrutiny of the substance.

This document identifies and analyzes source reduction measures in all three paint stripping sectors. Table 1.1 summarizes the options for original equipment manufacturers. Options include chemical substitution, process modification, product substitution, recovery and reuse of vapors, and recovery and reuse of liquid wastes.

In the maintenance sector, process modification options that could reduce or eliminate METH use are listed in Table 1.2. Plastic media blasting (PMB) is an abrasive technique that has been pioneered by the military. Sodium bicarbonate--another abrasive technique--also holds promise. Laser paint stripping, high intensity light and biodegradation are being investigated.

Table 1.3 presents technical options for the consumer sector. Three chemical substitutes are available. NMP is expensive and it is not presently used in consumer stripping formulations. A DBE based formulation is being marketed for consumer stripping. Flammable strippers and heat technologies are used today but have limited potential. Cryogenic techniques are expensive but might have some potential for replacing METH in contract stripping operations.

Table 1.1
Original Equipment Manufacturing

OPTION	ADVANTAGES	DISADVANTAGES
Chemical Substitution		
NMP, DBE, Furfuryl Alcohol, Alkyl Acetate, MAK, PM, PMA, and Paint Thinner	Eliminates use of METH, some are recyclable and/or biodegradable	Slow stripping rate, not effective on cured paint, photo-chemically reactive, flammable
Process Modification		
Strippable Coatings	Eliminates use of METH, generation of dry solid waste instead of wet sludge	Frequent stripping can be labor intensive, emissions from application of coating
Alkaline/Acid Stripper	Eliminates use of METH	Can be corrosive to metal, must be heated, parts must be rinsed, immersion use only
High Pressure Water Spray	Eliminates use of METH, no chemicals employed	Worker danger from spray
Ovens and Salt Baths	Eliminates use f METH, removed coating is incinerated	High energy cost, distortion of part shape, particulate air emissions
Physical Methods	Eliminates use of METH, minimal amount of waste generated	Very labor intensive
Cryogenic Techniques	Eliminates use of METH, minimal amount of waste generated	Very capital intensive, small parts only, distortion of part shape, worker safety, experimental
Formulated Sodium Bicarbonate	Eliminates use of METH, waste can be sewered after filtration to remove paint	May cause corrosion of aluminum, experimental
Product Substitution		
Unpainted or precolored Items	Eliminates need for painting and stripping	Very case specific

Table 1.1
Original Equipment Manufacturing
(continued)

OPTION	ADVANTAGES	DISADVANTAGES
Recovery & Reuse of Vapors		
Carbon Adsorption	Recovery METH for reuse in paint stripping	Complex separation, very difficult to operate and maintain, not appropriate for process
Condensation	Recover METH for reuse in paint stripping	Similar to carbon adsorption
Water Blanket	Suppresses evaporation of METH	Useful for immersion tanks only
Recovery and Reuse of Waste		
Filtration/Microfiltration	Simple equipment, extends life of solvent	Only removes particulate contamination, disposal of filter media
On-Site Recycling	Contamination of recovered METH with unknown solvents avoided, high recovery of METH value, reduced liability for transportation and disposal	Need for well designed equipment, increased worker exposure, disposal of still bottoms, useful for nearly pure METH formulations only
Off-Site Recycling	No need to purchase equipment, stripper purchasing and waste disposal services can be combined, minimal impact on existing operations	Possibility of receiving contaminated stripper, handling of waste material not fully under the control shop, full METH value not recovered
Gun Cleaning Station	Reduces METH used for cleaning, reduces air emissions, inexpensive equipment	Added constraint on operators, recovery of liquid waste requiring disposal

Table 1.2
Military Maintenance

OPTION	ADVANTAGES	DISADVANTAGES
Process Modification		
PMB	Eliminates use of METH, proven in field use	Need for particulate control, disposal of blast media, worker safety
Cryogenic	See Table 1.1	See Table 1.1
Lasers	Eliminates use of METH, highly controlled rate of removal	Limited area stripped, worker safety, experimental
High Intensity Light	See Lasers	See Lasers
Carbon Dioxide Pellets	Eliminates use of METH, no disposal of blast media	Expensive equipment, worker safety, emissions of CO_2 (greenhouse gas)
Sodium Bicarbonate	See Table 1.1	See Table 1.1
Biodegradation	Eliminates use of METH	Extremely slow, experimental
Product Substitution		
Unpainted or Precolored Items	See Table 1.1	See Table 1.1

Table 1.3
Consumer Sector

OPTIONS	ADVANTAGES	DISADVANTAGES
Chemical Substitution		
NMP	See Table 1.1	See Table 1.1
DBE	See Table 1.1	See Table 1.1
Flammable Strippers	See Table 1.1	See Table 1.1
Process Modification		
Cryogenic/Alternative Strippers	See Table 1.1	See Table 1.1
Heat Technologies	Eliminates use of METH, no chemicals	Poor level of stripping, consumer safety, damage to parts due to heat

Section II of this document, presents background information on chlorinated solvent use in and releases from paint stripping activities. It also describe the characteristics of stripping processes in the three main sectors and focuses on several facets of the regulatory regime.

Section III, identifies and analyzes the source reduction options for each of the sectors.

Section IV, presents the results of the field visits. The sites included five manufacturing facilities, six maintenance stripping facilities and two contract stripping operations.

Sections V, VI and VII analyze certain of the promising source reduction options in the original equipment sector, the maintenance sector and the consumer sector respectively.

Finally, Section VIII summarizes the qualitative potential of the options and comments on the future of the industry.

II. BACKGROUND

METH has been the predominate 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. It then describes, in considerable detail, the stripping process in each of the end use sectors. Finally, it summarizes the regulatory regime.

SOLVENT USE

METH is the primary chlorinated solvent used in paint stripping applications today. It is the only chemical stripper that can effectively strip cured coatings from a variety of substrates in a short period of time. Although small amounts of PERC, TCE and TCA are also used for this purpose, this analysis focuses on METH as the sole solvent used in paint removal.

There are a variety of different estimates for the level of METH used in stripping applications. These estimates are shown with the appropriate year in Table 2.1. In some cases , the source provides a detailed breakdown by application; in others, only total values are presented. The various sources have different categories as indicated. For instance, ICF's categories of "OEM" and "maintenance" are probably equivalent to Radian's category of "other industrial". Assuming that the values of Table 2.1 are correct, they show a decline in the use of METH of between 12 and 22 percent between 1983 and 1989; the reason for this decline is discussed later.

Table 2.2 shows estimates of present METH use in paint stripping. For convenience, ICF's categorization is adopted. The estimates assume that the CMR (1989a) value for total use is somewhat high. The "Original Equipment Manufacturing (OEM)" category includes activities in the automotive industry and in the manufacture of metal furniture, fixtures and appliances. "Maintenance" includes routine stripping activities at

TABLE 2.1
VARIOUS PAINT STRIPPING ESTIMATES
(thousand metric tons)

SRI - 1983[A]		RADIAN - 1984[B]		CMR - 1986[C]	ICF - 1987[D]		Industry - 1988	CMR - 1989A[E]
Architect	1.4	Automotive	15.4		OEM	12.7		
OEM/ Aftermarket Goods	49.2	Other Industrial	20.4		Maint-enance	19.1		
Govt./ Military	10.5	Military Maint-enance	14.5		Household	20.0		
Consumer Goods	9.1	Household	13.2					
TOTAL	70.2		63.5	59		51.8	50.8	54.7

[A]Middle of range in SRI (1985) was chosen. OEM means original equipment manufacturing.

[B]Data are apparently based on GAF estimates for 1984.

'Based on 23 percent of production as given in ITC (1986)

[D]Best estimate in ICF (1988).

[E]Assumes U.S. Demand of 195,000 mt.

Sources: SRI (1985), CMR (1986), Radian (1988), ICF (1988), CMR (1989A), Industry Sources.

TABLE 2.2

METH USE IN PAINT STRIPPING - 1989
(thousand mt)

APPLICATION	Use	
Original Equipment Manufacturing (OEM)	10	
Automotive		4.0
Other Industrial		6.0
Maintenance	20	
Military		12.6
Commercial Aircraft		3.2
Automotive		3.0
Other Industrial		1.2
Consumer	20	
TOTAL	50	

Source: SRRP staff estimates

Department of Defense (DoD) and other government facilities and commercial facilities--like airports--where large vehicles or structures are stripped. It also includes maintenance of automobiles and other industrial equipment. "Consumer" uses include stripping by the consumer directly and stripping by commercial contractors for consumers.

RELEASE CHARACTERISTICS

EPA surveyed a whole range of facilities that use METH strippers. Analysis of the questionnaires indicated that atmospheric emissions from automotive, other industrial and military sources amounted to about 80 percent of use; emissions from consumer sources were estimated at 100 percent (Radian, 1988). This analysis adopts the 80 percent estimate for maintenance and original equipment manufacture. Because there are no reliable data, half the remaining METH in the nonconsumer sectors is assumed to be disposed of as hazardous waste and half is assumed to enter the water. Two-thirds of the METH used in the consumer sector is employed directly by consumers and one-third is used by commercial stripping firms that contract with consumers. This analysis assumes that 100 percent of the METH used by consumers is emitted to the atmosphere and the METH losses for the commercial firms are apportioned in the same way as for the maintenance and original equipment sectors.

Table 2.3 summarizes the METH losses in the three sectors. Overall, 85 percent of the METH is lost as an atmospheric emission. Somewhat more than 7 percent is released to the water and the same percentage is disposed of as hazardous waste.

PROCESS DESCRIPTION

In general, the purpose of a paint stripping operation is to remove paint from a surface or substrate. The paint that must be removed can be urethane, epoxy, alkyd, acrylic,

Table 2.3

METH RELEASES IN PAINT STRIPPING

APPLICATION	1989 RELEASES (thousand mt)			
	Air	Solid	Water	Total
OEM				
Auto	3.2	0.4	0.4	4.0
Other	4.8	0.6	0.6	6.0
MAINTENANCE				
Military	10.0	1.3	1.3	12.6
Aircraft	2.6	0.3	0.3	3.2
Automotive	2.4	0.3	0.3	3.0
Other	1.0	0.1	0.1	1.2
CONSUMER				
Consumers	13.3	0.0	0.0	13.3
Contract	5.4	0.7	0.7	6.7
TOTAL	42.7	3.7	3.7	50.0

Note: Totals may not add due to rounding.

Source: SRRP staff estimates.

cellulosic or vinyl resin-based. Further, it can be cured or uncured. Substrates can be wood, plastic or metal and the removal mechanism can be chemical, mechanical or temperature controlled. The choice of method depends on a variety of factors including the type and condition of the paint and the substrate, location of the paint stripping activity, the size and configuration of the item being stripped, the number of paint coats requiring removal, and the disposal environment.

There are three widely used types of stripping. Chemical paint strippers may be based on solvent or aqueous formulations. Mechanical stripping works by abrading the paint from the substrate. Temperature dependent technologies are generally combined with a mechanical stripping method. This section focuses on chemical paint stripping using METH formulations.

In all applications, the function of a chemical paint stripper is to penetrate the cured paint film matrix, cause swelling of the film by expanding the interstitial structures, dissolve uncured additives and uncured synthetic polymer, create stress at the film-substrate interface, lift the cured paint film from the substrate, and come between this film and the substrate to prevent rebonding.

Substances like METH and other chemicals used in stripping are not effective strippers alone. Formulated products are required, particularly to remove cured paint. Solvent based strippers commonly have a number of components to accomplish all of these required functions. The first is a primary solvent for penetration of the film and swelling. METH is especially useful in the role of the primary solvent. The second is a cosolvent for increasing penetration and solvent effectiveness and keeping the various components in formulation. Methanol and isopropyl alcohol are commonly used as cosolvents with METH and for water soluble components of the formulation. The third is a surface active agent and emulsifier for attacking the bond between the film and the substrate. Petroleum sulfonates function as wetting and emulsifying agents. The fourth component is a thickener: this allows the formulation to be used on vertical surfaces. Methyl cellulose derivatives have been found to be the best general purpose thickening agents. The fifth is a sealant--such as crude or refined paraffin wax--that retards evaporation so that penetration of the coating can occur. The sixth is a corrosion inhibitor which can be added to protect metal substrates from chemical attack. There are sometimes other additives depending on the specific applications (Occidental, 1989).

Solvent based strippers are available in a range of viscosities, ranging from liquids to colloidal gels. Although small amounts of other chlorinated solvents--notably TCA, TCE and PERC--have been used for stripping, METH is the preferred chemical in most solvent based-strippers. This latter solvent can remove a variety of coating types. Because of its low molecular weight, appropriate polarity and solvency, METH penetrates the coating and swells it to three to four times its normal volume. The coating bubbles and blisters and is released from the substrate. The residue is then chipped or washed from the surface with water.

Paint Strippins Markets

As indicated in Table 2.2, there are three primary paint stripping markets. In Original Equipment Manufacturing (OEM), stripping is performed in the manufacture of new goods. In maintenance, stripping is required in the periodic maintenance of a range of equipment. In the consumer market, stripping is done on household goods.

Original Equipment Manufacturing. METH is used in paint stripping in a range of industries including automotive manufacturing, metal furniture and fixtures, electronic and electrical equipment, transportation equipment and wood flatstock and furniture (ICF, 1988). Formulations in the OEM market typically contain between 50 and 75 percent METH. In these industries, paint is applied to parts of products or complete products. METH is used for two purposes in these industries. First, when coatings are applied, some of the paint does not reach the target. This so-called over-spray must be removed from paint spray booths and floors, hooks, hangers and racks used in the painting process and paint lines. Second, defective items are reworked: they are stripped, repaired and repainted.

According to Table 2.2, the automotive manufacturing sector accounted for two-fifths of METH use in the OEM market in 1988. Indeed, there are some 72 locations in the U.S. where automobile manufacturing takes place. As discussed later, many automobile manufacturers have developed policies for moving away from METH entirely and use has declined significantly in the last few years. In the automotive sector, METH was used in spray booth cleaning, floor cleaning, line purging and spray gun cleaning. It is probably not widely used in spray booth cleaning or floor cleaning any longer: it is still used for line purging and perhaps, also gun cleaning. In the industrial sectors, METH is still widely used for all these activities.

The amount of METH required for booth cleaning depends on a variety of factors. First, the transfer efficiency of the painting method is a significant factor. The transfer efficiency is defined as the percentage of the paint used that actually reaches the item being painted. Obviously, the higher the transfer efficiency, the less paint there is to be cleaned from the booth. The second factor that affects METH use is whether or not the paint is cured. If not, then paint thinner solvents rather than METH may be sufficient for removing the paint. The third factor that influences METH use is how often the paint color is changed. More frequent changes of color require more frequent stripping. The fourth factor governing METH use is whether the painting operation is periodic and functional rather than cosmetic. If painting is done infrequently and the appearance of the item is not important, then booth stripping may not be required at all.

Two types of paint booths are in wide use today. In dry booths which have enclosed bottoms, tops and sides, air is exhausted through the back of the booth where filters catch the excess paint. In waterwash booths, a water curtain covers the back of the booth. Air is drawn through this curtain to collect excess paint and some of it can be separated from the water for reuse.

To clean dry spray booths, workers spray stripper with low pressure pumps on the inside surfaces of the booth. The stripper is allowed to penetrate and when it blisters, it is removed by washing the booth with water. The water, containing small amounts of METH, is sent for pretreatment before release to the sewer. For waterwash booths, there is no need to strip because the water carries the paint continuously into the pretreatment system. When the water becomes saturated, the solvent in the paint will be lost to the air, and at that stage, the water acts as an airstripping column. In both types of booths--dry and waterwash--the sides are sometimes sprayed with a peelable coating. The paint can be peeled away from the surface making chemical stripping unnecessary.

In many automotive water wash paint booths, the air flow is from top to bottom, as opposed to front to back. In such booths, the floor is a grid. Below this grid a river of water flows and picks up the overspray. The water is sent to a pretreatment plant and treated using a clarified before release.

Paint stripping of floors or grids is done periodically by rubbing, mopping or scraping. If it is done infrequently, the paint will always be cured and the stripping will require a significant amount of time.

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. METH stripper is circulated through the entire system to remove the paint. In another type of operation, the paint lines may be soaked in tubs (see immersion cleaning below) and wiped clean. Spray guns may be cleaned with towels or sponges containing METH.

There is an additional type of stripping--immersion stripping--where automobile, parts or assembly equipment are dipped in a tank (Radian, l988). The tanks are similar to cold cleaning equipment (see the companion document on solvent cleaning). As in solvent cleaning, the parts can be lowered manually or mechanically and the tanks can be fitted with covers (ICF, 1988).

In the non-automative OEM sector, the paint stripping activities are largely the same as those described above for the automotive sector. In the manufacture of all durable goods, the stripping process is assumed to be similar those described here. Immersion stripping is sometimes accomplished with formulations of nearly 100 percent METS. Parts may be placed in a tank of METH overnight to remove the paint.

Maintenance. As indicated in Table 2.2, 20 thousand of METH was used in maintenance paint stripping activities in 1989, about two-thirds in the military and one-third in commercial aircraft, automotive repair and other industrial uses. This Stripping is conducted at Department of Defense (DoD) industrial facilities, at commercial facilities and at other government facilities. In general, large items like automobiles, airplanes and ships are stripped in prepration for maintenance work and repainting operations.

For many years, the DoD has employed METH for stripping a variety of defense vehicles including planes, helicopters, jeeps and tanks. These vehicles are maintained and stripped according to periodic schedules. In general, the METH stripper formulation is sprayed onto the vehicle and allowed to stand until it blisters. The paint is then removed with a squeegee, a rubber edged scraping tool. The paint and METH sludge is generally collected and put in drums for disposal. The vehicle is then washed down with water which is sent to a central drain. This water will likely require treatment before it can be released to the sewer. Smaller assemblies like vehicle parts, ship components and aircraft components are stripped in dip tanks similar to those described above under "original equipment manufacturing".

Commercial aircraft stripping is performed in the same manner as military aircraft stripping. Each airline has a central maintenance facility and it is generally there that stripping activities occur. Some airlines do not do their own stripping and they contract with other firms which perform maintenance and stripping on corporate jets and other private planes.

Auto body shops strip automobiles or parts of automobiles when they are being repaired. METH is used in conjunction with hand sanding to remove paint from bodies and also to clean and purge paint supply lines. METH is also used to some extent, for removing paint from large vehicles like buses and railroad cars (ICF, 1988). This comprises the other industrial category of Table 2.2.

<u>Consumer</u>. Most of the METH used in the consumer sector is for stripping furniture which is most often made of wood. There are two types of activities in this sector. First, consumers strip furniture themselves by applying the METH with a brush and removing the paint with a scraper. Second, a commercial

furniture stripper provides a service to the consumer. These firms typically dip the furniture in a tank containing stripper and the part is rotated so that all areas are submerged. The paint blisters within one-half hour to an hour, and the piece is transferred to a separate area where the loosened paint is removed by hand scraping or water spraying. Stripper is brushed on areas where paint remains in crevices or dents. The waste paint which also contains some stripper is placed in drums for disposal. Some contractors also perform stripping at customer locations. In addition to furniture refinishers, contractors performing paint stripping include commercial painting and floor stripping firms (Radian, 1988; Radian, 1987).

Many items in the home are stripped using METH. These include doors, door frames, porches and decks as well as pieces of furniture. One source estimates that 95 percent of consumer paint stripper is used for furniture (ICF, 1988). Homeowners generally purchase stripper from hardware stores. Contractors may purchase stripper directly from the formulators or they may formulate their own.

THE REGULATORY REGIME

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". The workplace exposure level of METH has been set by the Occupational Safety and Health Administration (OSHA) at 500 parts per million (ppm). The OSHA is expected to reduce this level significantly--to 25 or 50 ppm--in the near future. The Consumer Product Safety Commission (CPSC) now requires household products containing METH to be labelled as hazardous substances.

