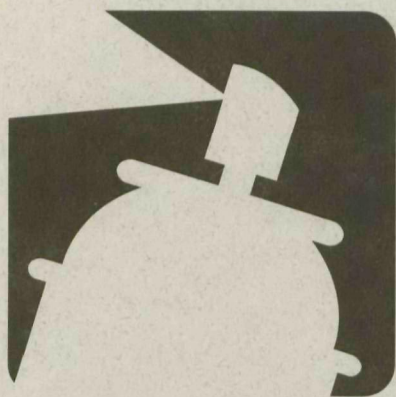


Source Reduction Research Partnership
Metropolitan Water District of Southern California
Environmental Defense Fund

**Source Reduction of
Chlorinated Solvents**

Aerosols Manufacture



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

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AEROSOLS MANUFACTURE

Prepared for

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

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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 and 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

The statements and conclusions of this report do not necessarily represent those of the State of California, the U.S. Environmental Protection Agency or any other contributors. The mention of any commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

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), 1,1,1-trichloroethane (TCA), methylene chloride (METH) and 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113). Of these, METH and TCA are commonly used in aerosol products. PERC and CFC-113 are also used to some extent, while TCE is not used in any significant amount.

This report is one of several companion reports that focus on source reduction of chlorinated solvents in the industries where the solvents are widely used. This document specifically addresses the aerosol packaging industry and provides an assessment of the source reduction potential within that industry. The aerosol products industry currently uses about 57 thousand metric tons (mt) of chlorinated solvents annually. In recent years, there has been a movement away from these solvents, particularly PERC and METH, in certain market segments. This is the result of increased regulatory pressure in the form of air quality regulations and labelling requirements. Aerosol fillers have replaced some chlorinated solvent based formulations with water based or flammable hydrocarbon solvent based products.

Much of the regulatory attention, particularly at the state level (California and New Jersey, for instance), focuses on the end use of the aerosol product, rather than emissions at the aerosol packing plant. Of the total amount of solvent used in aerosol products, very little is lost to the atmosphere during container filling. Virtually all of the emissions occur during product use at the consumer or industrial level.

In the balance of this document, we discuss the aerosol industry in detail. Section II focuses on the design and filling of aerosol products and discusses market segments,

solvent usage and industry trends. Section III describes the source reduction options that may be implemented to reduce chlorinated solvent usage in the industry. Options fall into four categories--process modification, solvent recovery and reuse, product substitution and chemical substitution. Section IV provides a case study of two chemical substitution options in aerosol products, and limited analysis of other options. Section V summarizes our findings.

II. INDUSTRY BACKGROUND

An aerosol product can be any of a large number of consumer or industrial use products packaged in a pressurized container. "Aerosol" refers to the packaged form, rather than the product contained therein. An aerosol product can be dispensed as a mist, fine or heavy spray, a liquid stream, foam or powder. Characteristics of the dispensed form are determined by the combination of ingredients in the formulation and by the choice of container hardware. Basically, an aerosol product consists of an active ingredient, a liquid propellant and an appropriate solvent in a container. The propellant is also present as a vapor, creating the pressure in the container. When the product is released, the propellant evaporates immediately.

Aerosol packaging provides the user with convenience, ease of product transfer, and efficient product distribution. The container seals itself after each use. The product retains its composition because there is no way for material to evaporate from the container. Since the aerosol package is always sealed, product contamination is avoided. User contact with hazardous ingredients is limited to intentional use, and accidental release of the product through leaks or spills is less likely to occur than with other product forms.

This section consists of eight subsections. The first addresses solvent usage in general and within market segments. The second subsection describes aerosol product design. The third subsection discusses U.S. aerosol packaging facilities. In the fourth subsection, the filling process is described and sources of releases are identified. The fifth subsection discusses costs of aerosol products. In the sixth subsection, we review the results of our site visits and surveys. The last two subsections address industry and regulatory trends that impact solvent usage.

TABLE 1.1
Source Reduction Option Summary

<u>Option</u>	<u>Advantages</u>	<u>Disadvantages</u>	<u>References</u>
Correction of over and under filling	Reduces production and management costs	Low potential for waste reduction	Flanner, 1988
Improved maintenance practices	Low capital expenditure		Martinez, 1987
Vapor recovery-refrig. condensation	Can reduce solvent emissions from storage tanks & mixing by 95%		Martinez, 1987
Vapor recovery-carbon adsorption	Can reduce solvent emissions from mixing by 95%	Hazardous wastes are generated from carbon recovery operations	Martinez, 1987
Solvent recycling from cans	Able to reduce production material requirements and costs	Recycling contents of some cans presents fire and explosion danger unless proper equipment used Proper can-puncturing equip. is not cost-effective for many shops to buy	Flanner, 1988
Cleaning solvent reuse	Low capital expenditure		
Non-aerosol packaging	Potential for large air emission reductions	Use not as convenient as aerosol packaging Some production still require haz. solvents as active ingredients	Geigel & Miller 1985 ICF, 1987 a,b Westate, 1987

SOLVENT USAGE

A wide variety of product types are packaged as aerosols. An estimated 2.9 billion units of pressurized products were filled in the U.S. in 1988 (CSMA, 1989a). The major categories included in this total are household products, personal care products, industrial and automotive products, foods, paints and related products, and insect sprays.

Various sources have estimated chlorinated solvent usage in the aerosols industry. As illustrated in Tables 2.1 through 2.3, these estimates vary widely. SRRP staff estimates of 1988 solvent usage are summarized in Table 2.4. Table 2.1 lists TCA usage estimates obtained from different sources for the years 1981 through 1988. The numbers range widely from year to year, which could indicate that TCA use has fluctuated in recent years. SRRP believes that this is not so, and that the 1987 value of 18 thousand metric tons (mt) significantly underestimates actual use. Based on these figures and discussions with industry experts, it is estimated that 34 thousand mt of TCA were used in the aerosols industry in 1988.

Estimates of METH usage also vary widely from year to year (Table 2.2). Even within each year, the numbers are inconsistent. For instance, one source estimates that 20 thousand mt of METH were used in 1987. According to another source, 41 thousand mt were used. As broad as the ranges are for estimated use of METH, the values indicate that METH use in aerosols has, in general, declined from 1984 to 1988. Various sources confirm this trend (ICF, 1987a; Dow, 1989a). We estimate that 20 thousand mt of METH were used in aerosol products in 1988.

Table 2.1

TCA Consumption in the Aerosols Industry

<u>Year</u>	<u>Volume (thousand metric tons)</u>	<u>Source</u>
1981	27	CMR, 1982
1982	27	CMR, 1983
1984	23	Geigel and Miller, 1985
	23-31	ICF, 1987a
1985	19	CMR, 1986
	29	HSIA, 1987
1987	19-24	ICF, 1989
1988	32	CMR, 1989a
	32	Cuzic, 1989
	34	SRRP Estimate

Table 2.2

METH Consumption in the Aerosols Industry

<u>Year</u>	<u>Volume (thousand metric tons)</u>	<u>Source</u>
1983	52	HSIA, 1985
1984	29-39	ICF, 1987a
	34-43	Geigel and Miller, 1985
1985	73	Chemical Week, 1987
	45	ICF, 1987a
1986	42	HSIA, 1986
1987	20	Pfetzring, 1987
	21	ICF, 1989
	41	HSIA, 1989
1988	41	CMR, 1989b
	20	SRRP Estimate

Table 2.3

PERC Consumption in the Aerosols Industry

<u>Year</u>	<u>Volume</u> <u>(thousand metric tons)</u>	<u>Source</u>
1984	4.5	Geigel and Miller, 1985
1987	4.3	ICF, 1989
1988	3	SRRP Estimate

Table 2.4

Chlorinated Solvent Consumption in the Aerosols Industry
1988 SRRP Estimates

	<u>Thousand Metric Tons</u>
TCA	34
METH	20
PERC	3
CFC-113	0.6
TCE	<u>-</u>
Total	57.6

Only a small amount of PERC is consumed in aerosols. The figures in Table 2.3 indicate that use ranges from 3 to 5 thousand mt. PERC use is expected to decline in the future because of concerns over the health effects of PERC exposure. CFC-113 usage in 1988 was less than one thousand mt. No significant amount of TCE is used in aerosols. Because of its relatively small volume of use, source reduction of TCE will not be discussed in the balance of this report.