METH has been exempted under Section 111 of the Clean Air Act as a photochemical smog contributor. Its atmospheric lifetime is somewhat longer than that of photochemically reactive substances. Its atmospheric lifetime is not long enough, however, to classify the chemical as a stratospheric ozone depleter. In 1985, EPA published an intent to list METH as a hazardous air pollutant under Section 112 of the Clean Air Act but has never actually done so.

In California, the State Air Resources Board has declared METH to be a toxic air contaminant. The agency will enact regulations on the industries where METH is used over the next few years. In Southern California, the South Coast Air Quality Management District has imposed a fee of $0.24 per pound on METH emissions. METH is also listed under California's Proposition 65 as a chemical known to the State of California to cause cancer.

In the last few years, there has been a movement away from METH in many applications. In automotive manufacturing, for instance, METH is rarely used today for booth stripping. The CPSC labelling requirement may reduce the use of METH in consumer stripping. The California ARB's recent ruling will cause users in that state to reduce or eliminate their use of METH in the future.

III. SOURCE REDUCTION OPTIONS

This section discusses the source reduction options that might be effective in reducing or eliminating the use of METH in paint stripping applications. Source reduction options fall into several generic categories including chemical substitutes, process modification, product substitutes, recovery of vapors and recovery of waste. Each of these is evaluated below for the paint stripping end use sectors specified in Table 2.2.

ORIGINAL EQUIPMENT MANUFACTURING-AUTOMOTIVE

The automobile industry has traditionally relied heavily on METH as a paint stripper. As mentioned earlier, the industry has moved away from METH strippers primarily for worker exposure reasons. Indeed, although virtually all automotive plants at one time employed METH for booth stripping, line purging, gun cleaning, floor cleaning and immersion cleaning, probably only a few plants still do so. METH is likely used today primarily in applications like line purging where no worker exposure occurs or in floor cleaning where the paint has cured and other strippers cannot remove it.

Booth cleaning in most automobile plants commonly occurs every night after the day's painting activities. Because there is a short time between painting and stripping, the paint does not have time to cure and booth strippers need not be capable of stripping cured paint. In general, the METH formulation is applied to the interior surfaces of the booth, sometimes with a wax applicator. The formulation is allowed to stand for several minutes and then the residue is washed with a hose into the spray booth water tank. Under Section 114 of the Clean Air Act, EPA required automotive plants to submit information on their METH use. One Section 114 respondent leaves the stripper on the booth walls only 10 minutes (U.S.

EPA, 1987a); another respondent allows the formulation to work for 15 minutes but the application process requires 90 to 120 minutes and removal requires 150 to 180 minutes (U.S. EPA, 198733). If the plant is a large one, it probably has a waste water treatment plant. The residue reaches the treatment plant, is treated and the water is released to the Publicly Owned Treatment Works (POTW).

Line cleaning is required when the paint type or color is changed. For line and gun cleaning, the METH is poured into the circulation system that is used to transfer paint from the mixing room to the paint booths. The internal surfaces of the lines are cleaned as the stripper is pumped through them. Frequently, the used stripper is captured and reused for line purging multiple times. Because the paint in the line is still liquid when the purging takes place, the stripper need not be capable of stripping cured paint.

In floor cleaning, METH stripper is poured onto the floors and spread around, sometimes using wax applicators. After several minutes when the METH has "lifted" the paint, absorbent material is used to pick up the residue and the mixture is sent for disposal. Floors are stripped infrequently--perhaps once a year--and the stripper should be capable of removing cured paint. One Section 114 respondent uses an 85 percent METH formulation for floor cleaning. It takes one hour to apply, is left on for two hours and takes three hours to remove. Absorbent material is placed on the floor and the paint waste, METH waste and absorbent is sent for land disposal (U.S. EPA, 1987c). Since land disposal of chlorinated solvents was banned by EPA in November 1986, these practices presumably predate that time.

Immersion cleaning of hooks, racks, masks, belts and reject parts is also performed in automobile plants. The tanks contain METH alone or in formulations and the parts are dipped in the tanks or left in the tanks for long periods of time. In general, for this application, the stripper should be capable of removing cured paint. One Section 114 respondent cleaned screens and small parts in a dip tank containing METH for 72 hours (U.S. EPA, 1987d). Another respondent leaves masks in a dip tank for 30 to 45 minutes (U.S. EPA, 1987e). A third respondent places defective parts in a dip tank for 24 to 48 hours, sprays them with water and puts them through a washer for 10 minutes (U.S. EPA, 1987f).

Hooks, racks and other related track parts commonly have multiple coatings which are difficult to remove with chemical strippers. Often these are stripped in high temperature ovens or with high pressure water blasting.

EPA solicited data from several automobile manufacturing plants on their 1985 use of METH strippers. These data indicated that spray booth cleaning accounted for the largest fraction--60 percent--of the METH use. Immersion cleaning, line purging and gun cleaning, and floor stripping accounted for 20, 10 and 10 percent respectively (ICF, 1988). In the last few years, since these questionnaires were received, METH use in spray booth cleaning has declined significantly and the percentage of METH allocated to this activity is likely to be much lower. SRRP staff estimate that today booth stripping accounts for only 35 percent. Immersion cleaning, gun and line cleaning and floor stripping account for 35, 15 and 15 percent respectively. The same values are assumed to apply for the nonautomotive manufacturing sector.

There are several source reduction options for the automotive manufacturing industry. They include a variety of chemical substitutes that could serve as alternatives to METH. There are also several process modifications that might reduce or eliminate the use of METH. Recycling of waste and vapors are also potential source reduction options.

<u>Chemical Substitutes</u>

There is,a range of paint strippers on the market today or in the research phase that could serve as alternatives to METH. Several of these are discussed including N-Methyl-2-Pyrrolidone, Dibasic Ester, Furfuryl Alcohol, alkyl acetate, methyl amyl ketone, and Propylene Glycol Monomethyl Ether and acetate and paint thinners. In general, these are flammable or combustible heavy hydrocarbons.

<u>N-Methvl-2-Pyrrolidone (NMP)</u>. NMP is manufactured by GAF Chemicals Corporation (GAF, 1986) and BASF Chemicals Corporation. It takes several minutes to remove paint from surfaces using NMP in contrast to METH's almost immediate action. NMP breaks the bond between the coating and substrate and lifts the coat away from the substrate. It can dissolve multiple paint layers in a concerted action.

NMP is much less volatile than METH. Although the chemical is not exempt from VOC regulations, high levels of emissions will probably not occur during use because of the low volatility. The low volatility also allows the stripper to remain on the substrate longer and less of it will be required to do the same stripping job as METH. Indeed, industry sources claim that one gallon of formulation with 70 to 90 percent METH can be replaced with half a gallon of a formulation of 25 to 40 percent NMP. Thus, four to six times as much METH must be used.

The responses of the auto industry to the EPA questionnaires indicate that METH stripper is left on the booth surfaces for 10 minutes to one hour. The manufacturers claim that NMP formulations can remove uncured paint as quickly as METH formulations. For booth walls for instance, NMP formulations can remove paint in 20 minutes: it takes only 3 to 5 minutes to remove paint from spray guns.

For cured paint, it takes much longer for NMP based formulations to work. In tests by one manufacturer, it took 24 minutes for a METH based stripper to remove four coats of alkyd (one of the most difficult coatings to remove) in three applications. It took NMP 66 minutes to remove the same four coats in two applications. Cured paint would be encountered in floor stripping and immersion cleaning of reject parts. The longer time for NMP to remove cured paint effectively will not present a problem because these activities are commonly done overnight. Even if more time were required, it probably would not affect the assembly line process.

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 costs of using the strippers may be roughly the same for uncured paint. For cured paint, much more time is required for the stripping activity and this increased time could entail an additional cost.

In principle, NMP can be recycled. Immersion cleaning is the only application where this is technically feasible. Recyclers need vacuum stills to remove the contaminants and few have this capability presently. Even fewer users have vacuum units.

In spite of the fact that NMP is biodegradable, sewer release without treatment is unlikely to be allowed because the NMP will contain contaminants from the paint. In booth cleaning, water is used to rinse the removed paint and the NMP formulation into the drain. Although the NMP may not itself require treatment, metals in the paint probably would.

NMP is combustible; it has a closed cup flash point of 199 degrees F. The manufacturers recommend an internal Threshold Limit Value (TLV) of 100 ppm which is lower than the current workplace exposure level of METH placed at 500 ppm. As discussed later, however, OSHA is expected to lower the level to 50 or 25 ppm. NMP has not been tested for chronic toxicity.

Dibasic Esters (DBE). DBE is the name used to describe a stream of mixed 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 16.5 percent dimethyl succinate. Unlike METH which swells and lifts the coatings with bubbling, DBE strippers soften the coating without lifting and bubbling.

For spray booth cleaning, one recommended formulation is (Lucas, 1988):

Component	%(Wt)
DBE	40
NMP	15
Aromatic 150 solvent	35-38
Monoethanolamine	2
Potassium Oleate	4
Thickener	0.8-4

Note that NMP is present in fairly high concentration. Indeed, it has been found that various strippers in combination with one another perform better than each does alone.

Formulations that are successful for immersion stripping include 100 percent DBE; 60 percent DBE and 40 percent NMP; and 60 percent DBE and 40 percent ethyl 3-ethoxypropionate (EEP) (see below). These formulations give batter stripping results with increasing temperature; 95 to 100 degrees F appears to be the best range. Line purging and gun cleaning can best be accomplished with 100 percent DBE (Lucas, 1988). In general, DBE takes two to three times longer than METH to perform equivalent stripping (ICF, 1988).

Like NMP, DBE is not exempt from VOC regulations. Because it is not especially volatile, however, emissions of the substance are likely to be low. Again, the lack of volatility allows DBE to remain on the surface longer than METH so that less of the chemical is required for a particular stripping operation.

DBE is biodegradable and if washed after booth cleaning into the sewer, a biological waste water treatment facility could successfully treat a discharge with up to 1,000 ppm DBE. Paint waste released into the sewer with the DBE, however, may not be allowed by the local sanitation district, particularly if the paint contains heavy metals.

In principle, DBE, like NMP, could be recycled using a vacuum still. Again, however, most recyclers do not have vacuum stills. In immersion stripping, the contaminated DBE would likely be considered hazardous waste because of the waste paint content. DBE, like NMP, has not been tested for chronic toxicity.

Furfury1 Alcohol. These formulations are blended by CLM Company, Nalco and Charles J. Haas. Furfuryl alcohol cannot be used on cured paint without being heated, but is used to remove uncured paint. One source estimates that it is used for 20 to 30 percent of the 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. This would probably not be a problem at most automotive plants since they are generally equipped with explosion proof equipment. The furfuryl alcohol Short-Term Exposure Level (STEL) 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 are probably well below the ppm range. The substance is not exempt as a contributor to photochemical smog.

Furfural alcohol formulations generally contain 20 to 30 percent of the chemical, naptha 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 Acetate. These products are made from 6 carbon to 13 carbon alcohols. Their primary market currently is as solvent ingredients in paint formulations. They are also marketed for paint stripping and are being used for booth cleaning, line purging and gun cleaning. Like the other heavy hydrocarbons, they perform better on uncured than on cured paints.

Again, alkyl acetates take longer to dry and remove paint than METH because of the lower volatility. They are in the combustible category with flash points ranging from 134 to 200 degrees F. Exxon, the manufacturer of the alkyl acetates, has internally set an 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.

Methyl Amyl Ketone (MAK). MAK is made by Eastman Chemical Products, Inc. and Union Carbide. Once again, it is a heavy hydrocarbon with a flash point of 104 degrees F. It is more effective on uncured than cured paint. It takes longer to remove paint than METH. It is not exempt as a VOC but its low vapor pressure would likely result in low emissions. It is more expensive than METH but less is required to strip a particular area. It is sometimes blended with other materials to suppress its odor. Eastman Chemical has set an internal TLV for the material of 50 ppm.

Pronylene Glycol Monomethyl Ether (PM) and Acetate (PMA). Arco is investigating PM and its acetate, PMA, for paint stripping. One formulation contains 50 percent PM and 50 percent NMP. In a test of this formulation, METH lifted an alkyd and a phenolic/alkyd paint film in 15 and 30 seconds, respectively. The 50 percent PM/50 percent NMP formulation required 45 seconds to lift the alkyd film and softened the phenolic/alkyd film in 3 minutes, 30 seconds, but did not lift it (ICF, 1988). Alkyd paints are widely used in machinery, equipment and furniture applications.

Paint Thinners. Many of the auto plants have switched their booth, gun and line cleaning operations to paint thinners which can strip uncured paints. Thinners include active solvents--esters and ketones--like methyl ethyl ketone (MEK) or acetone; latent solvents--alcohols--like methyl or ethyl alcohol; and diluents--aromatics or petroleum solvent--like toluene, xylene or mineral spirits. Baked phenolic paints like acrylics and alkyd epoxy, are not soluble in thinners but air dried paints and lacquers are. However, even though the automobile industry utilizes alkyds and acrylics, they are not usually cured when booth stripping occurs.

Process Modification

There are several alternative processes that can be used to remove paint. They include strippable coatings, alkaline/acid strippers, high-pressure water spray, ovens and high temperature salt baths, physical methods, cryogenic techniques, and sodium bicarbonate.

Strippable Coatings. 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 torn down and replaced. The frequency of disposal depends on the over-spray accumulation and can vary from once a month to once every six 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 tear down coating so frequently. They are already used in other industrial booth applications, however, and could be more widely employed.

Alkaline/Acid Strippers. Alkaline strippers are more commonly used than acid strippers. Acid strippers are more corrosive to metals and they should not be allowed to contact high-strength steel (Hans, 1980). Such strippers operate by oxidizing or dehydrating the paint vehicle and/or the pigment. They can be combined with solvents like alcohols and glycol ethers which may make them easier to work with and more easily inhibited for metal attack (Sizelove, 1972). Acidic strippers can be inhibited against attack on most metals except zinc and some aluminum alloys. However, phosphoric acid in a heated stripper can be used for aluminum and zinc substrates. Nitric acid is used for tough, hard coatings (Mallarnee, undated) and, indeed, can effectively remove even epoxy coatings (Martens, undated).

Alkali strippers have been used for many years. They are commonly heated from lower temperatures up to the boiling point and contain a concentration of caustic in the one to three pounds per gallon range. Generally, the alkaline strippers cannot completely remove pigments and a residue is left on the metal. Alkaline strippers, like acidic strippers, can corrode some metals and they are most commonly used to strip paint from steel parts. These strippers saponify the fatty acid component of the vehicle in the case of oil-based paints and alkyds or the breaking of ester linkages in the case of cellulosics (Sizelove, 1972). They are also effective on gum varnishes and phenolics (Mallarnee, undated), but they are not effective on epoxies. Additives like sequestering agents, surfactants and activators are added to caustic strippers to make them more effective. An example of a caustic formulation in its dry form is shown below (Martens, undated):

Component	Weight (pounds)
Sodium hydroxide	85
Sodium lignosulfonate	6
Sodium gluconate	5
Cresylic acid	3
Nacconol (Registered Allied Chemical Trademark)	1
Total	100

Acidic and alkaline strippers are most appropriate for immersion type applications because they are commonly heated. They would not be especially appropriate for booth cleaning, line and gun cleaning or floor cleaning. They might be suitable for cleaning reject parts and perhaps hooks. Alkaline strippers are reportedly used to clean the grates from paint booths in automobile plants (ICF, 1988).

High Pressure Water Spray. So-called water blasting can be employed to remove uncured paint from booths. One automobile plant in California uses this technique. There are two disadvantages of this method. First, the high pressure water blast may pose a danger to workers. Second, the paint must be removed from the water before sewer release but an adequate filtration scheme could accomplish this.

Ovens and High Temperature Salt Baths. Burn-off ovens operating at temperatures of up to 800 degrees F are used to burn off paint over-spray from hooks, racks or other assembly parts. These ovens may not be appropriate for parts that cannot survive exposure to such high temperatures. Stripped parts are left with a residue of ash which may contain heavy metals and pigments.

The high temperature molten salt bath containing sodium hydroxide is operated at 900 degrees F. In automotive plants, this bath is used to remove accumulated paint from the body carrier or "mouse" (ICF, 1988).

Physical Methods. Cured paint can be removed from body carriers and hooks and racks by chiseling it off. In principle, the same technique could be used for booths in low volume operations. This method is extremely labor intensive.

Cryogenic Techniques. This method might be 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 forces between the substrate and the coating which contract because of the low temperature. Steel commonly shrinks about one percent when the temperature is cooled from 293 degrees K to 173 degrees K whereas a powder coating will shrink 6 times that amount (Industrial Finishing, 1986). The difference in contraction between the substrate and coating causes hairline fractures in the coating.

In one type of cryogenic stripping operation, the brittle, highly stressed coating is bombarded with high-velocity plastic media causing it to crack and debond from the substrate. In another type of operation, after immersion, the parts are placed in a vibratory trough where the paint is removed. The vibration frequency can be adjusted for the part. The plastic media removal method is used for larger parts whereas smaller parts can be effectively stripped in the vibratory trough.

Figure 3.1 depicts a typical cryogenic chamber. The liquid nitrogen is pumped into the chamber. When the rack has been in the chamber for about 10 minutes, the paint is removed with plastic media. The spent plastic media is separated from the paint chips and dust particles for reuse. The residue is disposed of as hazardous waste.

Paint hangers and racks with baked on acrylic are cryogenically stripped 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. 375 racks and hangers require stripping each day. The chamber is operated at a temperature of -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 (Industrial Finishing, 1985).

There are limitations to this method. First, some coatings are more difficult to remove than others. Alkyd, acrylic, polyester, vinyl and lacquer coatings have been removed successfully, but epoxy and urethane coats are not as easy to remove. For these coatings, lower nitrogen temperatures in the -250 degrees F range, are required. Furthermore, coatings between 0.01 and 0.5 inches thick are effectively removed whereas thicknesses less than 0.01 inches are not (Industrial Finishing, 1984). Second, large bulky parts cannot be stripped in this manner. The weight of parts in the chamber is limited to 400 pounds per cycle and the length of the cycle varies between five and fifteen minutes. Third, there are two safety concerns in the process, the inert character of the nitrogen and the extremely low temperatures. The spent nitrogen is exhausted to the outside air and the workers must wear gloves when unloading the parts. Within two to five minutes after the processing has ended, the parts can be handled with bare hands. Fourth, in some cases, the spent media and paint chips are hazardous waste requiring disposal.

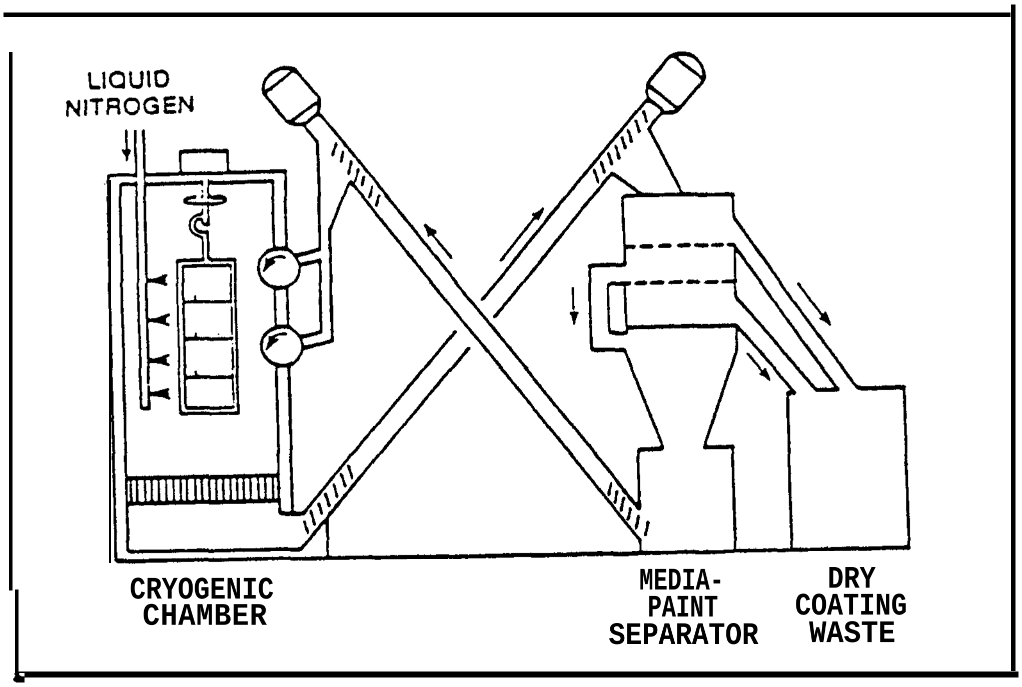


Figure 3.1
Cryogenic Chamber

SOURCE: Industrial Finishing, 1984.

Formulated Sodium Bicarbonate (Bicarb). This is a new technique that utilizes the advantages of abrasion but does not have the disadvantage of the high disposal costs for spent media. The method uses wet air abrasive media in the form of sodium bicarbonate (Amex, 1989). The advantages of wet over dry media are that it keeps the substrate cool, it protects the substrate from damage and it is preferred for dust control. The bicarbonate is 10 percent water soluble, so the surface can be washed down after use. The manufacturers claim that the paint waste can be filtered out for disposal and the water, containing bicarbonate, can be released to the sewer. The blast media, the sodium bicarbonate, cannot be recycled but it can be reused to neutralize any acid streams the plant might have. The technique is potentially appropriate for booth stripping but it should be used carefully so workers are not exposed to a high pressure stream.

Product Substitution

This category would include use of unpainted or precolored items. In the case of automobiles where the cosmetics are of seminal importance, these options are not appropriate.

Recovery and Reuse of Vapors

In principle, the METH vapor releases might be recovered using carbon adsorption or condensation techniques. The METH used in booth stripping, gun cleaning and line purging would be most amenable to capture because booths generally already have airflow systems that could be adapted to capture. Recovery options are discussed in much more detail in the companion document on coatings. As mentioned earlier, virtually all of the automotive plants have already switched away from METH in these applications or plan to do so. Vapor capture and recovery techniques for METH may not be necessary in the future. METH vapors might also be captured from reject parts tanks but this method is less likely to be effective. More appropriate options include water blankets and use of covers.

Carbon Adsorption. Activated carbon adsorption could be used to recover the METH emissions in spray booths. The system would probably not be purchased for METH recovery, but rather, for recovery of other solvents in the painting operation (see the companion document on coatings). One disadvantage would be that multiple solvents--from painting and from stripping--would be collected and separation, probably using fractionation, would be required after steam desorption. If the METH could be recovered, it would have to be reblended with other components in the paint stripping formulation before reuse. A second disadvantage is that steam stripping would generate wastewater that would likely require treatment. A third disadvantage is that carbon systems are difficult to operate and maintenance intensive. A fourth disadvantage is that air flows in paint booths are sometimes very high for worker protection and high air flows raise the cost of carbon adsorption systems substantially.

The KPR system is an unusual rotary carbon adsorption unit that can be employed for solvent capture from spray booths (Modern Metals, 1989). It contains a rotor consisting of a honeycomb element made up of activated corrugated carbon fiber paper. The rotor is divided into two sectors, one for adsorption and the other for desorption. It rotates continuously. solvent vapors in the 5 to 500 ppm by volume range in the booth process exhaust are adsorbed in the proper sector. Hot air is used to desorb the solvent.

The major problem with use of carbon adsorption or, indeed, any other recovery technique, is that the desorbed solvent might not be reusable because it is a mixture of multiple components which cannot always be recovered individually. In this case, the unit is not a recycling operation but is treatment. If the solvent cannot be recovered, the cost of such a system can be very high because it must be accompanied by a catalytic oxidation device or an incinerator. If METH were present in these devices, then scrubbers would be necessary to remove the HCl from the combustion process, increasing the cost of destruction even more.

Condensation. This is another removal technology that might be used to collect METH with other paint solvents. It reduces the gas volume, reclaims solvents and is effective for concentrated vapors. The method is very energy intensive because the entire gas stream--including the air--must be cooled so it can be condensed. Condensed water vapor would become contaminated with METH and could present a water treatment problem. Again, incineration rather than separation and reuse of the components may be the only feasible technique, raising the cost of the system significantly.

Absorption Process. A continuous closed-loop absorption process has been designed without a requirement for steam regeneration. This eliminates the wastewater treatment requirement. The air stream is introduced to a scrubber section where a proprietary solution absorbs the vapors. The solution and absorbed vapors are routed through a filter. The liquid is passed to a vacuum stripper column where the components are separated. They are condensed and available for reuse (Ehrler, 1987).

Water Blanket and Covers. Immersion stripping is performed in tanks that are similar to cold cleaning units (see the companion document on solvent cleaning). One method of reducing vapor emissions is to cover the METH surface with a water blanket, a thin layer of water. This water cover prevents METH evaporation. Another method of reducing losses is to cover the tank when access is not required. In many instances, parts are placed in the tank for several hours or overnight to be stripped. After the parts are placed in the tank, it can be covered: the cover needs to be removed only when the part is completely stripped.

Recovery and Reuse of Waste

METH and formulations containing METH are used in immersion stripping. In this case, the parts to be stripped are placed in a bath and allowed to sit, sometimes overnight. When METH is used alone, solvent recycling firms may take back the contaminated METH. Such firms may then use distillation or thin-film evaporation to reclaim the METH and sell the reclaimed material back into the metal cleaning or paint stripping market.

One Clean Air Act 114 respondent reported that the plant generated 800 gallons per year of waste METH stripper from an immersion stripping operation. The waste contained between 30 and 90 percent METH. If the chlorinated solvent content was high enough, then the solvent was reclaimed by a recycler. If not, it was used for fuel blending (U.S. EPA, 1987c).

There are three options for recycling METH formulations. The first option involves off-site solvent recylers. Some recyclers may be willing to take contaminated formulations and reclaim the METH for sale back into the market. Several automotive plants have used METH alone or almost alone for immersion stripping (U.S. EPA, 1987e; U.S. EPA, 1987g). Others use formulations with less METH, 40 percent by volume (U.S. EPA, 1987d); 49.5 percent by weight (U.S. EPA, 1987b); 56.4 percent by weight (U.S. EPA, 1987f) and 76 percent by weight (U.S. EPA, 1987g). One of these, the user of the 56.4 percent formulation, sends the spent stripper to a recycler (U.S. EPA, 1987f). Solvent recyclers may not be able to utilize the other major components of the formulations which can include phenols and formic acid. They would have to do the separation and arrange for incineration of these substances. One recycler refuses to accept spent paint stripping formulations containing acids. He claims that processing the materials would endanger workers. On the other hand, this recycler does take back METH from paint stripping operations when it is used alone. Use of METH alone for paint stripping would increase the METH requirement but it might also allow more of the METH to be recycled. This could end up in a net reduction of the virgin METH requirement. The disadvantage of this strategy is that METH, by itself, is not an especially good stripper.

The second option is on-site recycling of METH when it is used alone for immersion stripping. Distillation units are available for solvents and this technique is employed by many firms that use METH for metal cleaning. One firm in the Section 114 questionnaire reports using a 100 percent METH stripper for mask stripping. This firm has an on-site still for reclaiming the contaminated METH (U.S. EPA, 1987g). Advantages and disadvantages of on-site recycling are laid out in detail in the companion documents on solvent cleaning and electronics.

The third option would be for stripper formulators to take back the waste METH and reuse the components in new formulations. To our knowledge, none of the formulators currently offer this service but at least one large formulator is exploring the possibility. In principle, formulators would be in a better position to take back METH formulations than solvent recyclers because they could use the non-METH formulation components as feedstock in their new blending operations.

There is one option for recycle and reuse of METH used in line and gun cleaning. One firm is marketing a gun cleaning station that can be mounted on top of a sealed 55 gallon drum or a work bench (Burbank Paint and Hardware, 1989). It is an air-driven, solvent condensing unit and it can be used with siphon-feed or pressure-feed spray guns. The device draws the

METH into a fiberglass unit and condenses it for reuse.

Recovery from Wastewater

In automotive plants, after METH stripper is applied, the walls are generally washed down with water. The water, now containing METH, is commonly sent to the pretreatment system. In the Clean Air Act 114 responses, one automotive plant reported that the METH concentration in the influent was not measured and only total organic limits are met in the effluent discharged to the POTW. The METH is air stripped in treatment tanks (U.S. EPA, 1987d). Another plant reported that more than 50 percent of the METH in the influent evaporated and that the effluent discharge to the POTW contained a concentration of METH less than 1000 g/l (U.S. EPA, 1987a). A third plant estimated the influent and effluent METH concentrations at 20 and zero g/l, respectively (U.S. EPA, 1987g).

A fourth plant reported on its operation in detail. The booth stripping was performed every night and the stripping material was rinsed into the water system. The paint sludge was skimmed off the surface of the water regularly. About 8,000 gallons of water per day are aerated. The amount of METH in the effluent in the waste water treatment facility entering the POTW ranged from 0 to 800 ppb (U.S. EPA, 1987c).

In principle, the METH could be recovered from the wastewater for reuse. The METH could be stripped from the water, collected on a carbon adsorption device, and desorbed for reuse. This technique would be very expensive and the dilute concentrations of METH in the water stream make it even more expensive.

ORIGINAL EQUIPMENT MANUFACTURING - OTHER INDUSTRIAL

One source provides a breakdown of the use of METH for paint stripping in various manufacturing sectors of the economy

(ICF, 1988). The sectors definitely using METH include metal furniture where METH is employed in high volumes for reject stripping and equipment cleaning. Paint is generally applied electrostatically because the substrates are metal and can accept a charge, and METH based strippers are employed for cleaning guns and lines, booths and reject items. METH is also used in electronics for stripping various items. Such activities including stripping metal electronic boxes, removing varnish from PC boards and stripping computer boards and cabinets.

Another sector where METH is employed for paint stripping is the aerospace industry. A small amount of METH is used for booth and equipment stripping and METH based strippers are used for reject stripping. METH is also used for maintenance stripping of ground vehicles and aircraft and this particular application is discussed in more detail later.

The appliance sector likely uses METH for reject stripping. In this sector, there is a trend toward prepainted metal sheets. Indeed, one garbage disposal manufacturing firm SRRP staff visited used prepainted canisters for one line and did its own painting for another line. There is no evidence of METH use in the Machinery and Equipment, Marine, and Transportation sectors where mechanical methods are commonly employed. In the coil, film, paper, wood flatstock, and containers and closures sectors, METH is probably not used because roller coating is common and metal sheets are precoated and molded to shape. In Wood Furniture and Fixtures manufacturing, flammable solvents (paint thinner) are used to clean equipment and sanding is commonly used for rejects (ICI?, 1988).

In the automotive industry the cosmetic appearance of the paint is of paramount importance. In other industries, cosmetic appearance may not be as important. Indeed, metal filing cabinets need to look good but do not require the finish of a new automobile. The lower emphasis on cosmetic appearance in these applications suggests that less stripping of rejects is required in the nonautomotive manufacturing sector on a per unit basis. However, the characteristics of use are the same. METH is employed, to some extent, for line and gun cleaning, for booth stripping, for immersion stripping and for floor cleaning. The alternative strippers and stripping methods described in the automotive manufacturing sector apply in this sector as well. Their feasibility in a particular case will depend upon the characteristics of each specific operation.

MAINTENANCE - MILITARY

All of the military branches require periodic maintenance for vehicles including tanks, helicopters, jeeps and other aircraft. Currently, these vehicles are stripped by two methods. The first is chemical stripping with various METH based formulations. These formulations are used to strip paint from softer substrates like aluminum, copper, wood and composites. These strippers are generally sprayed or brushed on. After the stripper has softened the paint, the paint sludge is removed by mechanical scraping and a water wash. In the past, the sludge, which contained stripper as well, was simply flushed into the wastewater system.

Until a decade ago, most strippers were composed of METH and phenols or cresylic acids. The EPA discouraged the use of these compounds because of their toxicity and their deleterious effects on wastewater treatment plants. Most strippers were converted to formulations containing formic acid instead of the phenols and cresylic acid. [ed. note: Some phenolic-based strippers are still in use at military facilities].

The second type of paint stripping activity that is employed in the maintenance of military equipment is abrasive blasting. 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 particular applications.

Paint strippers are chosen in military applications through complex procedures or specifications (ICF, 1988). There are three types of specifications. The first cites an actual formulation that may be used. The second is a performance specification that includes a list--called the Qualified Products List or QPL--of products and manufacturers that have been approved. The third is a broad based performance specification that allows new products to be used as they become available. In spite of the existence of this third option, it is nevertheless an extremely complicated process to get a new product or process accepted. The command within the armed services branch responsible for the vehicle and the maintenance contract must give approval. When a new product or process is more cost-effective or efficient, the command must issue a waiver which becomes an amendment to the maintenance contract.

The military sector has pioneered use of and research into several techniques that are alternatives to METH stripping. Alternative chemical strippers are not especially appropriate for military vehicles because none of them can effectively remove the cured epoxy or polyurethane coatings on these vehicles. One alternative process--abrasive techniques--which are used by a number of military bases today are appropriate for stripping cured epoxy and urethanes. A number of other alternative processes--cryogenic methods, lasers, high intensity light, carbon dioxide, and sodium bicarbonate--are also appropriate.

Process Modification

As discussed above, there are a variety of abrasive media that can be used for removing paint and for other activities. Table 3.1 shows a range of media, together with a measure of their hardness called Mohs Number. The Mohs Number is a relative scale of hardness where talc has a hardness of 1.0 and diamond, a hardness of 10.0. Plastic media, with a hardness ranging from 3.0 to greater than 4.0, appears to have the best characteristics for stripping military vehicles.

Plastic Media Blastina (PMB). U.S. Technology Corp. was the first firm to introduce plastic media into the market. Three grades are available. The first is Polyextra(R) with an 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 media as well. DuPont manufactures two types--Type C(R) and Type L(R)--with hardness of greater than 4 and 3.5 respectively. Other suppliers include MCP industries, Aerolyte and Tierco; these latter two manufacturers also make plastic media blasting equipment.

In plastic media blasting, the plastic beads are forced at high velocity through a nozzle at the painted surface. The beads are abrasive because of their rough edges and they impact and dislodge paint or grit from surfaces. All of the blast media used in the past had limitations. Some were too hard and visibly damaged substrates whereas others were so soft as to be ineffective. Plastic media is manufactured to the desired hardness which is harder than coatings but softer than most surface materials. Uniform in its properties, plastic media is angular and contains irregularly shaped particles.

Table 3.1

Hardiness of Various Abrasive Media

MEDIA	MOHS NUMBER
Talc	1.0
Walnut	3.0
Plastic Beads	3.0 to >4.0
Glass Beads	5.5
Silica Sand	6.0
Stazurolite Abrasive Sand	7.0
Aluminum Oxide Pellets	9.0
Diamond	10.0

Sources: Batelle (1987), ICF (1988).

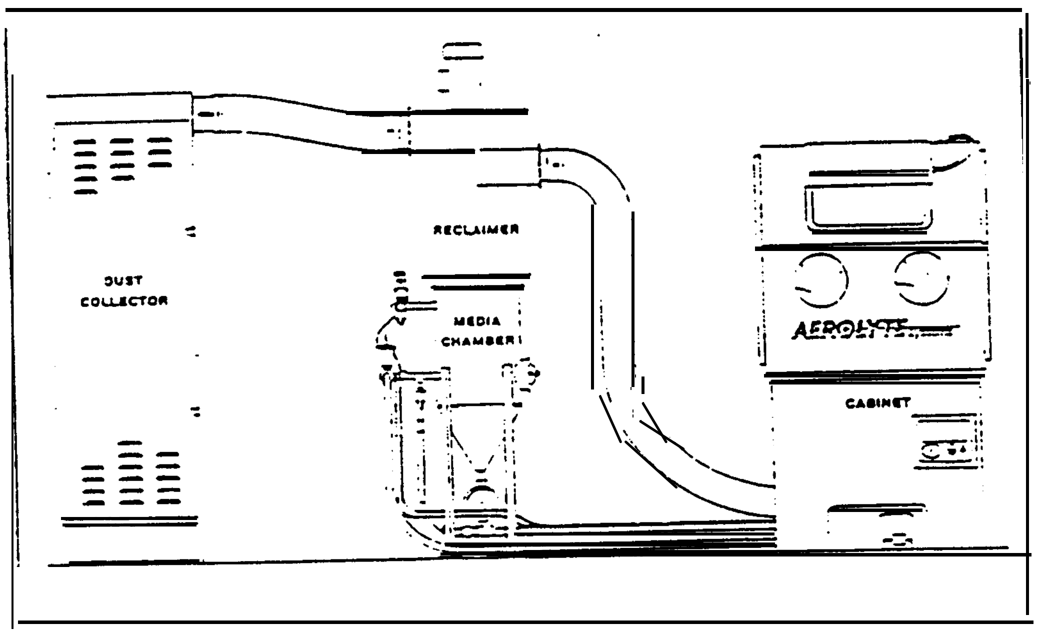
When plastic media was first introduced, equipment manufacturers tried to adapt traditional sand blasting equipment. They soon realized that PMB had different characteristics that made it necessary to redesign all modules of the equipment. Today, some firms with traditional blasting equipment also offer a separate line for PMB and there are new market entrants who offer only PMB equipment.

There are two types of PMB operations. This first is the blast cabinet or so-called glove box which can remove paint from smaller parts like aircraft subcomponents or other subassemblies. Pressure blast cabinets have small blast machines outside the glove box and a totally enclosed cabinet where all blasting is performed. Safety equipment is not required because the operator remains outside the cabinet. This type of operation is shown in Figure 3.2. The media is fed into the cabinet from the chamber. The used media and paint waste are pulled into the reclaimer where the usable media are separated from the residue which is routed to the dust collector.

The second type of operation is the blast booth or room which is a large area designed for stripping large vehicles or aircraft. Since operators perform blasting in the room, they must wear safety equipment. PMB chambers, whatever their size, must have certain fundamental components (NCEL, 1986). The first is the blasting machine itself. In the most powerful, a direct pressure type, plastic media is stored in a pressure vessel, fed prominently into a hose and ejected through a nozzle

Figure 3.2

Typical Blast Cabinet



MEDIA CHAMBER
- Pinch valve media control
- 45° media flow
- Remote controls
- 60° conical bottom
- Pressure relief valve

CABINET
- High volume foot valve
- Large armholes
- Rubber curtains
- Moisture separator
- Pressure gauge
- Pressure regulator
- Doors on both sides

DUST COLLECTOR
- Tubular cloth filters
- Steel enclosure
- Dust drawer
- Air volume damper

MEDIA RECLAIMER
- Adjustable air inlet
- Debris screen
- Efficient dust separation

SOURCE: Aerolyte, undated.

at high velocity. A second type of machine is the suction or venturi design in which compressed air expands through a nozzle creating a venturi effect. The second essential component of a blast system is an air compressor for supply of clean, dry compressed air. The third and fourth components of a blasting system are a recovery method for recycling plastic media and a dust control system for protection of the workers.

In a media recycling system, the spent media and the removed paint must be recovered, transferred to the recycler where the reusable media is separated from the waste, and additions of fresh media must be made. In blast rooms and booths, pneumatic floor recovery systems scavenge the spent media. Operators in blast cabinets must generally pick up the media, perhaps with handheld tools, transferring them to a vacuum. Media separators or cyclones classify the media, paint, and dust fines. The clean media is returned to the blasting machine and the dust fines and pulse are drummed for disposal. Manufacturers claim that 90 to 95 percent of the media can be reclaimed after each blast cycle and one claims that new media can be used 10 to 20 times before breaking down (NCEL, 1986).