It is important to note that the pattern of solvent usage has changed rapidly in recent years and continues to change in response to regulatory pressures, economic considerations and consumer preferences. Consumption data, even from as recent as 1988, may not accurately reflect current solvent usage.

The aerosols market can be described in terms of general product categories, with each category further divided into product segments. One industry trade group identifies the following eight categories:

- insect sprays,
- paints and finishes,
- household products,
- personal products,
- animal products,
- automotive, industrial and miscellaneous household
- food products, and
- miscellaneous products.

Table 2.5 summarizes the number of containers filled in each of these categories in 1988 and their contribution to the total. Several studies have analyzed chlorinated solvent usage in aerosol products. Among them are Geigel and Miller, 1985;

Table 2.5

Containers Filled in Eight Categories in 1988

	Number of Units Filled (in millions)	Percent of Total
Personal Products	1,100	37.8
Household Products	650	22.4
Automotive and Industrial	440	15.1
Paints and Finishes	331	11.4
Insect Sprays	190	6.5
Food Products	157	5.4
Miscellaneous	31	1.1
Animal Products	<u>8</u>	<u>0.3</u>
Total	2,907	100.0

Source: CSMA, 1989a.

Westat, 1987; and ICF, 1989. Some of these report detailed analyses of chlorinated solvent concentration in product formulations, and estimate solvent usage by industry segment. We will refer to these studies where appropriate but do not reproduce all of the data here. The pattern of solvent usage has changed in recent years, and continues to change at present. Solvent consumption estimates from as recent as two years ago cannot be considered reliable estimates of current usage trends. We attempt to address solvent usage in the industry in general, and use specific examples to illustrate successes or difficulties in implementing various source reduction options.

Based on U.S. market estimates, personal products represent over a third of all aerosol products filled in 1988 (CSMA, 1989a). Included in this category are hair sprays, mousse and other hair products, deodorants and antiperspirants, shaving lather, colognes and perfumes, and other personal care products. Medicinal and pharmaceutical products are also included in this category. Other than a small amount of METH, no chlorinated solvents are used in personal care products. One source places 1987 METH consumption in personal care products at 0.4 thousand mt (ICF, 1987a). In the past, METH was widely used as a co-solvent in hair spray products. When the industry moved away from CFC propellants in the late 1970s, the flammable hydrocarbon propellants isobutane and propane replaced the CFCs. METH was found to be very good at reducing the flammability of the newer hair sprays, and also served to solubilize the resins and propellants into an alcohol base. Because of its volatility, it causes the hair spray resin, when applied, to dry and set quickly (Aerosol Age, 1989a). One estimate places METH use in hair sprays at about 13.6 thousand mt in 1983 (Geigel and Miller, 1985). Because of concerns over the health hazards associated with METH exposure, and pending

federal regulations requiring labelling of consumer products containing METH or an outright ban on the use of METH in cosmetic products, its use in hair sprays declined dramatically. A solvent trade group states, in comments to the U.S. Food and Drug Administration (FDA), that "all or virtually all manufacturers or formulators" had stopped using METH in cosmetics. According to FDA, however, at least one manufacturer is currently using METH in aerosol cosmetics (Aerosol Age, 1989a). By and large, METH and the other chlorinated solvents are not widely used in personal care products, but we are aware of at least one pharmaceutical product that contains TCA. Chlorinated solvent usage in personal care products is not expected to increase in the future.

The second largest use of aerosols in the U.S. is in the household products category. Its share of the 1988 U.S. aerosol products market has been estimated at 22 percent of the total market (CSMA, 1989a). Included in this category are household cleaners (i.e. for rugs, appliances, walls and other surfaces and fabrics), laundry products (pre-wash sprays, spot removers, etc.), room deodorants, waxes and polishes, water repellants and water proofing products for shoes and other items, and miscellaneous other products. Some of these products are likely to contain TCA, PERC or METH. For instance, any of these three can be used as the active ingredient in laundry spot removers. In cleaning products, a high degree of solvency is desired, which is why PERC, METH and TCA are good choices. Water repellants are usually silicone based products in which TCA or PERC is used as a solvent. Many fabric protectors and sprayable shoe polishes are formulated with TCA. Estimates of solvent consumption in household aerosol products are 0.5 thousand mt of METH, 7.5 thousand mt of TCA, and 1.0 thousand mt of PERC (ICF, 1987a).

Automotive and industrial products make up the third largest use of aerosol products in the U.S. Based on 1988 data, this market accounted for 15 percent of the aerosol products filled (CSMA, 1989a). Automotive products include carburetor, choke, fuel injector, and brake cleaners, engine starting fluid, tire inflator and sealant, automotive spray undercoatings, engine degreasers, cleaners for vinyl, leather, upholstery and tires, and windshield and lock spray de-icers. Refrigerants, lubricants, mold releases, adhesives and other products are also included in the automotive and industrial category. In many automotive and industrial products that contain chlorinated solvents, such as cleaners, the solvents are present as active ingredients. Chlorinated solvent usage is higher in this category than in any other. TCA is used most often, followed by METH, PERC and CFC-113. Solvent consumption in automotive and industrial aerosol products has been estimated at 8 thousand mt of TCA, 7 thousand mt of METH, and 1.7 thousand mt of PERC (ICF, 1987a).

TCA is formulated into engine cleaners because its high dielectric strength allows engines and appliances to be cleaned while they are operating. Lubricants include metal cutting fluids, mold release agents and silicone compounds. There are many different types of these products, and they are used in a wide variety of applications and environments. General purpose lubricants are likely to contain TCA, METH, or petroleum distillates. For technical reasons, TCA or the petroleum distillates are favored. METH is less often used. Silicone lubricants designed to be used in broad temperature range applications are generally formulated with TCA and METH as solvents. For these products also, TCA is reportedly preferred over METH. TCA, being a slower evaporating solvent, tends to spread the silicone lubricant better before all of it evaporates. Conversely, METH is preferred over TCA as the

solvent in aerosol mold release agents because it evaporates more quickly. Often, a blend of METH and TCA is used in industrial and automotive aerosols to achieve desired product properties.

There are many types of adhesives available in aerosol form. Of those that contain chlorinated solvents, METH is almost always the solvent used. Some formulators have switched to TCA as the solvent in sprayable adhesives although its slower drying properties make it less desirable. Some adhesives containing METH cannot be reformulated. Where a fast drying adhesive is required, only METH provides good solvency characteristics, fast drying, and an acceptable spray pattern.

CFC-113 is used in only one segment of the aerosols market. In industrial applications, CFC-113 and TCA are used in cleaners for electronic equipment and electrical contacts.

In the automotive market there are a number of aerosol products that contain METH, TCA and PERC. In many cases, chlorinated solvents are used in cleaning and degreasing products because they are such good cleaners. They serve partly as the active ingredient, and partly as the solvent in the blend. For some of these products, TCA is preferred since its slower drying allows the cleaner to remain on the part's surface longer and seep into cracks or small joints. Engine degreasers are commonly made with a blend of all three solvents, although PERC has historically been used more than TCA or METH. It has been reported that PERC use is dropping in this product segment, with TCA being used in its place.

Battery cleaners may contain METH, TCA and PERC in small amounts. Spray undercoatings contain METH, alone or in combination with TCA, or may use petroleum distillates as

solvents. Most brake cleaners contain a blend of TCA and PERC. METH and TCA are used in aerosol tire cleaners. The chlorinated solvents swell the rubber in tires and make cleaning easier. METH is frequently used in carburetor cleaners.

Paints and coatings accounted for approximately 11 percent of the aerosol products filled in the U.S. in 1988 (CSMA, 1989a). This category includes traditional spray paints, primers, varnishes, rust inhibitors, wood stains, paint strippers, and artificial snow and other decorative products. About 80 percent of these products are spray paints. Spray paints consist of pigments which provide color and capacity, a resin system that forms the continuous paint film upon drying, solvents and propellants. Four different kinds of materials must be contained in solution or in suspension within the aerosol container. METH is the solvent of choice in many aerosol paint products. Water is used as well, as is discussed in Section III. One source estimates that 10.5 thousand mt of METH were used for aerosol paint products in 1987 (ICF, 1987a).