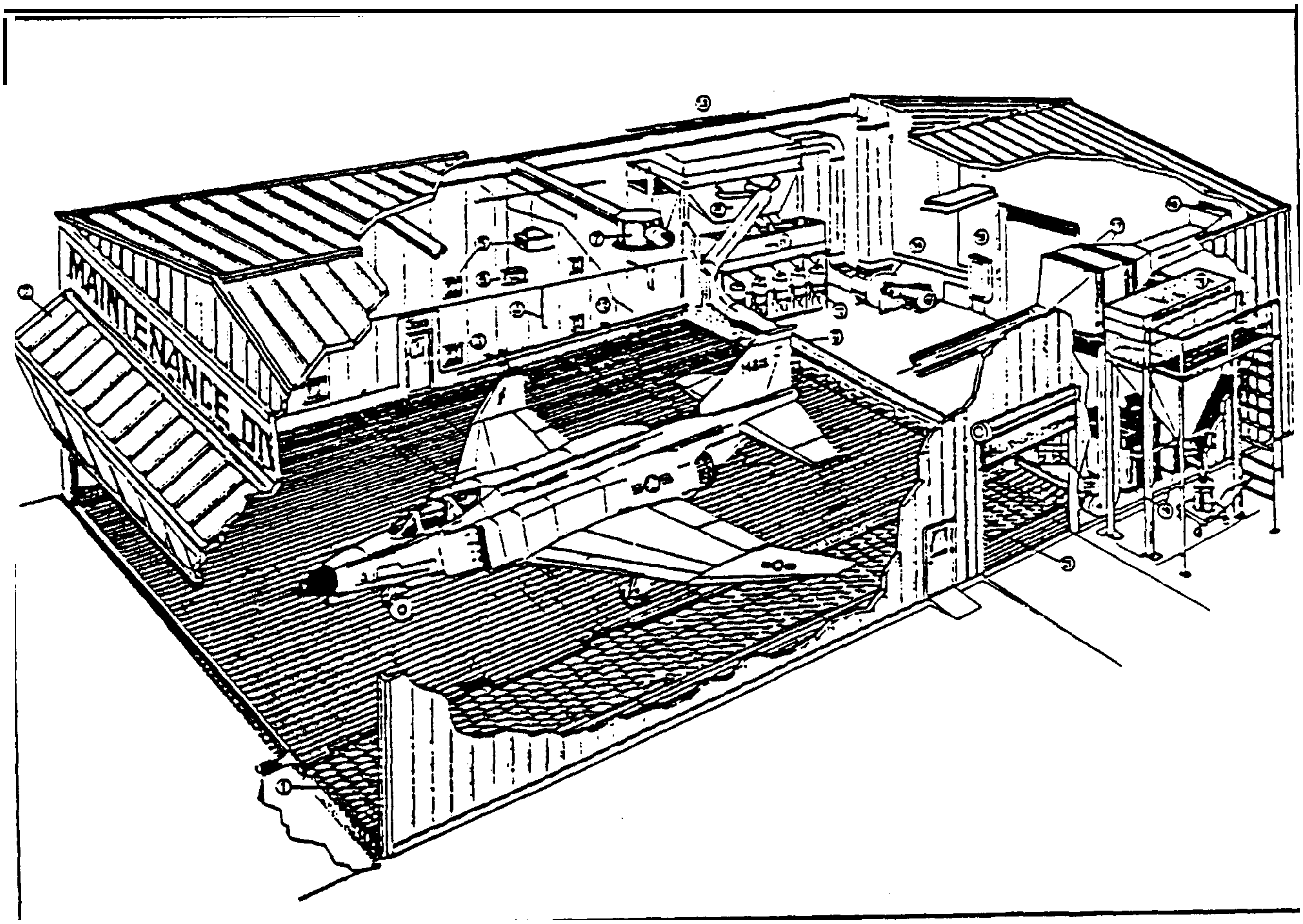
There are a variety of dust collection systems. The baghouse or tubular bag collector is the most common and probably the most reliable. Dust is collected on the inside or outside of the filter and the system must be shut down periodically to clean the bags. Reverse pulse jet collectors are self cleaning but much more expensive. There are also other dust control devices like cartridge collectors, envelope collectors and wet collectors.

Plastic media blasting has been pioneered by the military and it has been used with great success at a number of military facilities. Corpus Christi Army Depot (CCAD) has been examining PMB since 1983 (CCAD, 1984; CCAD, undated). CCAD is responsible for overhauling various types of helicopters which are stripped every five to eight years on average. One impetus in investigating PMB was the new requirement to switch to chemical agent resistent coating (CARC) which was projected to increase stripper requirements to three times the present level. The EPA NPDES permit issued to CCAD in 1984 was more stringent and the permit was scheduled to be reissued in 1989. If that permit were even more stringent, then METH would not remain a viable stripping option. The depot's investigation of PMB shows that the technique is more cost-effective than use of METH stripper. Indeed, CCAD projected savings associated with labor, materials and waste disposal at $1 million annually with PMB.

Hill Air Force Base has also investigated PMB for stripping, in this case, for F-4 aircraft (Hill AFB, 1986). A blast booth is the base depicted in Figure 3.3. These aircraft contain multiple coats of epoxy, enamel, lacquer and polyurethane which have been applied on top of one another. Because of a negative impact on performance, Hill AFB decided to strip the aircraft to bare metal and repaint with a standard polyrethane. PMB was investigated; projections were that the technique would save about $2.8 million annually and reduce the time to strip one F-4 aircraft from 364 hours to 183 hours.

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

Figure 3.3
Blast Booth For F-4 Aircraft
Hill Air Force Base, Ogden, Utah



SOURCE: Pauli and Griffin, undated.

In a Boeing Vertol program, stripping of exterior paint from the fuselage and interior areas of 436 CH-47 aircraft will be required over the next decade. PMB was investigated and found to be a viable alternative. In August, 1985, a temporary facility for 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).

In addition to the hardness of the media as described in Table 3.1, there are other variables that require attention so that the PM blasting technique can be optimized for a particular application. These variables include the blast pressure, distance from the nozzle to the workpiece and the angle of approach. Table 3.2 shows these variables for different thickness of aluminum aircraft skins and for a few different subtrates.

The values of Table 3.2 indicate that the thinner the aluminum substrate, the lower the nozzle pressure, nozzle distance, and the angle of repose should be. The F-4 at Hill Air Force Base required a pressure of 35 to 40 psi and the helicopters at Corpus Christi Army Depot required an even lower pressure--25 to 35 psi. The values of Table 3.2 also indicate that fiberglas and kevlar require the lowest pressure, distance, and angle of approach.

Another very important issue is worker training. Much testing to adapt the particular hardness and pressure equipment to develop a proper worker technique is required. Indeed, workers must be well trained to adapt to the method. Many plants have had problems with PMB and it is frequently because workers have not been trained sufficiently to deal with the new parameters.

Parameters for Paint Removal from Aircraft

PARAMETER	ALUMINUM SKIN 0.030 inches or greater	ALUMINUM SKIN 0.022 inches to 0.030 inches	ALUMINUM SKIN less than 0.022 inches	GRAPHITE EPOXY COMPOSITES	FIBERGLASS AND KEVLAR
Nozzle Pressure (psig)	45-55	35-40	25-30	25-30	15-25
Nozzle Distance (inches)	36-48	30-36	24-30	24-36	18-24
Angle of Approach (degrees)	45-75	30-60	15-45	15-45	15-30

Source: Aviation Mechanics Journal, 1986.

There are several disadvantages to stripping with PMB. First, some people claim that the dust generated during the blasting operation creates an unsafe working environment. The dust from particles of media and 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 the ignition source strength. The virgin plastic media is not by itself explosive, but the presence of fine particles can make the environment dangerous. To prevent exposure to the dust, workers must wear protective equipment in blast rooms and booths. This equipment 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).

The second problem with plastic media is that some people believe it causes damage to the substrate. There is considerable controversy on this issue and it is an extremely important one because of safety and reliability concerns. The four areas that could be a problem are that PMB might remove the protective cladding: it might reduce the fatigue life of the vehicle: it might cover over evidence of fatigue cracks; and it might itself cause cracks.

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).

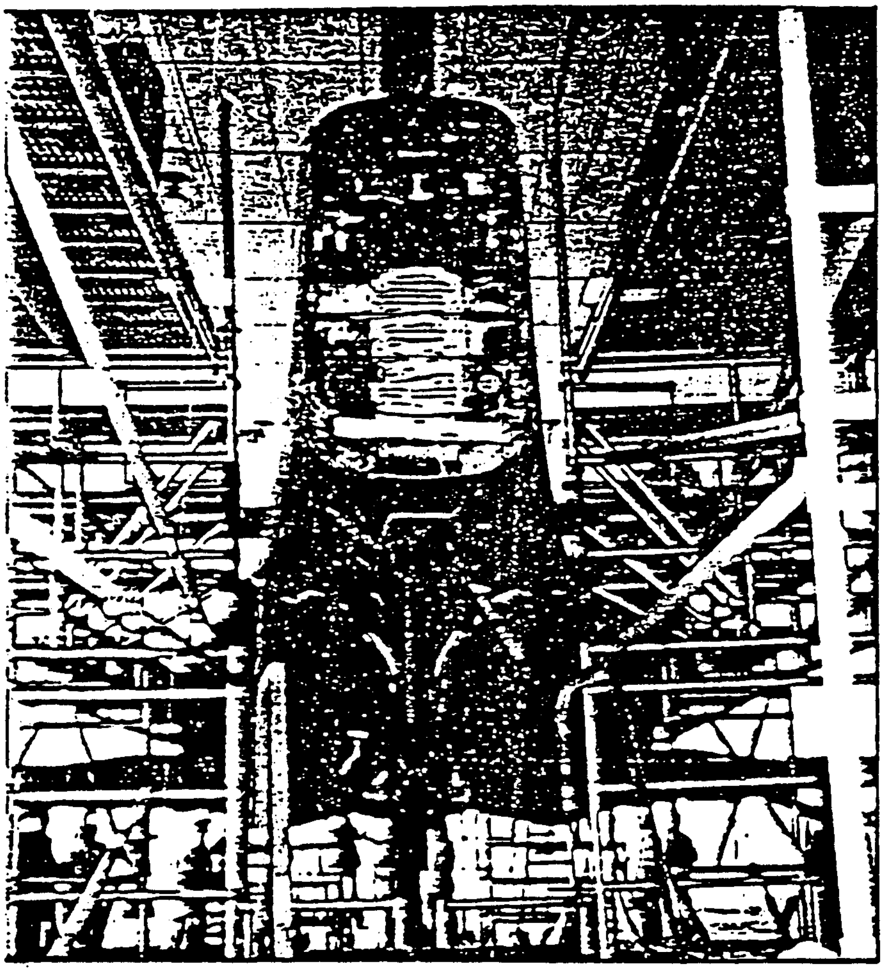
Tests sponsored by the Corrosion Office at Warner Robins Air Force Base were designed to determine whether PMB shortened the fatigue life of aircraft. The tests showed that with aluminum sheet of 0.065 inch thickness, the fatigue life is reduced by less than 25 percent, a modest reduction. With aluminum sheet of 0.030 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 (Batelle, 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).

The third concern is that PMB will move the cladding to cover fatigue cracks that already exist. Tests at Hill Air Force Base indicate that this 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).

The fourth issue is whether the PMB process can itself cause cracks to develop. In tests performed at Warner Robins Air Force Base, surface pits containing foreign metals or silica were found after blasting with plastic media. The pits containing foreign matter can act as so-called stress risers which can initiate cracks. This suggests that the media cleaning systems must be complex and contain devices for removing contaminants. In fact, even this may be insufficient since virgin media also appeared to cause the foreign contamination. Proponents of PMB indicate that more serious stress risers are created with hand sanding (ADL, 1987). Results of Batelle testing suggested that fatigue cracks were initiated at small surface craters which Batelle believed were produced by contaminants in the media. The findings indicated that PMB created stress that caused crack growth (Batelle, 1987).

Detractors of PMB cite the problems with 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). To some extent, these problems can be solved by masking entry points. Figure 3.4 shows an F-4 aircraft that has been masked in preparation for a PMB operation. Better equipment with nozzles that spray unused media and ingest loosened, blasted material can also minimize the problem (Aviation Mechanics Journal, 1986).

Rear View of F-4 Tail Section with Protective Masking and Exhaust Outlet Plugs



SOURCE: Aviation Mechanics Journal, 1986.

Another question that arises in PMB is whether or not the waste is hazardous. Table 3.3 shows the results of chemical analysis for heavy metals in virgin PMB and PMB floor dust generated in a stripping operation on Army Communications shelters. Military paint as demonstrated in the table contains fairly high levels of cadmium, chromium, lead, nickel and zinc. Under federal regulations, a waste is hazardous if leaching of heavy metals occurs under the EP toxicity test. Chromium and lead must not exceed 5 ppm and cadmium must not exceed 1 ppm (ADL, 1987). In the PMB floor dust of Table 3.3, the values for chromium, lead and cadium significantly exceed these levels. Although some operations might yield waste with lower metal concentrations, it is likely that most military paint waste, because of the chromium content, would end up being classified as hazardous.

The level of waste that is generated depends on several factors including the number of stripping operations, the amount of media used, the degree of recycling that is possible and the number of paint coats requiring removal. At Hill Air Force Base, for instance, PMB stripping of each F-4 aircraft yields 1500 pounds of waste. On an annual basis, the stripping of 205 aircraft results in 307,500 lbs or about 140 mt (NCEL, 1986). Although much of the media is recycled, this still represents a huge amount of hazardous waste requiring disposal.

With this in mind, the Air Force commissioned a study on reducing the amount of hazardous waste generated during plastic media blasting (Tapscott et al, 1988). The research involved collecting and analyzing PMB samples from various Air Force bases and analyzing different options for rendering the waste nonhazardous. The findings suggested that incineration was possible but that siting was likely to be a barrier.

Chemical treatment using extraction was effective for chromium but not for cadmium or lead--other components of paint.

TABLE 3.3
CHEMICAL ANALYSIS OF PMB

METAL	VIRGIN PMB	PMB FLOOR DUST
Antimony	<1	4
Arsenic	<l	<l
Cadmium	5	16
Chromium	5	72
Copper	2	4
Lead	<l	64
Mercury	<0.01	<0.01
Nickel	37	81
Silver	<l	<1
Zinc	490	570

Source: Wolbach and McDonald, 1987.

Aqueous extraction for chromium-only wastes has the disadvantage of generating liquid waste streams. Heating the PMB at high temperature to form a char would lead to permit problems and air pollution. Encapsulation would also require a permit and it increases the volume of the waste. Density separation through flotation using carbon tetrachloride successfully separated a metal bearing and nonmetal bearing fraction. However, the carbon tetrachloride metal waste would require disposal. Decreasing the amount of PMB that was recycled could reduce the metals concentration and render the waste nonhazardous. In this case, however, the raw materials costs and overall waste volumes could increase significantly. Size separation--the metals from the PMB--did not significantly reduce the hazardous waste volume. The study did not identify any especially promising techniques for reducing or eliminating the PMB waste.

A difference between chemical and plastic media stripping is that chemical stripping does not alter the rough-machined aircraft surfaces. In contrast, PMB leaves a rough "tooth" which is better for bonding the paint. Unfortunately, it may also require more fill and a somewhat larger quantity of primer than is required to obtain a smooth quality finish (Parrish, 1987). [ed. note: PMB may also hide or smooth over micro-cracks in the metal (especially aluminum), which makes visual safety inspections more difficult. Special crack detector equipment might be required to perform a thorough check.]

On balance, PMB seems to offer significant promise as an alternative to METH based strippers for removing paint from military vehicles and aircraft. It appears to be cost-effective, but the issue of substrate damage has not been resolved and is likely to remain controversial for years to come. METH dip tanks are also used for stripping small parts in military applications. PMB is an alternative and several firms that produce automated blast equipment have modified it for use with PMB.

Sodium Bicarbonate. This method was discussed under "Original Equipment Manufacture-Automotive". It is an experimental wet abrasive technique that utilizes sodium bicarbonate as the media. Kelly Air Force Base has tried the technique for stripping paint from aircraft. The base has put in a new PMB operation, but would like to avoid the high waste disposal volumes and cost. According to this user, the operating costs for PMB and the bicarbonate process are about the same. PMB requirements amount to 800 pounds per hour whereas the bicarbonate requirements are much lower--150 to 200 pounds per hour. The total cost of the bicarbonate process is lower because of lower disposal costs for the solid paint chips. The used bicarbonate cannot be reused in stripping but it can be used for neutralization of an acid stream in another part of the operation.

This technique holds significant promise for stripping aircraft. Although this technique is not as likely to mechanically damage the substrate as PMB, it does potentially pose another problem. There are concerns about possible long-term corrosion because of the water based process. For airframes, in particular, this can be a problem. Firms are also performing tests on the best method of adding corrosion inhibitors. Smaller parts, once they are stripped, can be immersed in a mildly acidic formulation to neutralize the basic soda ash that is formed in the process. For airframes, the soda ash can penetrate under the skin and into crevices.

One aerospace chemist is examining the possibility of using magnesium carbonate rather than sodium bicarbonate. She believes that this media has the proper hardness characteristics, but will not be as corrosive (Doscher, 1989).

Cryogenic Stripping. This technique, described in detail under Original Equipment Manufacture, might be used in military applications. Because the process must take place in a chamber, it cannot be used for stripping aircraft or other vehicles in the field. It could be used for stripping parts removed from vehicles and aircraft.

Laser Paint Stripping. The use of lasers for ablative material removal was first proposed in 1987. Although the mechanism of removal is not known with certainty, it may occur as follows. The light from a pulsed laser impinges on an organic molecule and breaks the chemical bonds holding the molecule together. This causes an instantaneous increase in the volume of the material which then causes the material to be blown away from the surface (Allison and Rudness, 1987). Although the paint, which is composed of organic molecules, could be removed using such a laser technique, laser removal is still in the early research stages and many issues remain to be resolved.

The advantage of the laser system is that a laser frequency could be chosen to maximize paint removal and concurrently minimize substrate damage. Characteristics of the paint and substrate must be well understood to take full advantage of the selectivity of the system. In principle, the frequency of absorption of the paint and the substrate would be known. The laser would be operated at the absorption frequency of the paint causing the paint to "blow off" the surface while the substrate remained unaffected.

One group has performed research to determine the feasibility of using a pulsed neodymium/yag laser for removing the polyurethane topcoat and the epoxy primer from a carbon fiber-epoxy composite. Four frequencies--1060, 532, 355 and 266 nm--were used and evaluated empirically. Paint removal was ineffective at 266 nm. At 532 and 1060 nm, there appeared to be broken fibers which may have been caused by the laser or they may have been present in the substrate from the outset. The 355 nm frequency seemed to give the best results (Allison and Rudness, 1987). This group compared laser removal with PMB and found a cleaner surface with the laser. Removal rates with the laser were slow but could potentially be scaled up.

There are several problems to address before such a system could be applied. First, optics for removing paint from curved surfaces would have to be developed. Second, a safety system for operators would be essential. In the ideal, the system would be completely automated with a sensing mechanism to control start-stop, laser power, rep rate and operating time. Third, the debris after removal would have to be characterized and disposed of. Particles would probably contain chromium, cadmium and other metals from the paint. The waste could also be composed of organic molecules of unknown structure; these would have been formed in the bond breaking process and recombination of radicals may have occurred. It would be vital to assess the makeup of the organic waste.

Another group is investigating a pulsed carbon dioxide laser for paint removal from aircraft (Lovoi, 1989). They used a computerized method based on color variation to control the laser pulsing. 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 substrate types (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, dried and placed in a waste receptacle. The vapors are thermally oxidized at temperatures above 1400^0 F to form carbon dioxide, nitrogen and water vapor.

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. The material may sublime, pyrolyze or chemically dissociate. If the frequency is chosen judiciously, there is no damage to the substrate. 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).