The amount of METH in a spray paint formulation depends on several factors. Important among them are the type of paint (e.g., flat, gloss) and the type and concentration of solids (resin and pigment) in the paint. For instance flat paints generally have a higher concentration of pigment and, consequently, a lower percentage of solvent (usually METH). Gloss paints contain less pigment and a higher concentration of solvent (ICF, 1987a).

Insect sprays accounted for almost 7 percent of the 1988 aerosol products market (CSMA, 1989a). Chlorinated solvents are used in many insect sprays. Products within this category include room insecticides (such as total release foggers), personal use sprays, pet flea and tick products and

insect repellants. Chlorinated solvents are most widely used in total release foggers, house and garden insect sprays, residual insecticides, and flying insect killers. The function and source reduction potential of pesticides is addressed in more detail in the companion document "Pesticides Industry".

Aerosol insecticides are formulated with toxic active ingredients, solvents and propellants. A mixture of active ingredients is used. A knock-down agent stuns the insect upon contact, another toxic ingredient kills the animal, and a synergist is added to improve the activity of the first two components. TCA is reported to be the most effective knockdown agent available for wasp and hornet sprays (CSMA, 1989b). It evaporates and rapidly cools the insect's body. The propellant system is a mixture of propane and isobutane, or CO₂. Other hydrocarbons (base oils) are added to the blend as carriers, but because of their poor solubility, do not function as solvents. Careful solvent selection is important to solubilize the various ingredients and propellants and to achieve the right droplet size. METH and TCA are used as solvents in insect sprays, although water and aromatic solvents will work in many cases. 1987 solvent use in aerosol insecticides has been estimated at 2 thousand mt of METH, and 1.7 thousand mt of TCA (ICF, 1987a).

Wasp killers represent one specialty product that uses only CFC-113. When utility employees are working on high voltage electrical lines, they need an effective, sprayable wasp killer that will not be conductive. CFC-113 is used for this purpose. EPA recognizes this product as an essential use of CFC-113, one in which alternative solvents are not feasible. It is estimated that 600,000 cans per year of wasp killer are produced, with CFC-113 concentration in the product ranging from 70 to 85 percent (ICF, 1987a). TCA, because of its electrical properties and nonflammability, is used in insecticides applied near transformers and other electrical equipment.

Total release foggers are designed to quickly release their entire contents in one application. They are used to exterminate insects in large areas. Total release foggers have traditionally consisted of 15 percent active ingredient and 85 percent propellant. CFCs were the propellants of choice until the late 1970s. Since the phaseout of CFCs in aerosol products, the formulations have changed. Typically, total release foggers now contain one to three percent active ingredients (toxicant) and about sixty percent of a METH/TCA blend. The percentage of relative METH and TCA varies by product.

In response to consumer concerns about the safety of total release foggers that contain flammable propellants, large quantities of TCA are added to the formulations. TCA is used because it is nonflammable (Johnsen, 1988). As in other products, the use of METH is declining.

The remainder of the major aerosol product categories are animal, food and miscellaneous products. Animal and food products do not contain chlorinated solvents to any significant degree.

PRODUCT DESIGN

An aerosol product is a combination of (1) the desired product to be dispensed, (2) a propellant and solvent system, and (3) the container hardware. Careful selection of each of these components is critical to the successful development of a product in aerosol form.

A typical aerosol container is shown in Figure 2.1. Major components of the hardware include the container itself, valve assembly and actuator. Most containers are made of

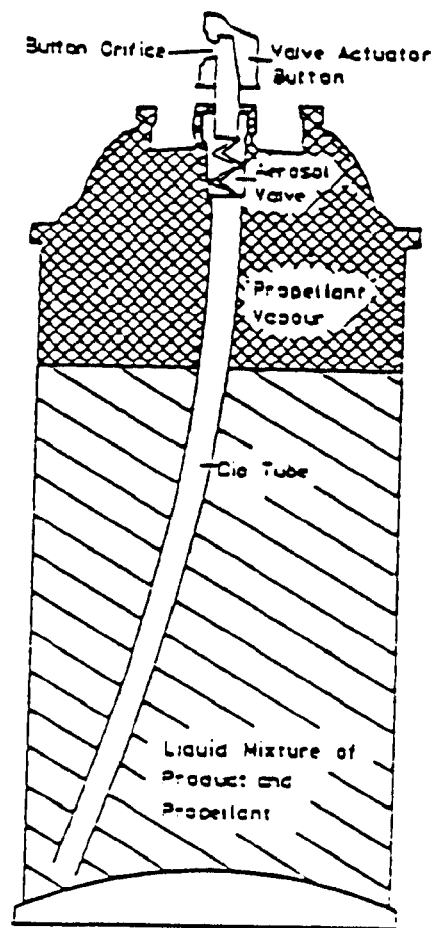


Figure 2.1

Basic Components of an Aerosol Container

Source: Geigel and Miller, 1985.

tinplate, although aluminum containers are available (approximately 13 percent of the aerosols market). Tinplate and aluminum containers are sometimes lined to prevent contact with a product that may react with the metal, or which may cause pitting or corrosion of the can. Glass and plastic containers are also used, primarily for personal care products such as perfume and cologne. U.S. Department of Transportation regulations don't permit the use of nonmetallic pressurized containers larger than 118.3 cc's (3.5 to 4 fluid ounces).

The purpose of the valve system is to dispense the product in the desired form, pattern, and dosage. The valve system also serves to keep the top opening of the container closed and to retain adequate pressure within the container. A valve assembly is illustrated in Figure 2.2. The choice of valve assembly determines the form and dose of the dispensed product. Valves are manufactured in standard sizes and are selected to produce the desired pattern, i.e. spray, foam or specialty valves. Hardware components must be chosen to be nonreactive with all ingredients in the blend, to function properly and to not contaminate the product in any way. The type of hardware used can influence the flammability of the aerosol product (Cuzic, 1989).

While proper selection of the valve system is important to proper dispensing action, selection of the formulation components is equally important. Components that must be considered include the active ingredients, propellant and solvent blends, and additives. Propellants used in aerosol products are either liquified or compressed gases with vapor pressures greater than atmospheric pressure. The propellant is present in the container in both the liquid and vapor phases. When the actuator button is pushed, the valve opens and the propellant vapor expands, providing the driving force to expel the contents from the container.

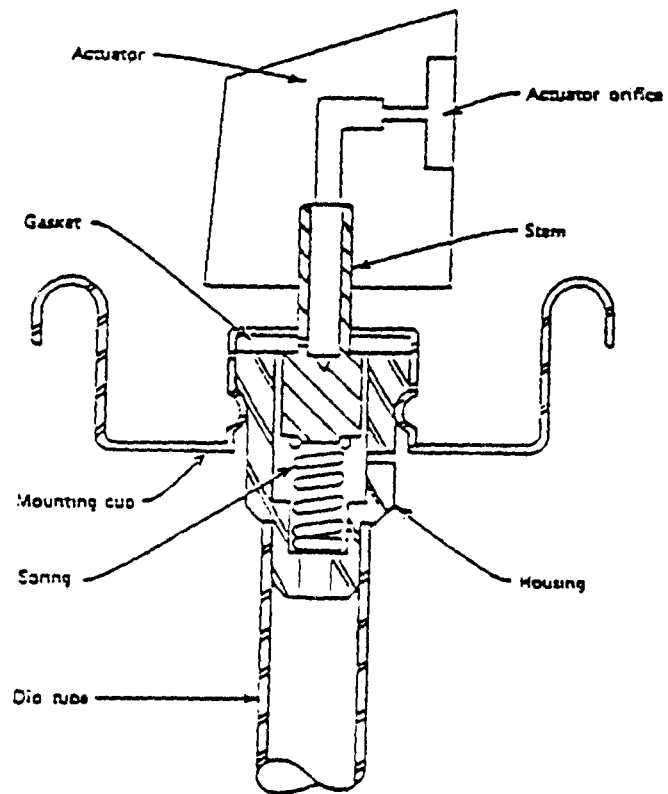


Figure 2.2

Aerosol Valve Assembly

Source: Adapted from Kawam and Flynn, 1979.