This method has been demonstrated on a fuselage panel from a navy aircraft. The residue from the flash lamp pulse was a fine, black dust that coated the panel. This dust can be wiped away with a rag which, presumably, would be considered hazardous because of the presence of metals. The technique is currently being demonstrated in the field.

Laboratory investigation of the flash lamp technique was performed at McClelland Air Force Base. The flash lamp was a 9-inch xenon arc flash lamp and is the largest manufactured to date. The tests were conducted on an F-111 aircraft wing with an epoxy primer and an acrylic topcoat and composites of graphite/epoxy with a fiberglass outer layer 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 capability for field use. Problems that remain to be investigated are that the flash lamp needs to be fitted with a mechanical movable quick disconnect head and specially designed heads are required for stripping paint from corners and various other geometries. The base anticipates a five-year savings of $1,661,824 from use of the flash lamp compared to chemical stripping.

Carbon Dioxide Pellets. Blasting of surfaces with carbon dioxide pellets was first proposed at Lockheed in California in 1969. The dry ice pellets were reasonably hard and they were thought to produce no debris (Fong, 1974).

At least one firm is marketing a carbon dioxide system (Del Crane Cryogenics, undated). The liquid carbon dioxide is maintained under pressure in a reservoir. When it is allowed to expand through a nozzle, the temperature declines to -110 degrees F as the carbon dioxide sublimes (forms a gas). Part of the carbon dioxide will flash into a snow and the rest is vaporized. The snow can be compressed and formed into pellets. Liquid carbon dioxide is transferred to a pelletizer; the pellets of dry ice are pumped up an air pressurized line and then to the nozzle. A jet of pressurized air and dry ice is directed to the surface. Tests with the pellets were effective in removing paint from metal surfaces. Their applicability for removing paint from military parts and vehicles would have to be investigated in-depth.

After the pellets are used for paint removal, there will be a mixture of pellets and removed paint. Within a few minutes, the carbon dioxide will sublime leaving a very small volume of contaminants which must be treated as hazardous waste. Again, the removed material includes paint particles which probably contain chromium and cadmium. Carbon dioxide contributes to global warming and there might eventually be restrictions placed on emissions of the substance.

Biodegradation. This technique, although still in the research phase, holds promise for stripping paint. The method is being investigated at Hill Air Force Base (Hedberg, 1989).

The base has completed two phase one studies of the applicability of the method. In the first approach, microorganisms were able to use polyurethane based paint as nutrients, in effect removing the paint. A drawback was that the organisms required four to five weeks to degrade the paint. One method for reducing this time would be to isolate the enzymes in the microorganisms rather than using the microorganisms themselves. This work is in progress and it may speed up the stripping time significantly.

The second approach involves reformulating the polyurethane paint to contain cellulose and elastin--two substances that are nutrients for the microorganisms. Then when it is time to remove the paint, the microorganisms can be placed on the substrate. This line of investigation is probably more promising over the long-term. [ed. note: 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, still in the research phase and are unlikely to have practical application for some years.

MAINTENANCE-COMMERCIAL AIRCRAFT

Commercial aircraft maintenance is similar to military aircraft maintenance. In this case, however, there is much more emphasis on cosmetic appearance. Many airline personnel believe that profits are directly linked to appearance. Thus, the primary reason for frequently removing paint and repainting is to keep the aircraft looking good. In addition to the airlines themselves, there are several firms that provide painting services to smaller airlines and corporate aircraft owners. Nearly all of these firms have traditionally used METH based stripping formulations.

In general, stripping of commercial aircraft is performed as follows. The formulations range from 50 to 85 percent METH and they are allowed to contact the aircraft for approximately two hours. The stripper and loosened paint are removed from the surface with rubber squeegees and plastic scrapers. The residue is collected on plastic sheeting spread beneath the aircraft. The sheeting and the residue is collected in drums and sent for disposal. After the stripping process, the aircraft goes through a series of rinsing and brightening steps. The rinse water, containing small amounts of METH, is sent to the pretreatment facility before release to the sewer system.

One Section 114 respondent indicates that the METH concentration in the waste is 2,000 g/l. After going through the pretreatment process, the concentration entering the POTW is much lower--at 50 g/l (TWA, 1987). Another respondent indicates that the concentration of METH in the waste amounts to less than 10 percent (Aircraft Paint Services, 1987).

As mentioned earlier in the discussion on military maintenance, there are really no alternative chemical strippers available today for removing the very tough epoxy and urethane coatings used on aircraft. Process modifications using abrasive techniques--and PMB and sodium bicarbonate, in particular--are the most promising. Several of the other process modifications discussed under military maintenance are also appropriate here. An additional option, a product substitute, not painting at all, is also possible in commercial aircraft depainting.

Process Modification

Six process modification options apply to commercial aircraft. They include PMB, cryogenic techniques, laser removal, flash lamp removal, carbon dioxide and sodium bicarbonate. The discussion that follows plastic emphasizes the differences between military and commercial aircraft.

Plastic Media Blasting. As indicated in Table 3.2, the nozzle pressure and distance and the angle of approach for any particular application must be selected judiciously depending on the thickness of the skin and type of substrate. As mentioned earlier, the F-4s at Hill Air Force Base and the helicopters at Corpus Christi Army Depot required pressures of 35 to 40 psi and 25 to 30 psi respectively. Commercial DC-9s stripped several years ago by Republic Airlines before it was taken over by Northwest Airlines required much higher pressures of 50 to 60 psi. The smaller general aviation aircraft have thin skins and would probably require much lower pressures, perhaps in the 25 to 30 psi range.

The first commercial airline to use PMB was Republic Airlines, now part of Northwest Airlines. They began the operation in May of 1985. Between May of 1985 and March of 1986, they used the process to strip more than 50 aircraft in changing over to a new paint scheme. The decals that Republic used on their aircraft proved especially difficult to remove. They 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. These savings resulted from reduced turnaround time; chemical stripping required 7 days, whereas PMB required only 5 (Aviation Week, 1986). Use of an aircraft has been estimated at $30,000 per day indicating that one day of down time requires $30,000. These savings are augmented by an average savings of $4,000 per plane in labor and other factors (Aviation Week, 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 inlet of the blasting machine. The machine separates the residue and dust from the reusable media (Aviation Mechanics Journal, 1986). Republic is able to recycle 90 to 95 percent of the media and the waste from the operation passes the EP toxicity test for metal leaching, so it can be disposed of in a sanitary landfill.

As in the military, many of the commercial airlines believe that PMB will ultimately damage the aircraft. There is a strong controversy over this point, in part because some airlines believe that PMB will ultimately damage the aircraft. They believe that if plastic media were used on an aircraft that failed, the accident would be blamed on PMB. They argue that safety should not be jeopardized. One proponent of PMB points out that even if PMB does abrade the aluminum layer, it is not likely to matter. This layer serves no structural purpose but is only there to prevent corrosion. The damage controversy will not be settled soon but it is notable that there are fewer PMB converts in the commercial sector than there are in the military sector.

Cryogenic Stripping. In principle, cryogenic techniques described under Original Equipment Manufacture - Automotive could be appropriate for stripping paint from commercial aircraft parts.

Not Painting

Paint protects aluminum surfaces on aircraft from salt water, oxidation and jet fuel spills. Commercial aircraft are painted every four years on the average. Alcoa, the nations largest producer of fuselage skin material recommends against painting for safety, cost and environmental reasons (Aviation Week, 1989). American Airlines has not painted its aircraft since the 1950s and the airline uses a corrosion resistant aluminum. US Air recently decided to not paint their aircraft. Both airlines use only decals for ornamentation and identification.

For airlines that do not paint, there are savings in not having downtime for painting and stripping, in labor, in waste disposal and in stripper and paint purchases. To prevent corrosion of unpainted surfaces, however, the unpainted 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 (Aviation Week, 1989). Indeed, one industry source claims that the total cost of painting and not painting are about equal.

Other Process Modification Options

The other options that could apply for commercial aircraft include laser and flash lamp techniques and carbon dioxide and sodium bicarbonate blasting. The characteristics of these methods were described in detail under Maintenance-Military.

MAINTENANCE - AUTOMOTIVE AND OTHER INDUSTRIAL

As Table 2.2 indicates, METH is used in automotive maintenance and it is also used in the maintenance of other large vehicles like buses and railroad cars. In auto body shops, vehicles are repaired by pulling out dents, patching and welding, sanding and repainting (ICF, 1988). Most of the paint removal occurs through hand sanding but stubborn paint and paint in relatively inaccessible areas is sometimes removed with METH based formulations. In principle, alternatives most applicable in these areas should be capable of removing cured paint. Thus, many of the abrasive methods described for aircraft maintenance might be appropriate.

CONSUMER

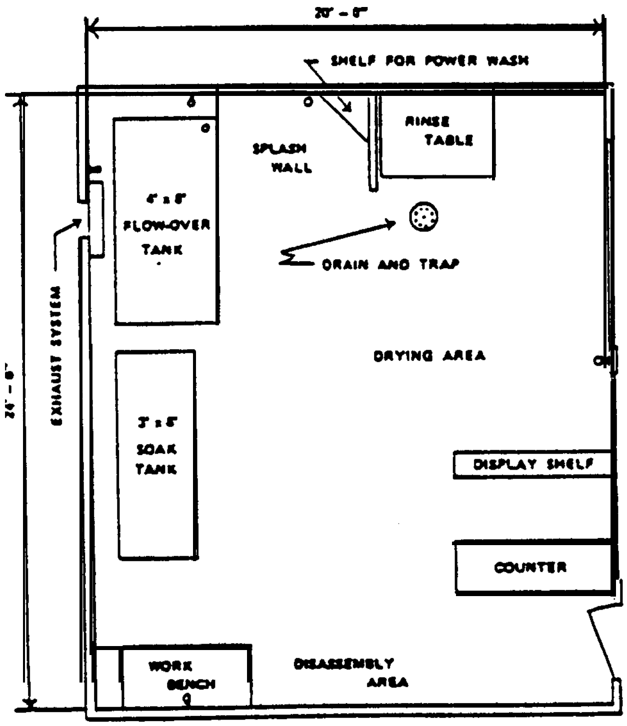
As indicated in Table 2.2, the consumer sector accounts for a significant fraction--40 percent--of the METH used in paint stripping activities. In contrast to industrial paint stripping where the substrate is generally metal, the substrate in the consumer sector is nearly always wood. One source estimates 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.

As mentioned earlier, there are two methods used by the consumer to strip furniture and other items. The first is the do-it-yourself sector where the consumer does the stripping at home. The consumer purchases the stripper from hardware stores which, in turn, are supplied by the formulators. About two-thirds of the METH in the consumer paint stripping sector is used by households. The second method is commercial firms that service consumers and businesses who need to strip goods for restoration or maintenance. In commercial stripping, there are two types of strippers: aqueous alkaline and solvent based which are composed of alcohol and/or METH. About one-third of the METH used in consumer stripping is used by commercial firms.

Paint removers in commercial operations are liquid or semi-paste. The semi-paste is brushed or sprayed on the piece of furniture. Liquid removers are used in a Flow-0ver[50] or soak tank application. After stripping, most businesses use a water rinse which neutralizes the stripper and cleans the wood. A typical shop layout is shown in Figure 3.5. The work is first brought to the disassembly area where, in some cases, the upholstery is removed. The furniture is then taken either to the soak tank or the flow-over tank which are depicted in Figures 3.6 and 3.7 respectively. Soak tanks are used for stripping long items like doors on a production basis. The flow-over tank can be used to strip all common household, office, hotel and restaurant furniture. In the flow-over system, instead of brushing the stripper on the furniture, it is pumped through a special line that is fitted with a scrub brush. All work is done on a special scrub table where the stripper can be collected, filtered and reused. After it has been stripped, the furniture is rinsed with water and the effluent is treated if necessary. The floor of the shop is sloped so all liquids will flow into the drain trap. The furniture then goes to the drying area (Kwick Kleen Op Manual, 1987; Kwick Kleen Chemical and Supply Catalog, 1989).

On an average stripping day, a typical commercial shop might use between 50 and 300 gallons of water in the rinse area (Kwick Kleen Manual, 1987). Small amounts of METH will remain in the water from the rinse procedure. Some local sanitation districts may set limits on organic sewer releases as a matter

Figure 3.5
Typical Shop Layout

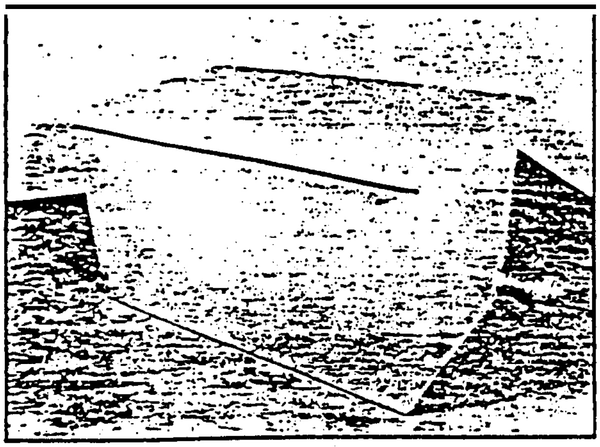


SHOP FLOOR PLAN
FLOW-OVER & COLD TANK

SOURCE: Kwick Kleen Chemical and Supply Catalog, 1989.

Figure 3.6

Typical Soak Tank



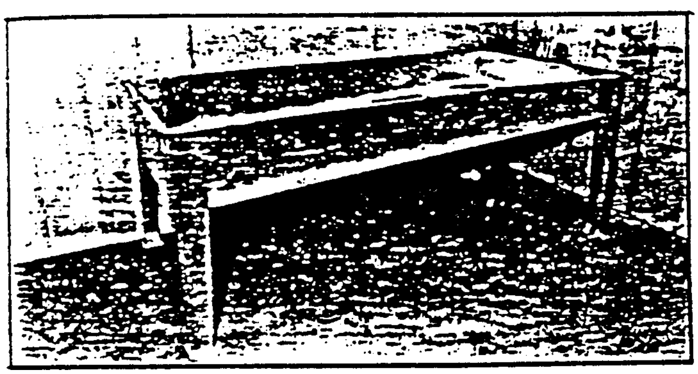
SOAK TANKS
(Non-Flammable Cold Solvent)

- Cold Solvents
- 14 Gauge Steel
- Double Weld Seams
- Piano Hinge Lid
- 30" Liquid Level

SOURCE: Kwick Kleen Chemical and Supply Catalog, 1989.

Figure 3.7

Typical Flow-Over Tank



FLOW-OVER® TANK

- Galvanized
- 14 Gauge steel
- Pail Hook

Large 4' x 8' Flow-Over® Tank. Constructed from 14 gauge galvanized steel to prevent rusting of tanks when clean. Welded scams guarantee a leak-proof tank. Top edge is folded to form a 1 1/2" frame to prevent breaking of edge with heavy furniture. 1 1/2" drain placed in middle of deep end of tank Leg package not included. Purchased separately if needed.

of course. In some cases, the rinse water from the flow-over tank will contain high levels of organics and the contaminated water will have to be disposed of as hazardous waste.

Hazardous waste is generated in another way as well. In the soak tank, the METH formulation continuously evaporates and make-up stripper must be added. Paint pigment and finish solids will settle to the bottom of the tank and operating manuals recommend that when the contaminant level reaches 4 to 6 inches, it should be shovelled out (Kwick Kleen Manual, 1987). This sludge is hazardous waste.

METH based strippers are used in another application where a totally portable system is used to spray a foam of paint stripper. It can be used to strip houses, boats, automobiles or large pieces of furniture. The areas that do not require stripping are masked with sheet plastic or newspaper. The stripping agent cannot be used on plastic parts, lenses or plexiglass. When the paint surface has been dissolved, the entire surface is scrubbed. A second coat of stripper is applied and when the finish is liquified, the remover is rinsed from the surface.

In the household stripping sector a variety of paints, primarily solvent-borne, are used on household goods. These include alkyd enamel, acrylic latex, urethane alkyd, polyurethane varnish, nitrocellulose lacquer, shellac and vinyl acrylic latex. The most common substrate is wood but household paint stripping is performed on metal and plastic items as well (ICF, 1988).

In the household market, there are two types of removers--paint and varnish cleaners which contain 20 to 40 percent METH and paint and varnish removers which contain 70 to 90 percent METH. The sales of paint and varnish removers heavily outweigh sales of cleaners and the household market is actually composed almost entirely of removers (ICF, 1988). There are two types of remover. The first type -- flammable -- contains acetone, toluene or other flammable hydrocarbons. The second type -- nonflammable -- contains METH.

The source reduction options that apply to the consumer sector primarily are limited to chemical substitutes. Abrasive processes are not especially practical even in commercial firms because of the nonuniformity of the surfaces of the items to be stripped. There is some limited applicability for heat techniques. The following sections discuss use of cryogenic techniques in conjunction with alternative chemical strippers in commercial plants. Also examined is vapor recovery for commercial firms.

Chemical Strippers

Two alternative chemical strippers--NMP and DBE might be used in the consumer sector in place of METH. Both products have entered the consumer market in the last few years.

NMP. Only one NMP-based product was available as a consumer stripping product. It is called Mr. Chem and was manufactured by General Texas Chemicals Company in Fort Worth, Texas. The company no longer markets the product and GAF, a producer of NMP, claims that the product contained only a small amount of NMP--perhaps 10 percent--and that the product could not remove paint.

In principle, an NMP consumer product could be formulated. The NMP concentration must be high enough to accomplish paint removal. The chemical is somewhat toxic and GAF, the producer, has set an internal TLV of 100 ppm for it. NMP is also a defatting agent so skin contact should be avoided. An NMP product would take much longer than METH formulations to remove paint. According to GAF, in one test, four coats of alkyd paint were removed by three applications of a METH formulation in 24 minutes. NMP required two applications and 66 minutes.

DBE- A new product containing DBE, called Safest Stripper, has recently been put on the market by 3M (Philadelphia Inquirer, 1989). The formulator claims that this stripper can be used with bare hands, has no harmful fumes and won't burn the skin. It is a water based product and hands and work areas can be cleaned and rinsed with water, an advantage over other solvent based strippers that require solvent cleanup. Because of the presence of water, the grain of the wood is raised which is a drawback. The item must then be sanded before repainting.

An advantage of the DBE based stripper is that it maintains its paste form for at least 10 hours. It therefore retains its stripping capability while METH based strippers dry out more quickly. A disadvantage is that the DBE formulation works much more slowly than METH formulations and it may require scrubbing action. The DBE is applied in a one-eighth inch layer using a paint brush and is left in place for 30 minutes to several hours depending on the number of layers of paint and its thickness. When the finish is dissolved or loosened, a wide-bladed putty knife is used to remove the finish.

A group tried the new formulation on an oak chair and a walnut dresser with two coats of paint over a coat of varnish. In two hours, the paint was removed but the vanish was not removed as easily as with a METH based stripper. A second application removed the varnish. The DBE is priced at $19.99 for a gallon--roughly the same price as METH based strippers. However, the group used about twice the amount of stripper in the case of DBE.

For commercial operations, the DBE formulation might be less practical. For one thing, the formulation is presently available only in one gallon containers. Contractors also care more about faster stripping time and DBE takes much longer than METH to work. Some contractors do all the stripping on one day, however, and perform other functions like refinishing and painting for the balance of the week. For these firms, DBE might be acceptable. Contractors who do on-site stripping also might favor DBE. The stripper could be applied one day and removal could take place the next day.

Flammable Strippers. Strippers based on acetone, methanol or other flammable strippers have a small share of the market today. The primary application of such strippers is for flat surfaces or for removing shellacs, varnishes or lacquers--the clear coatings. At least one source claims that polyurethane and some alkyd coatings can be removed if the flammable stripper is left on for three hours (ICF, 1988).

Process Modifications

Two process alternatives might be adopted in place of METH formulations in the consumer sector. They include a combination of Cryogenic techniques with substitute strippers and the use of heat technologies.