Selection of a propellant involves consideration of its vapor pressure, solubility, chemical compatibility with other product ingredients, and wetness or dryness of the desired product. Often, a blend of propellants is chosen to achieve the right properties of product delivery, solubility, cost, vapor pressure and degree of flammability. The propellant vapor pressure inside the container determines the product delivery rate, which is also influenced by the chemical composition of the propellant and its concentration. Droplet size and the "wetness" of the spray are also influenced by the choice of propellant. The propellant affects the solubility of other components in the formulation.

For effective product delivery, it is desirable to have the active ingredient, solvent and propellant in solution in the liquid phase. Liquified propellants don't usually go into solution well, making careful solvent selection important. Traditional liquified propellants include the chlorofluorocarbons CFC-11, CFC-12, and CFC-114; and flammable hydrocarbons such as propane, n-butane and isobutane. An advantage to using liquified propellants is that they maintain a constant pressure in the container until the contents are completely exhausted. CFCs are no longer used in aerosol products because they are known to deplete the stratospheric ozone layer. This is discussed in more detail in the section on regulatory trends.

The liquified petroleum gases are widely used as propellants, even more so since the use of CFCs has diminished. Because liquified petroleum propellants are flammable, flammability suppressants must be added.

Compressed gas propellants perform differently in an aerosol container. They are present only in the gas phase, not in the liquid phase. Carbon dioxide (CO₂), nitrous oxide

(N_2O), and nitrogen (N_2) are commonly used as compressed gas propellants. They are nontoxic, nonflammable, inert gases and are lower in cost than liquified propellants. As an aerosol package containing a compressed gas propellant is dispensed, the vapor pressure within the container diminishes. Since the propellant pressure released to the atmosphere provides the force to push product out of the container, this gradual decrease in vapor pressure effects the spray characteristics and rate of flow. This causes performance problems with certain types of formulations.

Most propellants, especially halocarbons and hydrocarbons, tend to have poor solubility characteristics. One or more solvents must be added to the blend to mutually solubilize the active ingredients and the propellant. Selection of the appropriate solvent or solvent blend is important in order to ensure that the active ingredients are present as a homogeneous solution with the propellant, or to solubilize a compressed gas propellant into an ingredient concentrate. Choice of the solvent also influences the rate of spray and droplet size. In some products, the solvent itself performs as an active ingredient.

Substances used as solvents in aerosol products include water, acetone, methyl ethyl ketone (MEK), alcohols, chlorinated hydrocarbons, and other organic compounds. An indication of the relative solubility of different solvents can be obtained by comparing their Kauri-Butanol values. A Kauri-Butanol value is a measure of how well a solvent solubilizes a standard solution of Kauri resin in butanol. A high Kauri-Butanol value indicates strong solvency properties. In general, chlorinated solvents have high Kauri-Butanol values when compared to other organic solvents. Table 2.6 lists Kauri-Butanol values for the chlorinated solvents under study, as well as other common solvent characteristics.

Table 2.6
SOLVENT PROPERTIES

Chemical	MEH	TCA	CFC-113	PERC	ACETONE	MEK	Water	Xylene (mixed)
Formula	CH ₃ Cl	CH ₂ Cl ₂	CCl ₃ FCClF ₂	CCl ₂ CCl ₂	CH ₃ COCH ₃	CH ₃ COC ₂ H ₅	H ₂ O	
Molecular Weight	85	133.4	187.4	165.9	58.1	72.1	18	
Boiling Point (°F)	104	165	118	252	133	175.4	212	140
Density (g/cc @ 70°F)	1.33	1.33	1.57	1.62	0.80	0.81	1.0	
Solubility in Water (wt % @ 70°F)	2	0.07	0.02	0.02	100	27	N/A	
Kauri-Butanol Value	136	124	31	90				95
Flash Point (°F, Closed Cup)	None	None	None	None	-15	23	N/A	79
Vapor pressure (MMHG @ 20°C)	300	125		18	185.5	70.9	17.5	
Solubility Parameter	9.7	4.64	7.3	9.3	10	9.3	23.4	8

In some products, the solvent itself performs as an active ingredient. TCA and METH are widely used in aerosol products because they possess unique characteristics that improve product quality, efficacy and safety. When used with flammable hydrocarbon propellants, TCA and METH serve to reduce the flammability of the product so that it can be safely used. They solubilize compressed gas propellants, and depress the vapor pressure of flammable propellants, allowing more propellant to be put in the container. This results in more uniform spraying, less waste and longer product shelf life. Both TCA and METH are especially good solvents for use with CO₂ propellants.

TCA and METH have excellent solvency properties, and can solubilize most active ingredients. Most resins, such as those in paints and adhesives, are not highly soluble in water or in the common hydrocarbon propellants. They are often soluble in chlorinated solvents, especially METH, which accounts for its use in aerosol adhesives and spray paints. Chlorinated solvents keep solid materials in suspension longer than other solvents. This helps to improve spray characteristics and reduce valve clogging (Cuzic, 1989). Chlorinated solvents provide more weight to each package because they are denser than most other commonly used solvents. Higher density is beneficial because it retards product settling, and also helps prevent valve clogging.

Because of its high evaporation rate, METH is a very good solvent for products that require quick drying properties. Rapid drying improves atomization, yielding smaller particles and a drier spray. TCA evaporates a little more slowly, and is useful in products that require less rapid drying. PERC evaporates even more slowly, and is used in products where it is desirable to have the product stay on a surface longer. Automotive engine degreasers, for example use PERC.

Of the chlorinated solvents used in aerosols, only METH is used as a component of the propellant system where it serves as a propellant co-solvent. There are several grades of METH available. One has an inhibitor added to scavenge hydrochloric acid (HCl) that may form when METH reacts with water or degrades. This is designed to be used in aerosol containers susceptible to corrosion and leak formation, or where contamination of the product could result.

The use of METH grew steadily from 1973 through 1982. Part of this growth was a result of the decrease in CFC propellant use. As hydrocarbon propellants replaced the CFCs, more chlorinated solvent was used to solubilize the propellants. Since 1982, METH use in aerosols and particularly in personal care products has declined. Reasons for this decline are discussed in the subsection on regulatory trends.

There are two general types of aerosol mixtures. A homogeneous aerosol mixture is one in which all of the components are mutually soluble under pressure. To achieve this, more than one solvent is usually required. A homogeneous aerosol is a single, liquid phase mixture in equilibrium with the vapor phase in the container. The package does not need to be shaken before use. Examples of homogeneous aerosols include hair sprays and some insecticides (Geigel and Miller, 1985).

In a heterogeneous aerosol mixture, the ingredients are not mutually soluble. This type of aerosol product usually consists of three or more phases in a single container. Examples of heterogeneous aerosols include antiperspirants, foot sprays and other powdered products. Powder aerosols are more difficult to produce than other aerosol types. Sedimentation and agglomeration of the powder ingredient within the liquid phase can occur, both in the container and as it is dispensed. Powders can clog the valve system and cause leaks. Formulation,

selection of hardware and the filling process must be carefully examined to successfully formulate powder aerosols. Powder sprays consist of an insoluble powder (active ingredient) suspended in a liquid propellant. Oily dispersants and suspending agents aid in keeping the powder dispersed.

An emulsion is a mixture of two or more liquid phases, usually an oil phase and water, in equilibrium with a vapor phase. Oil-in-water emulsions are dispensed as foams. The propellant is present in the internal, dispersed phase. When the product is released from the container, the propellant vaporizes and expands into the continuous, aqueous liquid phase. Shaving lather is an example of an emulsion foam.

U.S. AEROSOL PACKAGING FACILITIES

Aerosol packing facilities are identified in SIC Codes relating to the products they fill (i.e., paints, chemicals, cleaning preparations, etc.), in SIC Code 3411, Metal Cans, or or in SIC Code 7399, "Business Services Not Elsewhere Classified". Large fillers usually produce a wide variety of products from several product categories. Smaller fillers, and some dedicated facilities owned by large companies, may fill as few as one or two product types. Custom fillers are manufacturers that fill aerosol packages for other companies.

A 1984 industry survey indicated that there were 217 companies in the U.S. with aerosol filling lines (CSMA, 1985). According to that survey, 130 of these facilities are reported to account for 88 percent of the total number of containers filled. In a study done for the U.S. EPA, 212 aerosol fillers were identified (Martinez, et al, 1987). Another EPA report states that there are 117 U.S. fillers. Yet another study for EPA reports 215 aerosol packing plants (ICF, 1988). A more recent industry survey conducted by CSMA reports that 151

fillers represented 94 percent of all the containers filled in the U.S. in 1988 (CSMA, 1989a).

Table 2.7 lists 104 U.S. custom fillers, their locations, and the types of products they package. Other manufacturing plants that fill their own aerosol products are not included in the list.

Within Southern California, U.S. EPA reports that there are 17 aerosol packers. Other sources count 22 facilities in Los Angeles County, 5 in Orange County, and 2 in San Bernardino County.

THE FILLING PROCESS AND SOURCES OF RELEASES

Aerosol container filling is an automated process. A schematic diagram of an aerosol filling line is shown in Figure 2.3. Empty cans, open at the top, are automatically fed from cartons or skids onto a conveyORIZED belt. Product components, such as active ingredients and other additives, are mixed in a batch mixing tank according to a recipe or standard procedure. The individual ingredients are poured into the mixing tank from drums, or are transferred from bulk storage tanks. After thorough mixing, the material is pumped to the filling station. Alternatively, a portable mixing tank can be moved directly next to the filling line.

At the first stop in the filling line, a controlled amount of the product mixture is dropped into the empty aerosol can. The feed nozzle is positioned directly over the container, or is inserted inside the container. The conveyORIZED belt moves the partially filled containers to the next station, located in close proximity to the first. At this point, solvent is pumped from bulk storage and a small amount is added to the can. Immediately afterwards, the valve assembly is inserted

into the container. Because the three steps of active ingredient addition, solvent addition and valve insertion are done in quick succession, very little product or solvent vapor escapes to the atmosphere.

Some fillers add the solvent directly to the mixing tank with other product components. This practice can result in increased solvent vapor emissions, since there is more opportunity for volatilization to occur during material transfers. Sometimes custom fillers receive premixed concentrates in bulk storage containers shipped to them by their customers. For these products, on-site blend make-up does not occur.

After the valve assembly has been placed in the container, the can passes to a crimping station where the valve is mechanically tightened to the container. Next, the can is conveyed into a separate gassing room where the propellant is added. Aerosol propellants are stored in large bulk storage tanks outside the facility. In the case of flammable hydrocarbon propellants, the tanks are located a distance from the building. Gassing rooms are explosion proof rooms designed to be used only for adding propellant to the containers. No other operations are conducted in the gassing room. The propellant is charged under pressure into the small valve opening on the container. Then, outside the gassing room, the valve is covered and product filling is completed. Cans are automatically weighed; underfilled or overfilled cans are removed from the conveyor. The filled containers are conveyed through a water bath heated to 180° to 200°F, to test for leaks. Cans are visually inspected for leaks as they pass through the water bath, then cleaned and dried. Labels and caps are attached and the cans are packed for shipment.

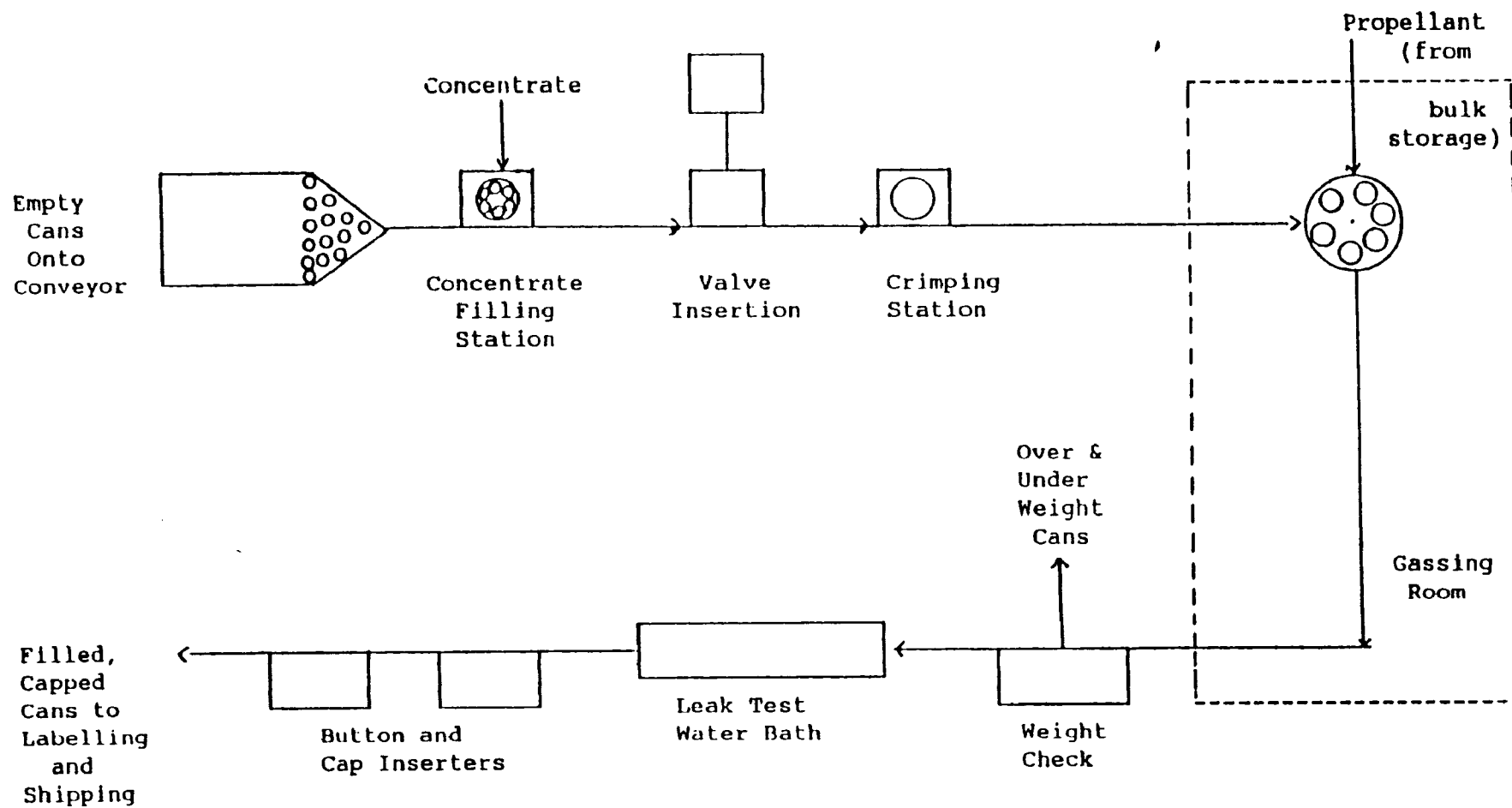


Figure 2.3

Simplified Schematic of Aerosol Filling Line

There are very few releases or waste streams from the filling process. As mentioned above, the cans are covered almost immediately after active ingredients and solvent have been added. Vapor emissions from this step are negligible. Most filling lines are equipped with local exhaust systems that pull air away from process equipment and vent directly to the atmosphere. There may be fugitive emissions from storage tanks, transfer equipment and lines, but these are considered insignificant.

The only place where substantial solvent vapor emissions would be likely to occur is during mixing--only in those cases where solvent is added into the mixing tank. Available data indicate that most mixing operations do not have dedicated process vents or vapor control equipment (Martinez et al, 1987). This may be especially true for smaller operations (Pfetzing, 1987).

There is a potential for waste generation in the hot water bath leak testing procedure. Any material that does leak from a can will remain in the bath or may volatilize into the atmosphere. When asked during the site visits where the waste water is discharged to, most operators didn't know or stated that the water goes to the sewer. They did not feel that contamination of the water was a problem. Some aerosol fillers treat the water from the leak test bath. One filler uses a filter system originally designed for the electroplating industry. Water from three baths is routed through one filter to remove particulates before the water is sewered. The contaminants are collected on diatomaceous earth, which is periodically replaced. The system works best for particulate collection, but does not collect organic solvents very well.