Cryogenic/Alternative Strippers

Although this technique would not be appropriate for consumers, commercial firms could employ cryogenic chambers in conjunction with an alternative stripper like DBE or NMP. The cryogenics would loosen the coating perhaps making the DBE or NMP work more easily or more quickly. The major problem with this option is the expense of the cryogenic equipment. It is unlikely that furniture refinishers could afford the capital cost.

Heat Technologies. Heat guns and blow torches are alternatives to METH in consumer stripping but it is unlikely they would be adopted on a large scale because they are dangerous. Heat guns discharge air at 800 degrees F, the paint blisters and is scraped off. Heat guns and blow torches may damage delicate furniture.

IV. RESULTS OF FIELD VISITS

This section summarizes and discusses the results of the SRRP staff field visits. These included five original equipment manufacturing facilities, six maintenance operations, and two consumer contractors.

ORIGINAL EQUIPMENT MANUFACTURING FACILITIES

Table 4.1 summarizes the major activities in the five manufacturing facilities visited by SRRP staff. As Table 2.2 indicates, METH is used in many automobile manufacturing plants. SRRP staff were unable to obtain approval for visiting any of these operations. The five operations described in Table 4.1 therefore fall into the category of "other industrial" in Table 2.2.

Plant #1

In this operation, aluminum alloys and stainless steel aircraft parts are painted. Painting is performed in booths with disposal filters, booth stripping is not performed. (In general, most firms that do not do extremely high volume painting appear not to strip their booths at all. The firm does, however, clean the lines and guns). Because the plant is in Southern California, the regulations on VOCs are very strict and the firm must employ an exempt solvent. TCA is used in spite of the fact that it is more expensive than the flammable alternatives. The firm recently purchased a gun cleaning station mounted on a drum as described in the last section on source reduction options.

Table 4.1

Description of Manufacturing Operations

PLANT	PRODUCT	ACTIVITY	STRIPPER	RECYCLE
1	Military Aircraft	Clean guns/lines	TCA	No
2	Cruise Missiles	Dip tank for reject parts, paint racks	METH	No
3	Commercial Aircraft	Clean guns/lines	TCA	No
4	Garbage Disposals	Clean guns/lines	TCA	Yes
5	Electromechanical actuators for military and commercial applications	Dip tank	METH	No

Plant #2

Plant #2 has a dip tank for cleaning paint racks. The racks go through an automated line and the uncured paint is stripped in a hot acid strip tank containing chromic and phosphoric acid. The dip tank dimensions are 3 feet by 10 feet and the tank is about 4 feet deep. A METH based stripper is used to strip cured paint. Peelable coatings are used in the dry filter paint booths and a flammable solvent is employed for flushing the lines.

The stripper is about 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 of the stripper annually. If a density of about 10 pounds per gallon is assumed, use amounts to about 9,500 gallons per year. The firm disposes of about 1,200 gallons annually by sending it directly to an incinerator at a cost of $9,000.

Plant #3

Plant #3 uses booths to paint parts. The firm either does not strip the booths at all or they chisel the cured paint off with a hammer. Spray guns and lines are 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 the drum recycling system in the near future.

Plant #4

This operation employed water wash booths for painting plastic garbage disposal units. Some of the canisters were prepainted so they did not require painting on-site.

Periodically, the operation would be shut down, and the walls of the booth would be stripped manually by workers who would scrape the solids from the walls. The firm used TCA to clean the guns and lines because it is an exempt solvent. The used TCA was sent to a recycler. Reconstituted TCA (a mixture of virgin and recycled solvent is purchased back from the recycler.

Plant #5

This firm manufactures actuators for aerospace customers. The firm uses a dip tank with a formulation of 50 percent METH and about 20 percent cresyic acid. They dip electrical motors and tooling in a stainless steel tank containing the METH formulation at room temperature. The parts are left in the tank overnight to remove baked on varnish. The parts are dripped over the tank, washed with water and then dried with air.

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 galls or two drums of waste. It is disposed of through a recycling firm. The cost is about $720 annually, including $240 per drum of liquid and $30 per inch for eight inches of solids. The recycler sends the waste to a cement kiln. The firm uses a water blanket to reduce atmospheric emissions which account for about 50 percent of the losses.

MAINTENANCE

The maintenance operations visited by SRRP staff included four involved in aircraft stripping, one that stripped buses and one that stripped automobiles. These operations are summarized in Table 4.2 and discussed in more detail below.

Table 4.2

Description of Maintenance Operations

PLANT	PRODUCT	ACTIVITY	STRIPPER METHOD	REMARKS
6	Military Aircraft	Strip primers and topcoats from aircraft and parts	METH for aircraft PMB for parts	Converting to PMB for aircraft stripping
7	Commercial Aircraft	Strip paint from aircraft	METH	
8	Private Aircraft	Strip polyurethanes and epoxy from aircraft	METH	
9	Commercial Aircraft	Strip polyurethanes and epoxy from aircraft	METH	Converting to PMB for aircraft stripping
10	Buses	Strip paint from buses	PMB	Used METH for stripping in the past
11	Automobiles	Remove paint from automobiles	Sand, METH	Abrasive paint removal with sand, touch-up removal with METH

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, ten 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 like 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 but a small amount is retained in the waste and wastewater. Presumably some of the METH remains in the paint waste which is sent for incineration. The wastewater is treated with flocculants to settle the particles, the metals are treated and the effluent is sent through a W/Ozone device where the organics (like METH) are catalytically decomposed. The HCl is scrubbed.

This firm also has a small plastic media blasting cabinet which is used for removing paint from small parts. The PMB is recycled with a cyclone separator. The waste PMB and paint chips which contain chromium are sent to an incinerator because the firm does not want to face the potential liability of landfilling. The firm is planning to convert a hanger to a PMB blasting operation for removing paint from the aircraft in the next few years.

Plant #7

This commercial airline strips 20 planes annually. They employ a non-phenolic METH based stripping formulation. The planes are sprayed with the stripper and it is allowed to sit. It is then taken off with squeegees and the solid material is collected on plastic spread beneath the plane. 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 3 drums per week and the amount of waste generated is one drum per week at a cost of $200 per drum. The firm will not consider converting to PMB because there is a belief that it damages the aircraft skin.

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 with METH is taken off the planes with a brush or squeegee. The solid waste resulting from this operation is sent for incineration. The plants are rinsed with water which contains about 300 ppm METH. This aqueous stream is also sent for incineration at a cost of $1.30 per gallon. The firm is reluctant to convert to PMB because the land disposal of metals would make them potentially liable.

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 scraped off with rags which are sent for incineration. The aqueous wash stream is also incinerated.

Plant #10

Plant #10 strips 2,500 buses annually. The regular maintenance schedule requires stripping every six years but because of severe graffiti the paint surface degrades more quickly. In such cases, stripping may be required every four years. Every two years, the primer is left on and only the topcoat is stripped.

The firm employs PMB and the workers wear masks when stripping. Seventy percent of the buses are fiberglass which must be hand sanded. They are planing to convert to an all metal fleet and can then use PMB for all coaches. After the stripping operation, the waste is vacuumed up and 70 percent of the plastic media is reused. The remainder is hauled away as hazardous waste with the paint waste which contains chromium. The waste amounts to one 55 gallon drum for stripping five buses. Purchases of PMB are 8,000 pounds annually. Disposal amounts to 20 drums per quarter. The use of PMB is apparently labor intensive. With PMB, one bus a day can be stripped. When the firm used chemical stripping with METH, two buses could be stripped each day.

Plant #ll

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 4 one-gallon cans of stripper each year for touch up stripping. In addition to METH, the formulation contains methanol, ammonia, sodium and lithium chromate.

CONSUMER

Table 4.3 summarizes the visits to consumer sector paint removal operations.

Plant #12

This firm refinishes thousands of wood and metal items each year. They offer the full range of services including on-site and off-site 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 bondo is sometimes used to fill in recesses. It is washed down with soap and water and sometimes lacquer thinner or METH stripper is used. Then 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 one-year period, the firm generated about 1,800 gallons of liquid waste, and disposed of it at a cost of $7,500.

Table 4.3

Description Consumer Sector Operations

PLANT #	PRODUCT	ACTIVITY	STRIPPER METHOD	REMARKS
12	Contract Finishing	Paint, reupholster metal, wood furniture	METH	
13	Furniture Refinishing	Antique furniture	METH	Home operation

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 combination into the basin. Eventually the solid contaminants build up and the stripper can no longer be used. It is then disposed of in the garbage. Over a two year period, 10 gallons of sludge were accumulated.

SUMMARY OF VISITS

In the original equipment manufacturing sector, site visits seemed to confirm that most firms do not use METH for booth, line and gun cleaning. METH is still employed in dip tanks reflecting the fact that other paint strippers are not effective at stripping cured paint. Many of the plants visited now employ TCA in gun and line cleaning. TCA is more expensive than other flammable solvents that might be used for this purpose but flammable solvents are not widely used in Souther California because they are photochemically reactive. In other parts of the country where VOC regulations are not as stringent, there may be many firms using combustible or flammable solvents.

In the maintenance sector, the firm involved in the production of military aircraft is converting to PMB. One commercial airline cited fear of substrate damage as a reason for not converting to PMB. This issue may prevent other commercial airlines from adopting the abrasive technology.

V. ANALYSIS OF SOURCE REDUCTION OPTIONS IN ORIGINAL EQUIPMENT MANUFACTURING

This section analyzes the costs and use reductions that can be achieved through adoption of the source reduction options. As indicated in Table 2.2, original equipment manufacture is the smallest end use category for METH use in paint stripping. It accounts for one-fifth of total METH use in the sector.

SELECTION OF OPTIONS

Table 5.1 classifies the options into three categories. The first category, no further analysis, includes options that could achieve only small use reductions options that have not been demonstrated, options that are either technologically or institutionally infeasible, options that have known potential or cost, or options for which there is no cost or use reduction information. The second column, limited analysis, includes options for which there are incomplete cost and use reduction information. Options in the third category, full analysis, are those for which there is better -- but still incomplete -- cost and use reduction information. These options are analyzed in some detail.

Table 5.1 indicates no further analysis on various flammable and combustible alternatives including furfuryl

Table 5.1

Classification of Original Equipment Manufacturing Options

NO FURTHER ANALYSIS	LIMITED ANALYSIS	FULL ANALYSIS
NMP		DBE/NMP
Furfuryl Alcohol		Cryogenic
Alkyl Acetate		Off-Site Recovery of Waste
MAK		Gun Cleaning Station
PM and PMA		
Paint Thinners		
Strippable Coatings		
High Pressure Water		
Physical Methods		
Alkaline/Acid Strippers		
Sodium Bicarbonate		
Ovens/Salt Baths		
Carbon Adsorption		
Condensation		
Absorption		
Water Blanket/Covers		
Recovery from Waste Water		
On-Site Recovery of Waste		

alcohol, alkyl acetate, methyl amyl ketone, propylene glycol monoethyl ether and propylene glycol monometheyl acetate. The characteristics of many of these materials are similar and full analysis is performed on a combination of two of them--DBE and NMP--to represent the group in general terms. Paint thinners for gun and line cleaning and strippable coatings for booth stripping are already widely employed today. High pressure water is used, to some extent, in booth stripping. Physical methods are also used. Alkaline/acid strippers are used for immersion stripping of some parts. Sodium bicarbonate may be used to some extent for booth stripping. Ovens and salt baths have only limited application. Carbon adsorption, condensation and absorption share a common problem. If they are used to capture METH, other components like VOC solvents from the paints will be present. It is not clear how they could be separated and the cost of separation would be prohibitive. Water blankets and covers are employed by many users today in immersion stripping. Recovery of METH from wastewater would reduce releases only to a small extent and it would be very costly. On-site recovery of waste is not practiced today and is likely to be practical only for users of pure METH in dip tanks. This represents only a small fraction of users.

FULL ANALYSIS OPTIONS

Full analysis is performed on DBE/NMP formulation substitution for METH in booth stripping. Cryogenic stripping is also classified in the full analysis category. It is a reasonably good alternative to immersion stripping with METH and paint thinners. Off-site recovery of METH waste in immersion stripping is also analyzed. Finally, full analysis is performed on the gun cleaning station which can be effective in reducing atmospheric losses. In each of these analyses, case studies are developed and estimates of how these cases can be translated to the industry as a whole. It should be noted that the study methodology is far from rigorous and that the results should be viewed as case studies. Factors involving interactions among the options have not been taken into account.

DBE/NMP

An analysis of the DBE/NMP alternative is based on the case of a hypothetical manufacturer who currently uses a METH based formulation to strip the booth. The booth is assumed to be intermediate sized, one that is 30 feet long, 14 feet wide and 12 feet tall. The ceiling, walls and floor of the booth are exposed to overspray from the paint. This represents about 1,176 square feet.

About 10 gallons of stripper are required to strip the booth once each day. It is assumed that this activity occurs 250 days each year. It is also assumed that it takes 20 minutes to apply the stripper and about 20 minutes to remove it. The stripper is in contact with the surface for 15 minutes before it is blasted off with water. Use of the stripper amounts to 2,500 gallons per year.

Several METH formulations are suitable for booth stripping. For one such formulation (Kirk Othmer, 1979), the raw materials cost were determined (CMR, 1989b) which amounted to $0.428 per pound. Assuming a density for the METH formulation of 10 pounds per gallon, the price would be $4.28 per gallon. METH based strippers can be purchased by users for about $8.00 per gallon - an 87 percent markup.

Table 5.2 presents the ingredients of a DBE/NMP formulation suitable for booth stripping (Jackson, 1989). DBE and NMP represent about 40 and 15 weight percent of the formulation respectively. The raw materials cost of this formulation is $0.559 per pound and it has a density of 8.2

Table 5.2

Components of a DBE Based Booth Stripping Formulation

DBE
NMP
Aromatic 150
Monoethanolamine
Potassium Oleate
Thickener

pounds per gallon. The price of the formulation amounts to $4.58 per gallon. Assuming the same markup as for the METH based stripper, the price to the user would be $8.56. The 2,500 gallons used by the manufacturer described above would cost $21,400 annually.

The DBE/NMP formulation would take slightly longer to work than the METH. For uncured paint, the increased time would probably not be significant. In this case, it is assumed that the formulation would require a 20 minute stripping period instead of a 15 minute period for the METH formulation. This would not necessarily increase the labor requirement for the stripping operation. During the additional five minutes required for the stripper to work, the worker(s) could focus on other tasks. As long as there was no time constraint on the assembly line operation, there would be no incremental increase in labor.

Electricity and water requirements are likely to be the same for the METH based formulation and for the DBE/NMP based formulation. It is not clear if the waste disposal requirements would be significantly different. A water wash booth is the most likely kind to be used in a high volume operation. After the formulation has loosened the paint, the walls are hosed down and the paint waste, water and stripper combination enters the water. As mentioned earlier, METH is much more volatile than DBE or NMP and most of the METH will volatilize to the atmosphere. Only a small amount will be left in the water after the rinsing operation. This METH in the water is generally not treated but is volatilized to the atmosphere as it goes through the wastewater treatment plant that some large users have. More diligent users could drum the METH/water mixture and send it off-site as hazardous waste.

In contrast to METH, much more DBE and NMP will remain with the paint waste and enter the water because they are much less volatile substances. Generally, in water wash booths, the water is recirculated and the paint waste is taken out with an additive. Some of the DBE/NMP will remain in the water after each stripping operation and it will build up over time. Because DBE/NMP formulations generally have surfactant additives to make them water soluble, they may be removed by the additives together with the paint waste. This sludge is dewatered and sent off-site as hazardous waste. Pure DBE and NMP are biodegradable and could be released to the sewer or to the wastewater treatment plant if the user has one.

The differential waste disposal costs for the METH formulation on the one hand and the DBE/NMP formulation on the other hand cannot be evaluated. The circumstances are very case specific. For purposes of analysis, it is assumed that the costs associated with wastewater treatment and waste disposal are roughly equal.

The only cost differential considered in this analysis is the price of the stripper. Table 5.3 present a summary of the annual costs and METH savings for substitution of a DBE/NMP based stripper for stripping the booth described earlier. Following the estimate in Section III, booth stripping is assumed to account for 35 percent of the METH used today in the OEM sector nationwide. In some cases, the paint is cured and the stripping formulation would not perform adequately. In other cases the formulation might not strip the paint quickly enough to accommodate an existing assembly line procedure. For these reasons formulation is considered to be appropriate as a substitute for only half the METH used in booth stripping. For Southern California, METH use is assumed to be proportional to the population which is 6 percent of the U.S. population.

Table 5.3

Annual Cost and METH Use Reduction for Substitution of DBE in Booth Stripping

	COST (THOUSAND $)	METH USE REDUCTION"	COST PER METH USE REDUCTION ($mt)
User	1.4	11.3	123
Southern California	37	300	123
U.S.	617	5,000	123

'Assumes a density of 10 pounds per gallon for the METH formulation.

The values of Table 5.3 indicate that substitution of the DBE/NMP formulation would require $123 per mt of METH used. This is about 6 cents per pound of METH use reduction.

Cryogenic Techniques

Two substitutions of cryogenic stripping for immersion stripping with METH are presented: a user that strips small metal parts; and a larger user with large racks and hangers.

Small Parts User. This firm strips a variety of small parts ranging in size from one-half inch by one-half inch to about three inches by three inches. These parts are made of steel and aluminum and are generally symmetric; that is, they do not have crevices or intricate shapes. This firm presently uses a METH based formulation with phenol and formic acid as an immersion stripper for removing an alkyd type cured coating. The stripping tank is 2 feet by 7.5 feet and is 4 feet deep. It holds 600 gallons of stripper.

At the beginning of the year, the tank is filled with 600 gallons of stripper and topped with a water blanket. It is used throughout the year and by the time it is emptied for disposal, the tank is half water. The contents of the tank are incinerated at a cost of $4,500 annually. The firm pays 92 cent per pound for the stripper. Assuming a density of 10 pounds per gallon, annual purchases amount to 6,000 pounds at a cost of $5,520 per year. The formulation is 70 percent METH so the METH use is 4,200 pounds annually. Total annual costs to the user are the purchase and disposal costs which amount to $10,020.

The firm considers purchasing a cryogenic tumbler, priced at $50,000 installed, which is most appropriate for small parts. These tumblers consist of a chamber containing nitrogen at about -200 degrees F. The chamber tumbles the parts and the cryogenic temperatures cause the paint to contract, loosening it. The parts abrade the paint from one another if they are symmetrical. If the parts have complex shapes, tumbling media can be added.

Two tumbler sizes are available--a 6 cubic foot unit priced at $30,000 and a 25 cubic foot unit priced at $50,000. The cycle time is 10 to 15 minutes. The firm, because it needs to strip some larger parts decides to investigate the large tumbler in more detail. It has an operating capacity of half the tumbler volume, or 12.5 cubic feet and has a limit of 640 pounds of parts. The firm will strip 150 pounds of parts in each cycle and operate the unit for 5 cycles each day. Nitrogen is currently priced at 6 cents per pound and the large tumbler requires one-half pound of nitrogen per pound of parts. Each load of parts generates paint waste of about one-half cubic foot which is separated from the parts after they are removed from the tumbler.

The installed capital cost of the tumbler is $50,000. If we assume a 10 percent cost of capital and a 10 year equipment life, then the annual capital charges amount to about $6,510.

The cost of using the tumbler includes the electricity cost to run it, the purchase of the nitrogen and the cost for disposal of the paint waste. The electricity cost is small and is ignored for convenience. Each load of 150 pounds of parts requires 75 pounds of nitrogen. Five cycles per day, 250 days per year will require 93,750 pounds of nitrogen. At 6 cents per pound, the total annual cost of the nitrogen is $5,625. The paint waste is considered hazardous in California but is not in most other states. The disposal cost is ignored.

The total annual costs of using the tumbler are the sum of the annualized capital cost and the purchase of the nitrogen This amounts to $12,135. Although there would also be labor costs for workers to load and unload the tumbler, they would also have to do that with the immersion tank. Differential labor costs are assumed to be negligible. The cost of the cryogenic stripping unit--at $12,135 per year--is higher than that of the immersion stripper--at $10,020. The data are shown in Table 5.4.

The incremental cost and METH use reduction for a user, for Southern California and for the nation are shown in Table 5.5. As mentioned earlier, 35 percent of the METH used in the OEM sector is devoted to immersion stripping. The values assume that cryogenic stripping using the tumbler described is appropriate for only one-tenth of that market. Many firms do not have high volume stripping requirements or parts that are small enough to be suitable for the tumbler. The cost values of Table 5.4 were determined by assuming that the user defined here is the average user. And again, that METH use in Southern California is proportional to the population there.

The figures of Table 5.5 indicate that conversion to cryogenic tumblers would involve a net cost. This cost amounts to $1.10 per mt or about 50 cents per pound of METH use reduction. It is worth noting that the costs estimated here apply to a facility that currently uses METH for a conversion to cryogenic stripping. The capital cost of a METH immersion tank is not included.

<u>Larger Part User.</u> The larger user has an appliance assembly line. The appliance parts are carried through the painting operation with hangers and racks. After a time, the hangers become caked with the water based acrylic paint used to coat the

Table 5.4

Cost Comparison of METH and Cryogenic Tumbler for Small User

Item	ANNUALIZED COST ($)	
	METH	Cryogenic Tumbler
METH Purchase	5,520	
Tumbler Purchase[a]		6,510
Nitrogen Purchase		5,625
Disposal	4,500	
Total	10,020	12,135

[a]Installation costs are included.

Table 5.5

Annual Cost and METH Use Reduction for Cryogenic Tumbler for Small User

	ANNUAL COST (THOUSAND $)	ANNUAL METH USE REDUCTION (mt)
User	2.1	1.9
Southern California	23.3	21
Nation	388.6	350

appliances. This plant uses an immersion tank that is larger than the one discussed earlier. Its dimensions are 3 feet by 10 feet, it is 4 feet deep and it holds 1,200 gallons of stripper. This tank has much more use than the one above since 600 hangers per day must be stripped. The tank is dumped once each year and the contents are sent for incineration at a cost of $9,000 annually. 6,800 gallons of makeup stripper is added over the year to replace the METH cost. Total use of the stripper, which is 70 percent METH, amounts to 8,000 gallons per year. At an average density of 10 pounds per gallon and a stripper price of 92 cents per pound, the annual cost for METH purchases amounts to $73,600. Total costs for purchases and waste disposal are $82,600 per year.

The installed cost of a cryogenic chamber is between $250,000 and $300,000. It is a vertical chamber with a spindle in the center. Trolleys, hangers or racks can be placed in the chamber for stripping. The liquid nitrogen temperature causes the paint to contract and plastic media is used to abrade and remove the paint completely. One cycle requires 10 to 15 minutes but the stripped parts cannot be handled without gloves for 5 to 10 minutes after they are removed from the chamber. Thus, the total time for a complete cycle including parts removal requires about 20 to 25 minutes.

The plant runs the chamber for one 8-hour shift per day. About 400 parts are stripped each day in an average of 20 cycles. After each cycle, the plastic media and the paint waste are separated by particle size: the paint chips are much smaller than the plastic particles. Much of the plastic media can be recycled but eventually the particles become very small from abrasion and they are disposed of with the paint waste. The operation requires 2,000 pounds of media per year.

The cost of using the chamber includes the annual capital charges, the maintenance cost, the nitrogen cost, the cost of the plastic media and the cost of disposal of the paint chips and the plastic media. The installed capital cost of the unit is $275,000. Assuming a 10 percent cost of capital and an equipment lifetime of 15 years, the annual capital charges amount to about $36,155. One manufacturer estimates normal preventative maintenance at $5,000 to $10,000 each year; the middle value of $7,500 per year is used.

A chamber manufacturer estimates that the nitrogen requirement is about one-half pound per pound of parts processed. Assuming that each of the 400 parts stripped day weighs 5 pounds and that the firm operates 250 days per year, then 250,000 pound of nitrogen are required annually At a price of 6 cents per pound, the annual nitrogen cost would be $15,000 annually.

One distributor indicates that electronics grade plastic media is required for cryogenic operations. The cost of such media is $3.30 per pound. About 2,000 pound of media are required for this operation annually for a net cost of $6,600. The paint used in this operation contains no hazardous material so the media/paint waste can be disposed of as nonhazardous waste. The associated costs are ignored.

The annual costs of continuing to use METH are compared to purchasing and using a cryogenic chamber in Table 5.6. The costs of using the chamber are lower largely because of the expense of purchasing METH based stripper. Two factors that qualify the results are notable here. First, the cost of METH stripping would be lower for a user who sent recycled solvent to an off-site recycler. Second, users with different stripping requirements could have higher expenses for using the cryogenic chamber. In particular, many aerospace firms use an epoxy

Table 5.6

Cost Comparison of METH and Cryogenic Chamber
for Larger User

Item	ANNUALIZED COST ($)	
	METH	CRYOGENIC TUMBLER
METH Purchase	73,600	-
Chamber Purchase[a]	-	43,655
Nitrogen Purchase	-	15,000
Media Purchase	-	6,600
Waste Disposal	9,020	-
Total	82,600	62,255

[a]Installation costs are included.

primer and a polyurethane topcoat for virtually all their parts. Polyurethane and epoxies require much lower nitrogen temperatures--perhaps down to -250' F--to cause paint contraction. This significantly increases the nitrogen requirement and thus the nitrogen purchase price. The polyurethane topcoats use by aerospace firms contains chromium for corrosion protection. When the paint is removed with the media, it must be disposed of as hazardous waste. This will increase the cost of cryogenic stripping.

On the other hand, the costs of using METH are likely to increase in the future--particularly in California. In that state, the Air Resources Board has declared METH to be an air toxic and will promulgate stringent emission standards over the next few years. The Air Quality Management District has proposed a fee on METH emissions of $1.20 per pound. If this were adopted and if the user defined above were in the district, the additional annual fee would amount to $57,000.

The cost comparison was performed for a current user of an immersion tank. For a new facility, where the user would have to purchase a new immersion tank, the costs of using the cryogenic chamber would be relatively more attractive.

Table 5.7 presents the cost and use reduction information on the cryogenic chamber for a user, for Southern California and for the nation. Again, as mentioned above, 35 percent of the METH used in the OEM sector is used for immersion stripping. The figures of Table 5.7 were calculated by assuming that the cryogenic chamber is appropriate for one-fifth of this market. This is probably an overestimate of the market potential because most users do not have a high enough thoughput to justify the high capital cost of the chamber. The costs were determined by assuming that the user defined is an average

Table 5.7

Annual Cost and METH Use Reduction
for Cryogenic Tumbler

	ANNUAL COST (THOUSAND $)	ANNUAL METH USE REDUCTION (MT)	COST PER METH USE REDUCTION ($mt)
User	(17.4)a	25.4	(0.68)
Southern California	(28.7)	42	(0.68)
Nation (478.0)	(478.0)	700	(0.68)

[a]Parentheses indicate a cost credit.

case. Again, it is also assumed that METH use in Southern California is proportional to population.

Off-site Recovery of Waste

This option has limited applicability for dip tank users. In most immersion stripping operations, the METH formulations contain high concentrations of acids. Over time, as the stripper is used, the more volatile component--the METH--selectively evaporates and the less volatile component--the acid--remains in the tank with the paint sludge. When the tank becomes too contaminated for further use, the stripping formulation is replaced and the contaminated material is sent off-site to a disposal facility.

In cases where the METH content is high, off-site recyclers might take the formulation to reclaim the METH. Some users place a water blanket on top of the tank to prevent vapor losses. The more water there is in the formulation, the less desirable it is to the recycler. Recyclers will therefore prefer spent stripper with high concentrations of METH and low concentrations of acid and water.

The analysis case is based on one of the plants SRRP staff visited that has a 50 gallon dip tank for removing baked-on varnish from steel electrical motors. The paint stripping formulation used by the firm is 20 percent cresylic acid and 80 percent METH. The firm uses 200 gallons of stripper per year.

The user dumps the tank twice a year when the bath becomes too contaminated for further use. At this stage, the 100 gallons contains 8 inches or 13 gallons of solid and 87 gallons of liquid. The 87 gallons of liquid contains 60 gallons of METH and 27 gallons of acid. The mixture has a slightly higher acid concentration than the original formulation because the METH preferentially evaporates.

If the user employs a recycler, the recycler will charge $30 per inch of solid material or $240 annually. For the liquid, the recycler charges $1.25 per gallon for the acid and pays $1.25 per gallon for the METH. The net cost to the user is about $200 per year. If the user simply disposes of the waste, a waste hauler will charge $550 to dispose of one drum of contaminated METH. The cost for 100 gallons would amount to $1,000. The net savings to the user for sending the METH formulation to a recycler instead of for incineration is $800 per year.

The recycler would reclaim the METH at a 90 percent efficiency and sell it back on the market. It is likely that the METH would end up in the metal cleaning industry because recyclers do not generally formulate paint strippers. The METH will be sold at a price about 4 cents per pound less than virgin METH, which is currently priced at $0.64 per kilogram. The savings to the user who purchases it is $27 annually. Total cost savings to both users amounts to $827 annually. The reduction in virgin METH that could be achieved in the process is 60 gallons or about 300 kilograms, 30 percent of virgin purchases.

As mentioned above, about 35 percent of the METH used in the OEM sector today is devoted to immersion stripping. This implies that 3.5 thousand mt is employed in such activities annually. Of this 3.5 thousand mt, about 2 thousand mt of the formulations are estimated to contain METH in concentrations too low to justify recycling: in these cases, recyclers could not economically reclaim the METH and the spent stripper would be sent for incineration. Thus, 1.5 thousand mt is used in formulations where recycling is possible. If the same savings in virgin purchases described above could be achieved nationwide, then the total reduction in virgin purchases would amount to 450 mt. Further assuming that the cost savings are proportional to the METH savings, then, the nationwide annual savings would amount to $1,240,500. Southern California has about 6 percent of the U.S. population. Assuming that paint stripping in OEM activities is proportional to population, then the Southern California reduction in METH purchases would amount to 27 mt at a cost savings of $74,430 annually. These data are summarized in Table 5.8.

Gun Cleaning Station

The case analyzed is the gun cleaning station for a large user of 500 gallons annually of a 90 percent METH formulation for gun and line cleaning. Presently, virtually all of the solvent is emitted to the atmosphere. It is run through the line and out the end of the gun. One manufacturer offers a gun cleaning station for $389. It consists of an air-driven solvent condensing unit that sits on top of a 55 gallon drum. The gun is inserted into this unit and the solvent is sprayed into the drum rather than emitted to the atmosphere. We estimate that this system prevents the release of 80 percent of the current losses. Assuming the formulation has a density of 11 pounds per gallon, then 4,950 pounds or 2,245 kilograms of METH emissions are prevented annually.

At this stage, the user has two options. First, the captured solvent can be sent off-site to a recycler. Of the total 450 gallons of METH, 90 gallons are emitted and 360 gallons are sent off-site. Recyclers pay $1.25 gallons for METH and charge $1.25 per gallon for sludge. The other components in the mixture and the contaminants in the mixture represent the sludge. The other components amount to 40 gallons and it is

Table 5.8

Annual Cost and METH Use Reduction for Adoption of Off-Site Recycling

	COST (THOUSAND $)	Reduction in METH VIRGIN PURCHSESE (MT)
Typical User	0.6[a]	0.3
Southern California	49.5	27
Nation	825	450

"Parenthesis indicate a net credit.

assumed that the contaminants are at the 10 percent level which implies they amount to 44.4 gallons. The payment for the METH is $450 minus the sludge charge of $105.50 leads to a net credit of $344.50 annually. The METH is reclaimed and 90 percent is sold back into the market, probably for metal cleaning, as a substitute for virgin METH.

The second option is for the firm to reuse the solvent on-site repeatedly in the gun cleaning process. Assuming the plant operates 250 days per year, the daily METH use is 1.8 gallons or about 9 kilograms per day. The lines and guns are cleaned once each day. Each time 20 percent of the METH--0.36 gallons--is emitted and the balance--l.44 gallons--is saved for reuse in the gun cleaning station. Virgin make-up solvent of 0.36 gallons each day must be added to the used solvent. This implies that virgin purchases of 90 gallons are required annually.

There are significant savings in exercising this option. Instead of purchases of 500 gallons of METH based formulations each year, only 100 gallons are required. Assuming a price of $8 per gallon for a METH based formulation, the savings amounts to $3,200 annually. There are still disposal costs for the sludge which is assumed to be filtered out and separated from the solvent. As mentioned earlier, the charge for sludge disposal is $105.50 annually. The user realizes a net savings of about $3,094.50.

The cost of the unit is $389. Assuming a cost of capital of 10 percent and an equipment lifetime of 10 years, the annual capital charges amount to about $63. In the first case where the solvent is sent to an off-site recycler, the net annual savings are $281.50. In the second case where the solvent is reused on-site, the savings are much higher--$3,031.50 per year.

Gun and line cleaning account for 15 percent of METH use in the OEM sector. (see Section III). This is about 1.5 thousand mt. Table 5.9 presents annual cost and METH savings that can be realized through purchase of the gun cleaning station. The values indicates that both options analyzed yield substantial cost savings. The savings are greater for the case where the firm reuses the solvent on-site. This firm does not purchase back the reclaimed solvent from the recycler and so does not derive a credit for purchasing recycled rather than virgin solvent. This savings, however, is realized by another user, probably one in the metal cleaning sector.

Table 5.9

Annual Cost and METH Use Reduction for Gun Cleaning Station

	ANNUAL COST (THOUSAND $)	METH USE REDUCTION (MT)
User		
No On-Site Reuse	(0.4)[a,b]	1.6
On-Site Reuse	(3.0)	1.8
Southern California		
No On-Site Reuse	(13.8)[a]	64.8
On-Site Reuse	(123.0)	72.0
U.S.		
No On-Site Reuse	(230.1)[a]	1,080
On-Site Reuse	(2,049.7)	1,200

[a]We exclude the savings to the economy for a firm to purchase recycled solvent rather than virgin. This savings amounts to about 10 cents per kilogram.

[b]Parentheses indicate a cost credit.

VI. ANALYSIS OF SOURCE REDUCTION OPTIONS IN MAINTENANCE

This section analyzes the costs and use reductions that can be achieved through adoption of the source reduction options in maintenance stripping. As shown in Table 2.2, this category accounts for two-fifths of the METH used in paint stripping. The largest portion is used in military applications.

SELECTION OF OPTIONS

Table 6.1 classifies the options into analysis categories. The first category includes those options for which there is no further analysis. Cryogenic techniques hold limited promise for large items like airplanes and buses because the chamber would need to be large. Furthermore, the technique has not really been demonstrated in these applications. Laser stripping and high intensity light are still in the experimental stage and not yet ready for application. Carbon dioxide techniques also have not been explored fully. Biodegradation methods are still in the research phase. A few airlines do not paint their aircraft and the option does not hold promise for other commercial aircraft. There is no available cost information on the technique, however.

PMB has been adopted by many organizations as an alternative to METH stripping. SRRP staff have fairly good information on the cost and solvent use reduction that could be realized. Therefore it is classified in the full analysis category. Sodium bicarbonate is a very interesting technique that holds promise for maintenance stripping. PMB and sodium bicarbonate are treated together in a case study.

Table 6.1
Classification of Maintenance Options

NO FURTHER ANALYSIS	LIMITED ANALYSIS	FULL ANALYSIS
Cryogenic		P M B
Lasers		Sodium Bicaronate
High Intensity Light		
Carbon Dioxide		
Biodegradation		
Not Painting		

<u>CASE STUDY</u>

This case study compares a maintenance operation using the traditional METH based stripper with PMB and with sodium bicarbonate The case study involves an aerospace firm that strips between one and six C-130 cargo planes each year. This plane has about 10 times the surface area of an F-14. Periodically, the polyurethane topcoat of the plane is stripped for maintenance and a new coat is added. After 10,000 flying hours, major maintenance is required and, in addition to the topcoat, the zinc chromate epoxy primer must be stripped as well.

<u>BETH Based Stripping</u>

In the METH stripping operation, the aircraft is brought to the wash rack. Stripper is applied to the entire aircraft with spray guns and some of the small parts are brushed with stripper by hand. After a time, the METH based stripper bubbles and the workers scrape off the paint/stripper and rinse the aircraft with water. The water containing the paint residue is sent to the plant's wastewater treatment plant where it is treated for heavy metals--particularly chromium. The METH based stripper with paint waste is sent off-site for incineration.

It takes 2.5 days for five people to strip one C-130. Preparation and post stripping hand sanding involves another 1.5 days. At a labor rate of $63 per hour, the total labor cost amounts to $10,080. About 110 gallons of METH based stripper with 60 percent METH content is required to strip one of the aircraft. At a cost of $10 per gallon, the total cost for purchasing stripper is $1,100. Five drums of waste are generated for each plane. At a cost for disposal of $750 per drum, total disposal costs amount to $3,750.

Between 35,000 and 40,000 gallons of water are required to hose down the aircraft after stripping: a value of 37,500 gallons is assumed. At a cost of water of $0.005 per gallon, the cost amounts to $187.50. The plant has a wastewater treatment plant. One source estimates that wastewater treatment for the effluent from an aircraft stripping operation amounts to $8.24 per 1,000 gallons (USAF, 1986). Assuming this value, the cost of treating the effluent from stripping one C-130 is about $309.

PMB Stripping

The plastic media blasting unit has an installed cost of about $75,000 including the set up for compressed air. It is much more costly--between $500,000 and $750,000--to install the media collection system and to render the hanger explosion proof. For our analysis, a value of $625,000 for the hanger conversion is used, giving a total capital cost for the system of $700,000. Assuming an equipment lifetime of 15 years and a cost of capital of 10 percent, the annualized capital cost for installing one system amounts to about $92,030. This plant plans to strip 6 C-130's each year so the capital cost attributable to one C-130 is one-sixth the capital charges or about $15,340.

After the aircraft is blasted, it is hosed down with water. We assume the water use cost is the same as for the METH based stripping case.

A detailed study on F-4 aircraft indicates that the aircraft stripping time with PMB including preparation and subsequent hand sanding is about half that of stripping with METH (Hill Air Force Base, 1986). Another study on Army aircraft indicates that the labor savings with PMB are 60 percent over those with METH based stripper (CCAD, 1984). A figure of 50 percent is assumed for this analysis. The labor cost, under this assumption, are $5,040 per aircraft with plastic media.

PMB use amounts to about 800 pounds per hour. More than 75 percent of the media can be recycled for reuse. It is assumed that total consumption amounts to 180 pounds per hour. As discussed above, one-half of the the METH labor costs is assumed for the PMB operation. For the METH stripping, 2.5 days actually involve stripping. The other 1.5 days are for preparation and hand sanding. If the PMB operation requires half the total time or 2 days, then one day is spent in stripping and one day for preparation. One day of stripping with 5 workers is 40 worker hours. Total consumption of plastic media at a rate of 180 pounds per hour amounts to 7,200 pounds. At a cost of media of $2.10 per pound, the purchase price is $15,120.

The PMB technique involves the disposal of the plastic media. As mentioned above, 7,200 pounds of media is consumed (or purchased) in stripping one C-130 aircraft. There is also 400 pounds of paint waste generated from stripping a C-130. The dust and the point waste must be disposed of as hazardous waste. One hauler estimates that the cost for disposal is about $200 per ton. This amounts to a cost of $760 per aircraft.

<u>Sodium Bicarbonate</u>

The installed capital cost for the sodium bicarbonate system is $13,500--much less than that of the PMB system. At an annual cost of capital of 10 and an equipment lifetime of 15 years, the annual capital charges are $1,775. Since the firm plans to strip six C-130 aircraft each year, only one-sixth of this cost, or about $300, is attributable to each C-130.