Cans that are underweight are filled or discarded, and overweight cans are discarded. One industry expert estimates that 0.75 to 1.5 percent of all filled containers are discarded either by the filler or the distributor (Johnsen, 1989). Other reasons for discarding a can include leakage, appearance defects, past expiration date, or because it was only a sample. For the largest fillers, this source estimates that 4,000 to 10,000 cans per day are discarded prior to sale, totalling 28,000,000 units a year industry-wide.

When aerosol cans are to be discarded, they are typically punctured, emptied, and the liquid contents are collected. [ed. note: While this is commonly done, puncturing is technically prohibited under the Federal Insecticide, Fungicide, and Rodenticide Act (City of Los Angeles, 1990). With few exceptions, the empty, drained cans are not considered hazardous waste. If, however, the cans contained listed hazardous wastes such as METH or PERC, the liquid contents must be collected and sent for incineration. There are several devices on the market designed to puncture aerosol cans and collect the liquid contents. In one kind of unit, discarded cans are conveyORIZED to a crusher/roller device. As cans are crushed, the propellant gases are exhausted upward through a short stack. A blower installed in the stack dilutes the propellants with air and releases them to the atmosphere. Liquids from the containers are collected below the device, sometimes diluted with water, and drummed to storage. The shredded cans are hauled away for disposal. The cans may or may not be rinsed with water. If the cans previously contained hazardous waste constituents, the rinse water may be hazardous.

Some fillers use a simpler method to discard unwanted containers. The cans are simply punctured in the bottom with a nail or other sharp object. Liquid is collected and drummed. Propellant gas and other vapors are emitted to the atmosphere.

This method could be dangerous to use with flammable propellants or products. There is also some danger of explosion even with nonflammable constituents. Some local air districts may require air pollution control permits for releasing the pressurized contents of aerosol containers.

Discarded cans that are not punctured may be classified as hazardous waste if their contents are flammable according to U.S. Department of Transportation (D.O.T.) standards. About six percent of all waste generated at an aerosol packing facility (other than sewage) is estimated to be hazardous waste (Johnson, 1989)

By far the most significant releases of solvents occur during aerosol product use. All of the components of an aerosol product are intended to be dispersed when the product is used. Whatever volume of material remains in a container is discarded as waste along with the container. Consequently, the entire volume of chlorinated solvent consumed by the industry is eventually released to the environment. According to one study that looked at METH and TCA use in aerosols, 90 percent of both the solvents consumed in aerosols are released to the air, including releases from consumer product use (IEI, 1988).

COSTS

Aerosol packaging contributes to the final market cost of a product, perhaps more so than other container types. Consumers are willing to pay more for aerosols because of the convenience that aerosol packaging provides. Two industry studies have estimated the cost contribution of aerosol products. A report by Geigel and Miller (1985) estimates that the can itself accounts for 27 percent of the manufactured cost of a product; the valve system, gasket and other hardware components cost an additional 20 percent. The remainder of the

cost is split between the concentrate (33 percent) and labor and overhead (20 percent). Of the concentrate, solvents represent a third of the cost. Chlorinated solvents are reported to contribute about half the total solvent cost. Raw material, labor and overhead costs vary according to product, operating practices, and facility.

Another report (ICF, 1987a) provides similar estimates, although it does not break down concentrate costs between active ingredients and solvents. The results of both studies are summarized in Table 2.7.

RESULTS OF SURVEYS

SRRP staff visited four aerosol packers in the Southern California area. In addition, questionnaires were sent to approximately 100 fillers in the U.S. Nine responses were received, eight of which were from fillers that use chlorinated solvents. In total, then, detailed information was collected from twelve facilities that use chlorinated solvents. The plants range in size from three employees to more than three hundred. Yearly production ranges from 25,000 to 40 million units filled, generating from less than one million to more than 40 million dollars in annual sales.

Products filled by these facilities included personal care products, automotive and industrial products, paints and coatings, foods, household products and insecticides. Use of all five chlorinated solvents was reported by the questionnaire respondents. Although some respondents did not provide information on volume of solvent used, the data we have indicates that solvent usage varies widely by plant, depending on the products filled and their formulations and on operating

Table 2.7
MANUFACTURING COST COMPONENTS

	Percent of Total Cost	
	I	II
Can	27	< 35-40
Other Hardware	20	
Concentrate	33	35-45
Labor and Overhead	20	20-25

Sources: I - Geigel and Miller, 1985; II - ICF, 1987a.

practices. Some facilities, for instance, use TCA to flush transfer lines and clean tanks. Other facilities have dedicated equipment and don't need to clean after each batch. In general, though, solvent usage ranges from 500 gal/yr to more than five million gal/yr.

For the facilities that provided data, TCA usage was the highest overall, followed by PERC, METH and TCE. CFC-113 usage was reported to be the lowest. This information reflects only those plants that provided chemical usage data. Of those that did not, at least two are high volume manufacturers that potentially use large quantities of chlorinated solvents. SRRP's estimates (Table 2.4), based on communications with our industry contacts and literature review, indicate a different distribution of solvent consumption than the questionnaire responses revealed. In both cases, TCA consumption is highest. It is estimated that much more METH is used than PERC, that CFC-113 use exceeds TCE, and that TCE consumption is very small. These differences can be explained by the fact that the questionnaire responses were voluntary and random. SRRP's solvent consumption estimates are "top-down" estimates based on total solvent production, and allocation among various industries. No facilities that were visited use TCE; this is attributed to the stringent air quality regulations in Southern California.

Waste generation appears to be primarily dependent on operating practices, and secondarily on production volume. Facilities that manufacture only one product do not need to clean their process equipment unless it has somehow become contaminated. Some multiple product facilities have dedicated process equipment so that frequent cleaning is avoided. Others clean equipment with TCA, a process that generates significant volumes of liquid waste that is sent to an incinerator or cement

kiln for destruction. Four facilities reported sending their liquid waste to an off-site solvent recycler. Two reported sending their waste to a landfill. One of the facilities we visited uses a detergent/water blend to clean process equipment, and alcohol to dry the equipment. The plant does not generate liquid hazardous waste.

At the facilities that responded, generation of off-spec or damaged cans amounts to 50 to 210,000 pounds annually. Two of the smaller plants reported that they dispose of waste cans in the trash. Most of the others ship the cans or their contents to a solvent recycler or to an incinerator or cement kiln. One plant sends the waste cans to a landfill, but sends the contents to a solvent recycler.

None of the plants is equipped with vapor control or recovery devices. In some cases, the gassing rooms, filling stations and mixing tanks are equipped with local exhaust that vents to the atmosphere. Some plants have no local exhaust, and only one had vents for all three areas. When asked if they had contaminated water from a leak test bath to dispose of, five plants reported yes and five said no. Of the facilities that answered yes, one said that the water goes "down the drain". Another explained that the waste water passes through a clarifier to the sewer. One plant that produces exclusively spray paints said that the paint is not water soluble. It floats on top of the leak test bath and is periodically skimmed off.

REGULATORY TRENDS

In this section, the discussion focuses on regulatory trends that impact the aerosols industry and, more specifically, solvent usage within the industry. These regulatory issues fall into the general areas of air quality and other environmental

concerns, consumer health and safety, and worker health and safety.

In the 1970s, scientific studies first determined that emissions of CFCs contribute to depletion of the earth's stratospheric ozone layer. In 1978, the U.S. EPA banned the use of CFCs in aerosols except for certain applications determined to be essential. In the 1960s and early 1970s, CFCs were the propellants of choice for certain personal care products, particularly hairsprays, deodorants, and antiperspirants. Hydrocarbon propellants were used for most other aerosol products. Because the hydrocarbon propellants are flammable, the CFCs were preferred in personal care products where consumer safety was of special concern. Prior to the regulatory ban, however, many aerosol producers had already switched away from CFC propellants. In response to concern about the role of CFCs in the environment, consumers bought less aerosol products and favored nonaerosol type packaging. By 1978, 98 percent of all aerosol products in the U.S. did not contain CFCs.