One source at Kelly Air Force Base has compared PMB and sodium bicarbonate. He indicates that the operating costs of the two processes are roughly the same. In the case of plastic media, about 800 pounds of the media are used per hour but much of the media--perhaps as much as 75 percent--can be recycled. This suggests that 180 pounds of media are consumed each hour. In the case of sodium bicarbonate, consumption is between 150 and 200 pounds per hour about the same as that for plastic media.

Above, 7,200 pounds of plastic media were assumed to be required to strip one aircraft. For this analysis, 7,200 pounds of sodium bicarbonate are assumed to be required to strip each aircraft as well. At a cost of 90 cents per pound for sodium bicarbonate, the purchase cost amounts to $6,480. Water is used with the bicarbonate in the process for temperature control and to reduce the abrasion. About 30 gallons of water are required per hour indicating that 1,200 gallons are required for one C-130. At a cost of $0.005 per gallon, the cost would amount to $6.00. Total costs for media and water are about $6,490.

The water rinse procedure would be the same for sodium bicarbonate as it would for PMB. The cost of the water use and treatment would amount to $190 and $310 respectively. The sodium bicarbonate does not require neutralization since its pH is 8.1. In this case the sodium bicarbonate can be separated from the paint waste with a filter. One industry source suggest that the cost of such a filter would amount to $6,000 (Lee, 1989). At an annual cost of capital of 10 percent and a 10 year lifetime, the annual capital charge would amount to $976. The cost attributable to each C-130 is about $160. Each C-130 generates about 400 pounds (one drum) of paint waste containing chromium. The cost for disposal of this material after it has been removed by the filter and backwashed would be about $500.

Depending upon the local waste water treatment requirements, the simple filter described above may not be adequate for removing metals. An ion exchange might be necessary to ensure adequate removal. In such a case, the cost of using the bicarbonate system would be higher.

Summary

Table 6.2 summarizes the major costs for stripping a C-130 using the three techniques. Sodium bicarbonate is the lowest cost stripping technique of the three. The capital cost of the plastic media technique is very high and indeed, the sodium bicarbonate system capital cost is extremely low. In the case of plastic media, as has been demonstrated before, labor costs and disposal cost are lower than for METH based stripping.

Many costs that have been left out could significantly change those given in Table 6.2. First, the electricity requirements are not considered . One comparative study estimates that the cost of electrical power for chemical stripping is twice that of the plastic media process (USAF, 1986). If such costs were included, they would make plastic media more attractive. Second, heating costs in certain parts of the country. A comparative study for Ogden, Utah, the costs of heating in the case of METH use was much higher than for PMB largely because of the METH ventilation requirements (USAF, 1986). In fact, OSHA will soon lower the allowable METH exposure level and the ventilation requirements for that process will be even higher. Sodium bicarbonate has lower ventilation requirements than either of the other processes because exposure

Table 6.2
Annual Cost Comparison for METH, PMB and Sodium Bicarbonate

ITEM	ANNUAL COST ($)		
	METH	PMB	SODIUM BICARBONATE
Capital Charges		15,340"	460[a]
Stripper/Media Purchase	15,000	15,120	6,490[b]
Labor Cost	10,080	5,040	5,040
Water Use	190	190	190
Water Treatment	310	310	310
Disposal	3,750	760	500
Total	29,330	36,760	12,990

[a]Includes cost of equipment and filter.
[b]Includes cost of sodium bicarbonate and water.

to the plastic media dust must be controlled as well. Third, the the costs for down-time of the aircraft have not been included. The plastic media and the sodium bicarbonate processes both require much less time for stripping than the METH process. The aircraft is available for operation for a longer period of time.

The three cost elements described here would all act to make the plastic media and the sodium bicarbonate processes relatively less expensive than the METH process. If these factors were taken into account, sodium bicarbonate would be the least expensive process followed by plastic media.

Table 6.3 summarizes the cost and METH use reduction for substitution of PMB and sodium bicarbonate. Table 2.2 indicates that 20 thousand mt of METH is devoted to maintenance paint stripping. Many parts are made of materials that cannot be stripped with abrasive techniques. Such techniques also are less appropriate for large aircraft like 747's and DC-10s where the metal supports are more widely spaced across the frame. Users are concerned that the skins on these aircraft may be more easily damaged. In the light of these limitations, the figures of Table 6.3 assume that plastic media and sodium bicarbonate are appropriate for only half the maintenance stripping. To calculate the figures of Table 6.3, it was assumed that plastic media and sodium bicarbonate are appropriate for only half the maintenance stripping. Thus, nationwide, the METH savings through adoption of either alternative could amount to 10 thousand mt. Cost figures for the nation assume that cost is proportional to the METH use. For Southern California, it was assumed that the costs and METH use reduction are 6 percent of the nationwide figures.

Table 6.3
Annual Cost and METH Use Reduction for PMB
Sodium Bicarbonate

	ANNUAL COST (THOUSAND $) PMB	SODIUM BICARBONATE	METH USE REDUCTION (MT)
User	7.4	(16.3)[b]	4.5[c]
Southern California	986.7	(2,173.3)	600
Nation	16,444.4	(36,222.2)	10,000

[a]Based on stripping one C-130.

[b]Parentheses indicate a cost credit.

[c]Assumes a stripper density of 11 pounds per gallon.

VII. ANALYSIS OF SOURCE REDUCTION OPTIONS IN THE CONSUMER SECTOR

In this section the options for consumer paint stripping are analyzed. As Table 2.2 indicates, the consumer sector like the maintenance sector, uses two-fifths of the METH that goes toward paint stripping.

SELECTION OF OPTIONS

Table 7.1 classifies the options into three categories. Further analysis is performed on only one option - substitution of DBE, a combustible solvent. It is used today in consumer formulation. NMP, also a combustible solvent, may be used in consumer strippers but is not presently.

Flammable strippers have some portion of the market but are not very good strippers. Cryogenic techniques could be used by contract strippers for metal furniture in principle but it is unlikely that the cost of this stripping technique would be reasonable. Heat technologies have a small fraction of the market but they are not promising as a METH substitute on a wider scale.

FULL ANALYSIS

A new DBE stripper is available for the consumer market. It is called Safest Stripper and is marketed by 3M. The formulation is a semi-paste paint and varnish remover which is apparently capable of stripping paint, varnish and other wood finishes. It is priced at $4.79 for a one pint container. The stripper remains effective for up to 30 hours and can be washed off with water.

Table 7.1
Classification of Consumer Sector Options

NO FURTHER ANALYSIS	LIMITED ANALYSIS	FULL ANALYSIS
NMP		DBE
Flammable Strippers		
Cryogenic/Alternatives Strippers		
Heat Technologies		

The DBE stripper can be compared with two METH based strippers. The first is a water rinsable semi-paste. It is capable of removing virtually any coating. It requires a 5 to 15 minute working time and when the surface has blistered, the finish can be removed with water and a spatula, steel wool or a cloth. This stripper is priced at $4.49 for a one pint container.

The second METH based stripper is also a semi-paste paint and varnish remover. It is flammable and contains acetone, methanol and petroleum distillates as well as METH. The stripper takes about 15 minutes to work and the sludge should be removed with a wooden scraper. The item can then be washed with water. This stripper is priced lower--about $3.69 for a one pint can.

A one gallon can of Safest Stripper reportedly costs about $20 per gallon. One source estimates the cost of a nonflammable METH based stripper at $18 to $23 per gallon (ICF, 1989). One trial required twice as much of the DBE based stripper but this is unlikely to be the norm. The DBE stripper must be left on for a longer period of time but, to the consumer, the increased labor time may not matter. This analysis assumes that one-third more DBE is required: in that the cost of one gallon of stripper of either kind is $20; that there is 80 percent METH in a gallon of stripper: and that there is no increase in labor for the DBE based stripping operation.

Table 7.2 summarizes the cost and METH use reduction data. It was assumed that two-thirds of the METH used in the consumer sector is used in household stripping and that DBE could substitute for half the METH used. The typical user employs half a gallon of METH annually for stripping activities. Paint stripping usage is assumed to be proportional

Table 7.2
Annual Cost and METH Use Reduction
for Substitution of DBE

User	13.30	0.002
Southern California	2,666,000	400
Nationwide	3,341,000	6,667

to population, so Southern California uses 6 percent of the stripper in the U.S.

The values of Table 7.2 show that the cost to the nation for substituting DBE based stripper in half the consumer sector nationwide amounts to about $2.04 million. The reduction in MBTH use is 6.7 thousand mt. This translates into a cost of about 30 cents per kilogram of METH reduced. In adopting this option, however, there would be an increase in use of DBE of about 8.9 thousand mt. The chemical has not been tested in lifetime animal studies and it is less scrutinized than MBTH.

VIII. CONCLUSIONS

METH based formulations have been effective paint stripping agents in a variety of applications for many years. There is no other paint stripper that can offer the same range of desirable characteristics as METH. Alternative chemicals, products and processes are available in each of the sectors for specific applications. In this section the results of this analysis are summarized, and the future of the paint stripping industry is discussed.

ORIGINAL EQUIPMENT MANUFACTURING

SUMMARY

Table 1.1 showed the options for reducing or eliminating METH use in the Original Equipment Manufacturing sector. In the automotive industry, spray booth cleaning accounts for 35 percent of METH use, immersion cleaning for 35 percent, line purging and gun cleaning for 15 percent and floor stripping for 15 percent. The movement away from METH in this industry has primarily reduced the relative amount used for booth stripping. In other OEM industries, METH use in booth stripping has probably decreased as well.

The process alternatives for booth stripping, like the chemical substitutes, have low potential. High pressure water has safety limitations and peelable coatings are likely already used in most applications where they are appropriate: both could be implemented over the short-term. Sodium bicarbonate is still being investigated for this application and it would take longer to implement it.

Recovery techniques for vapor losses include carbon adsorption, condensation and adsorption. Water blankets and covers can reduce atmospheric emissions. The vapor recovery methods apply to booth and immersion stripping. Adsorption, condensation and adsorption are expensive, they usually require sophisticated equipment and it is unlikely that the METH could be easily separated from the other solvents and contaminants for reuse. Such techniques, although they are available today, have only limited potential and it would take some period of time to implement them. Water blankets are cheap and easy to use and covers apply only to immersion cleaning.

Recovery of METH from waste is not widely practiced today. Because most METH is emitted to the atmosphere, a smaller fraction remains in hazardous waste. In many METH base formulations, acid and other components are preserved in large quantities. Frequently it is not feasible to recover the METH. Thus the potential for reducing METH was through recycling is small. It could be implemented immediately in cases where pure or nearly pure METH is used. Recovery of METH from wastewater offers only limited potential.

Immersion stripping accounts for 35 percent of the market, alternatives include alkaline/acid strippers, ovens and salt baths and cryogenic chambers. All of these are available today but each has only limited potential.

In maintenance paint stripping, all the process modifications listed in Table 1.1 could result in a large reduction in METH use if they were fully implemented. PMB has been tested and used for the last few years and it could be implemented over the short-term. Sodium bicarbonate is being investigated heavily. Cryogenic techniques and carbon dioxide pellets would take longer to implement while lasers, high intensity light and biodegradation are still in the R&D phase and could be adopted only over the longer term. Not painting is an option that is increasingly being chosen by airlines and it could be adopted immediately.

For the consumer sector, flammable strippers are used today but their market penetration is small and is likely to remain so. The new DBE stripper could penetrate a reasonable fraction of the market. NMP--a higher priced solvent--could take only a small share. An NMP based stripper is not yet available. Cryogenic techniques and heat technologies have only limited potential in the consumer sector.

THE FUTURE OF THE INDUSTRY

METH has been under regulatory scrutiny in the last several years and it will continue to come under increased scrutiny in the future. Because of the classification of METH as a toxic air contaminant by the California Air Resources Board, users in that state will have to begin reducing releases of the substance significantly.

METH is an excellent paint stripping agent. Indeed, it is the only chemical stripper that can effectively strip cured coatings from a variety of substrates in a short period of time. METH is the only effective chemical stripper for the tough epoxy and polyurethane coatings favored by the aerospace industry. There are a host of alternative chemicals that could be used in stripping but all are less effective than METH and all require significantly more time to strip coatings. Furthermore, all of the proposed alternative strippers are either flammable or combustible and all are photochemically reactive. Virtually none of these chemicals has been tested in lifetime animal studies for carcinogenicity.

In the original equipment manufacturing sector, users will continue to move away from METH. In low volume operations, peelable coatings can be used for paint stripping. In higher volume operations, the alternative chemical strippers mentioned above can be used for stripping uncured paint from booths. Such strippers can also substitute for METH in gun and line cleaning. Cryogenic stripping can substitute for immersion stripping with METH and, in some cases, the METH could be recycled, reducing the requirement for virgin chemical.

In maintenance stripping, there has been a movement away from METH and into PMB in recent years. Particularly in military applications, this trend will continue. In spite of recycling, PMB still generates a large volume of waste that requires disposal. Our analysis suggests that the sodium bicarbonate technique is less costly than PMB and a much lower volume of waste is generated because the media can be separates from the paint waste. Accordingly, SRRP staff believe that some military users and commercial users will begin to increasingly adopt sodium bicarbonate, particularly those who have not already made the capital investment in PMB equipment. There is still ongoing research to determine whether PMB contributes to long-term structural damage. Research has been initiated into the potential for sodium bicarbonate to cause corrosion.

In the consumer sector, consumers will begin purchasing the new DBE based stripper for home use in spite of the fact that it requires substantially more time than METH based strippers to remove paint. Although it was not analyzed, DBE may be appropriate for contact stripping operations as well. Whether or not the increased stripping time would pose a severe problem to contractors is a subject for future research. Although there is no reason to expect DBE to be a carcinogen, it has not been tested in lifetime animal studies and until it is, its chronic toxicity remains in question.

VII. REFERENCES

Aerolyte Systems, "Practical Systems Designed Especially for Paint Stripping with Plastic Media," brochure, undated.

Allison, S.W. and R.G. Rudness, "Laser Based Paint Stripping," Enrichment Technology Applications Center, November, 1987.

Arnex, "Announcing a Significant Advance in Aircraft Depainting Efficacy and Safety," brochure, Church 61 Dwight Co., Inc., 1989.

Arthur D. Little, "Draft Final Report for Implementation of Plastic Media Blasting," June 1, 1987.

Aviation Mechanics Journal, "Taking it Off," Part I and Part II, April and June, 1986.

Aviation Week & Space Technology, "Airlines Urged Not to Paint Fuselages as Concerns About Aging Fleet Rise," February 6, 1989.

Aviation Week & Space Technology, "Dry Stripping Cuts Hazardous Waste Materials," March 3, 1986.

Aviation Week & Space Technology, "Plastic Particles Peel Paint Without Pollution," January 12, 1987.

Batelle Columbus Division, "Plastic Bead Blast Materials Characterization Study Follow-On Report," November 13, 1987.

Bilbak, R., R.B. Thompson and J. Watson, "Plastic Media Blasting, Research, Implementation Factory Support,[11] Boeing Helicopters, May 20, 1986.

Burbank Paint and Hardware Co., Burbank, CA, brochure, 1989.

Chemical Marketing Reporter, Chemical Profile, Methylene Chloride, February 10, 1986.

Chemical Marketing Reporter, Chemical Profile, Methylene Chloride, February 20, 1989a.

Chemical Marketing Reporter, October 30, 1989b.

Chemical Week, "Safer, But Will They Cost More?", October 1, 1986.

Corpus Christi Army Depot, "Organic Coating Removal via Multiple Plastic Media Blast Cycles on Clad Aluminum Airframe Skins," J.B. Bullington and D.R. Williams, undated.

Du Pont Dibasic Esters, brochure, undated.

Del Crane Cryogenics, brochure, undated.

Doscher, P., Boeing Aerospace and Electronics, Telephone Conversation, December, 1989.

Ehrler, A.J., "Closed-Loop Adsorption for Solvent Recovery," Metal Finishing, November, 1987, p.53

Fong, C., "Pollution Free Blasting," Lockheed-California co., SAMPE Journal, October/November/December, 1975.

GAF, N-Methyl-2-Pyrrolidone, brochure, 1986.

Hans, H.B., "A Guide to Paint Strippers," Industrial Finishing, August, 1980, p.28

Hedberg, F., Hill Air Force Base, Telephone Conversation, November, 1989

Hill Air Force Base, "Paint Stripping of F-4 Aircraft and Component Parts Using Mechanical Methods," August 28, 1986.

ICF Incorporated, "Use and Substitutes Analysis of Chlorinated Solvents in Paint Stripping," April 26, 1988.

Industrial Finishing, "Freezing Paint for Removal," May, 1984.

Industrial Finishing, "Cryogenic Stripping of Paint from Hangers," Industrial Finishing, 1986.

Industrial Finishing, "Stripping Paint Hangers Cryogenically," January, 1985.

Jackson, H., DuPont, Telephone Conversation, November, 1989.

Kirk Othmer Encyclopedia of Chemical Technologies, 1979.

Kwick Kleen Chemical and Supply Catalog, Vinennes, Ind, 1989.

Kwick Kleen operations Manual, Vincennes, Ind, 1987.

Lee, R., Schmidt Manufacturing, Inc., Houston, Texas, Telephone Conversation, November, 1989.

Lovoi, P., "Waste Stream Management for the Laser Paint Stripping Process," presented at the Fourth Annual Aerospace Hazardous Waste Minimization Conference, May 23-25, 1989.

Lucas, D.F., "A New Solvent for Industrial Cleaning," E.I. DuPont de Nemours, September, 1988.

Mallarnee, W.R., "Paint and Varnish Removers," in Encyclopedia of Chemical Technology, undated.

Modern Metals, "Eliminating VOCs from Paint Booth Envisions, March 1989, p.74.

NCEL, Naval Civil Engineering Laboratory, Port Hueneme, Ca, "Plastic Media Blasting Data Gathering Study: Final Report," December, 1986.

Parrish, R.L., "The Art, Science and Politics of Paint Removal," Business and Commercial Aviation, November, 1987, p.63.

Paul and Griffin, "Pram Dry Stripping Systems," brochure, undated.

Philadelphia Inquirer, "2 Paint-Removal Products Can make Life Much Easier," January 28, 1989.

Radian Corp, "Monitoring Data for Paint Stripping," E. Pfetzing, September 25, 1987.

Radian Corp, "Emissions, Controls and HEM Inputs Memorandum of Paint Stripping Users," Claire Most, Memo, January 7, 1988.

Sizelove, R., "Paint Stripping Updated," Industrial Finishing, October, 1972, p.44.

Stanford Research Institute (SRI), "Integrated Analysis: Paints," W.F. Mullen and C.B. Mould, Menlo Park, Ca, December, 1985.

Surfprep, "Machines for Surface Preparation Using High Intensity Pulsed Light," A&R Industries, undated.

Tapscott, R.E., G.A. Blahut, and S.H. Kellogg, "Plastic Media Blasting Waste Treatments,"New Mexico Engineering Research Institute, July, 1988.

U.S. Environmental Protection Agency, General Motors, B-O-C Group-Lordstown Assembly, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987a.

U.S. Environmental Protection Agency, General Motors, Truck and Bus Group - Shreveport, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987b.

U.S. Environmental Protection Agency, General Motors, Truck and Bus Group-Flint, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987c.

U.S. Environmental Protection Agency, General Motors, Fisher Guide Division - Indiana, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987e.

U.S. Environmental Protection Agency, General Motors, Fisher Guide Division - Indiana, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987f.

U.S. Environmental Protection Agency, General Motors, Ford-Dearborn, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987g.

U.S. Environmental Protection Agency, TWA, Submission to OAQPS in Response to EPA Section 114 Questionnaire, March/April 1987h.

U.S. Environmental Protection Agency, Aircraft Paint Services, March/April 1987i.

Wolbach, C.D. and C. McDonald, "Reduction of Total Toxic Organic Discharges and VOC Emissions from Paint Stripping Operations Using Plastic Media Blasting," Journal of Hazardous Materials, Vol. 17, 1987, p.109.