Among the uses determined to be essential, and for which CFCs could continue to be used were products for specific industrial and military electronics applications and other miscellaneous industrial applications (such as mold release agents).

In accordance with the Montreal Protocol, EPA has promulgated regulations that, in July 1989, capped production of fully halogenated CFCs at 1986 levels. Future production will be further reduced to 50 percent of the 1986 levels by 1998. CFC producers have agreed to phase out production of fully halogenated CFCs, including CFC-113, by the end of the century. Approximately two percent of U.S. aerosol products contain

CFC-113. Therefore, the CFC regulations and phase out will not have a significant impact on the U.S. aerosols industry.

More recently, state and local regulators have developed or proposed stringent VOC emissions regulations for many industries and sources. Some air quality agencies have specifically listed aerosol products as a target for VOC emissions reduction regulations. In California, both the California Air Resources Board (ARB) and the South Coast Air Quality Management District (SCAQMD) have expressed the intent to regulate aerosols. To date, SCAQMD has postponed the development of aerosol products regulations, pending regulatory action at the state level. ARB has passed regulations that, over the next few years, severely limits the VOC content of aerosol antiperspirants and deodorants. This rule will have limited impact on chlorinated solvent consumption since these products do not contain chlorinated solvents. The new rule also specifies that the VOC content of these products cannot be replaced with ozone depleting substances (such as CFC-113 and TCA). There is speculation by many in the industry that this kind of regulation will be expanded to other aerosol products in the near future.

In 1988, the State of New Jersey proposed to limit the VOC content of air fresheners, disinfectants and consumer insecticides. When the final regulations were promulgated, only air fresheners were affected, 75 percent of which are estimated to be in aerosol form. Similar regulations were proposed in New York and Dallas/Fort Worth, Texas.

Attempts to control VOC emissions from aerosol products affect chlorinated solvent usage indirectly. VOC reductions will require that aerosol producers either reformulate their products or discontinue them. Reformulation impacts solvent

usage directly, since any change in propellant or active ingredients requires a change in solvent composition or concentration. In some products, use of hydrocarbon propellants or solvents can be reduced by replacing the solvents with TCA. While the outcome of these imposed changes remains uncertain, there is a possibility that one result may be an increase in the consumption of chlorinated solvents, particularly TCA, in aerosol products.

In California, METH was recently identified as a toxic air contaminant. As a result of this determination, METH use and emissions will be strictly controlled throughout the state. ARB is in the process of developing regulations that are likely to severely curtail METH use in California. PERC is currently under consideration as a toxic air contaminant. A determination as to its status is expected shortly. Other states across the country are considering similar action.

For some aerosol products, TCA is a potential substitute solvent for METH. The future of TCA, though, is questionable at present. There is some uncertainty whether the regulation of the fully halogenated CFCs and halons will be sufficient to prevent significant damage to the ozone layer. In response to this concern, the U.S. EPA recently published an Advance Notice of Proposed Rulemaking (ANPR) stating their intent to evaluate TCA as an ozone depleter. This could mean a freeze on TCA production or total phase out at some future date. EPA has taken no further action on the ANPR to date.

On another front, EPA has requested submission of available health and safety data from pesticide registrants whose products contain METH. Some of these pesticides are supplied in aerosol form.

Two federal agencies have taken action on consumer products containing METH. The Consumer Product Safety Commission (CPSC) considered a ban on consumer products containing METH. In December 1987, the commission voted not to restrict METH use in these products, but rather to work with industry to develop warning label standards and a consumer education program. The warning label requirements are in place, and a consumer education program has been implemented. Aerosol products most affected by this requirement are spray paints and furniture strippers, both of which commonly contain METH. In 1988, the CPSC's actions were challenged in court by a consumer group favoring a complete ban on METH in consumer products. The District of Columbia Circuit Court of Appeals rejected the group's challenge.

In December 1985, the U.S. Food and Drug Administration (FDA) proposed a ban on METH in cosmetic products, particularly hair sprays. Their proposal was based on results of scientific studies that indicate inhalation of METH causes cancer in laboratory animals. The ban became effective on August 28, 1989.

METH and PERC are listed on California's Proposition 65 list of chemicals known to the state to cause cancer, birth defects or other reproductive harm. Their listing requires that products containing METH or PERC be labeled. In addition, businesses cannot knowingly discharge these chemicals into any potential sources of drinking water and must provide warning to individuals exposed to significant amounts of the chemicals. Similar legislation is pending in other states.

In the area of employee health and safety, recent action by the federal Occupational Safety and Health Administration (OSHA) affects employers using chlorinated solvents. The permissible exposure limit (PEL) for PERC was

lowered from 100 ppm to 25 ppm. OSHA has announced its intent to lower the current PEL of 500 ppm for METH.

There are national, regional and local building and fire codes that stipulate how and where aerosol products are filled, stored and displayed. Manufacturing facilities, storage warehouses and retail stores are subject to these codes which may take the form of industry standards or enforceable regulations. These codes must be considered when evaluating the costs of reformulation strategies that will change the flammability of products.

INDUSTRY TRENDS

A significant decline in the number of pressurized products filled occurred in the years 1976 through 1978, and again in the period 1980 through 1982. Since 1982, product sales have steadily increased. The number of aerosol packages filled increased 6.8 percent in 1988 over 1987 figures (CSMA, 1989a). Much of the gain has come from market segments that don't traditionally have chlorinated solvents in the products. Significant growth has occurred in personal care products, most notably in new hairsprays, antiperspirants and saline sprays for contact lens care.

One reason for the continued growth in product sales is an increase in consumer preference for "do-it-yourself" products. Consumers are buying more automotive and industrial products for home use. CSMA also attributes growth to "continuing consumer confidence in the aerosol form of packaging" because it offers convenience and performance, and a healthy economy in general (CSMA, 1989a).

Sales of aerosol food and pharmaceutical products are expected to increase in the future, although aerosol food products have been more widely accepted in Europe than in the U.S. These products don't traditionally contain chlorinated solvents.

New packaging and delivery systems have been introduced and others are under development. The new technology permits a wider variety of products to be packaged and dispensed in aerosol form, including pharmaceuticals, cosmetics, foods and toiletry products (CMR, 1989c). Some of the new developments allow a wider range of propellants to be used, or in at least one case, no propellant at all. New developments that influence chlorinated solvent usage are discussed in Section III.

III. SOURCE REDUCTION OPTIONS

This section examines source reduction options that, if implemented, could reduce solvent usage and emissions in the aerosols industry. Four categories of potential options have been identified and summarized in Table 3.1. They are process modification, solvent recovery and reuse, product substitution and chemical substitution. Each of these alternatives is addressed in a separate subsection.

PROCESS MODIFICATION

One way to reduce solvent use and release is to modify production processes. In the case of aerosol packing, process modification provides limited source reduction opportunities. Solvent emissions during filling operations are minimal. Very little emissions reductions would be achieved by changing the filling process.

Two options are considered here for their potential to reduce solvent releases. The first is a method to minimize the disposal of over- or underweight cans. The process of filling aerosol cans with product virtually never results in over- or under-filling. Adding propellant to the cans is less precise (Flanner, 1988). Cans can be over or under filled with propellant or damaged and crushed by the propellant filler.

Some of these problems can be corrected. Excess propellant can be released from overweight cans, and propellant can be added to under filled cans. This reduces the volume of cans discarded because they are out of specification. According to Flanner (1988), this practice can be more cost-effective than disposal for some plants.

Table 3.1
SOURCE REDUCTION OPTIONS

Process Modification

Correction of Over and Under Filling
Improved Maintenance Practices

Solvent Recovery and Reuse

Vapor Recovery: Refrigerated Condensation
Carbon Adsorption
Liquid Solvent Recovery

Product Substitution

Non-aerosol Packaging

Chemical Substitution

Hydrocarbon Solvents
Water
Reformulate Active Ingredients
Recycled Solvents
Alternative Propellant Technologies

Improved Maintenance Practices

Another way to reduce solvent use is to identify and control fugitive emissions sources. Fugitive vapor emissions can be controlled and minimized through improved maintenance practices. Frequent leak detection inspection and regular equipment maintenance should be included in normal plant operating procedures. The study by Martinez, et al (1987) specifically identifies periodic leak detection and equipment repair as an effective means to reduce fugitive emissions. Achievable emission reductions were estimated to be 59 percent to 73 percent for various types of process equipment. Leak detection requires additional manpower, but little or no capital equipment purchases. Automatic sensors distributed around the plant that trip an alarm when a leak is detected can also be helpful in minimizing solvent releases from a leak.

Total solvent consumption can also be reduced by changing filling equipment cleaning procedures. The use of dedicated transfer mixing and equipment eliminates the need for thorough cleaning between process batches. Alternatively, cleaning solvent can be collected and reused many times before it is disposed of. Solvent life can be prolonged by filtering out solids after each cleaning cycle. A third way to reduce chlorinated solvent consumption for cleaning is to use another solvent or water instead. One plant we visited cleans process equipment with water, followed by an alcohol rinse to dry.

SOLVENT RECOVERY AND REUSE

Chlorinated solvents can be recovered from manufacturing processes in three ways. Liquid solvents can be collected from the contents of scrapped cans that are crushed and emptied before being shipped off-site. Solvent vapors that are emitted during the filling process can be collected and condensed. Solvents used to clean process equipment can be collected and reused. All three techniques reduce the amount of chlorinated solvent sent off-site as waste. The recovered solvents can be used on-site in the formulation of new products or to clean process equipment. Alternatively, the collected solvents may be sent to an off-site recycler. In this subsection, we discuss solvent recovery techniques and solvent reuse for cleaning. In the section to follow on chemical substitutes, we address the issue of using recycled solvents in aerosol products.

A study of chlorinated solvent emissions from aerosol filling operations determined that significant solvent emissions occur only in the mixing step (Martinez et al, 1987). The study included emissions data from eleven aerosol facilities that use PERC, METH and TCE (one facility). The data were provided in response to a U.S. EPA request for information under Section 114 of the Clean Air Act. Emissions can occur as solvents or other ingredients are added to the mixing tank and while mixing takes place. Releases can also occur when the mixed blend is dispensed into the empty aerosol cans. There are fugitive emissions from transfer equipment and storage tanks as well.

While the study did not include information on the sizes and production capacities of the facilities that responded, it did provide emissions estimates. As noted above, mixing operations generated the highest emissions, on the order of 200 to 18,100 kg/yr per facility (1986 and 1987 data).

Emissions from solvent bulk storage tanks ranged from 200 to 6,600 kg/yr per plant. One facility that stored solvent in pressurized tanks estimated that it had no releases from storage. Equipment leaks, from valves and pumps for instance, were 100 to 4,200 kg/yr per facility. Since the report was generated for a specific, limited purpose, it is not clear that these data would be representative of the industry as a whole.

In the study, refrigerated condensation was identified as a control measure for reducing solvent emissions by 95 percent from storage tanks and mixing operations. Carbon adsorption was identified as an alternative control measure for mixing operations that could also achieve a 95 percent reduction of emissions over systems without such control measures. Both options, which are discussed further below, have the potential for solvent recovery and reuse on-site or by an off-site solvent recycler.

Refrigerated Condensation

Refrigerated condensation involves installing ductwork from the mixing tank or storage tanks to route emissions to the condenser. Collected vapors are refrigerated to below their dew point, generally using CFCs as refrigerants. As the vapor stream cools, chlorinated solvents, water and other vapors present from the mixing condense. The liquid mixture can be shipped off-site as hazardous waste for treatment or incineration. Alternatively, the chlorinated solvent can be separated out of the liquid mixture either on site or by a third party recycler. Both METH and TCA contain stabilizers that are water soluble and separate from the solvent in the condensation process. For reuse on-site, METH or TCA needs to be reblended with stabilizers. TCA hydrolyzes in the presence of water, creating hydrochloric acid that can damage the condenser and cause additional waste handling problems. There may also be

problems with any other vapors (i.e. active ingredients) from the mixing or filling operations. Depending on what the other chemical constituents are, fractional distillation might be necessary in order to separate the various components.

Carbon Adsorption

In a carbon adsorption unit, vapors collected from the process area are passed through a carbon bed. Organic materials are adsorbed on the carbon. When the bed has adsorbed its capacity of organics, the bed is heated, usually with steam. The organics are desorbed from the carbon into the steam. The steam is condensed; and the organic material can be separated from the water. As with refrigerated condensation, there are difficulties in restabilizing the METH or TCA for use on-site, and there are problems with TCA in water streams. Carbon adsorption is thus not a feasible option for recovery of TCA. It can be used to capture PERC, and, with some difficulty, to recover METH.

Another problem associated with the use of carbon adsorption is that the efficiency of the unit depends on the concentration of solvent vapor in the gas stream. Given the relatively low levels of solvent emissions, whether METH or PERC is present, the unit efficiency will be low and operating costs will be high.

A carbon adsorption unit transfers organic materials from an exhaust (air) stream to the carbon bed and then to a water stream. Some residual solvent or product active ingredient will remain on the carbon after it has been desorbed. The carbon can only be regenerated a finite number of times and will then need to be disposed of as waste. Depending on the chemicals present and their concentrations, the carbon may be hazardous waste. There are also water pollution concerns

to be addressed. After solvent is removed from the condensed water stream, residual contaminants remain in the water. Depending on local sewer regulations, the waste water may require treatment before it can be released to the sewer.

Capital and operating costs are major obstacles impeding the implementation of refrigerated condensation and carbon adsorption in many aerosol packaging plants. Given the relatively low volume emissions that are present, both methods can be prohibitively expensive. Technical problems also exist. Neither method is designed for capturing TCA. PERC is easier to recover, and doesn't require the addition of stabilizers or inhibitors, but much less of it is used in the aerosols industry. Reblending stabilizers into recovered METH and TCA for on-site use may be too complicated for many facilities to adopt. For instance, some of the filling plants we surveyed have ten or fewer employees and may be unlikely to devote manpower resources to reblending operations. These facilities, though, could conceivably send the recovered liquid to an off-site recycler for further processing.

Solvent Recovery From Can Disposal

When off-spec or damaged cans are crushed, the liquid contents are collected. The liquids are either shipped off-site for solvent recovery, incineration or for use as supplement fuel. If kept on-site, the liquids can be reused in two different ways. First, if the concentrate came from only one type of product or from very similar products, it may be possible to use the recovered material directly in the formulation of new product. In some cases, reuse of the concentrate may require a primary treatment step to remove unwanted components. If the separation is complex, for instance, if fractional distillation would be required, it is very unlikely that fillers would adopt this practice. Another

way to reuse the recovered concentrate is to use it for cleaning process equipment. In this way, less virgin solvent would be needed for cleaning.

As noted in Section II, some fillers use a homemade device with a nail to puncture waste cans, and a drum to collect the liquid contents that drain from the cans. There are also commercial units available in which cans are punctured within an enclosed chamber and the liquid contents drain to a drum. The propellant gases are released to the atmosphere. An improvement over this method is a newer device that crushes cans within a chamber and collects the liquid contents and 99 percent of the propellant gases. The liquids and propellants are stored under pressure and transferred to a pressurized storage vessel. One manufacturer provides these devices on two sizes. The smaller unit processes 600 to 1,000 cans per hour and the larger unit processes 1,200 to 2,000 can per hour (Beacon Engineering, undated).

These units are relatively expensive, and are only cost-effective for large volume filling operations. Smaller facilities are not likely to purchase one of these can crushing devices. One advantage of the automated units is that solvent (and other components of a blend) are fully contained and collected. The "homemade" can puncturing units are open to the atmosphere, allowing some solvent to evaporate and not be collected, and are also dangerous to use for cans containing flammable hydrocarbon propellants.

A supplier of can evacuation units reports that waste disposal firms have shown more interest in the devices than have most aerosol fillers. Waste disposal companies collect waste cans from fillers and crush them at the disposal facility. They charge the filler whose waste they take as much as one dollar per container (Shields, 1989). Because of the larger volume of

containers they process and the fees received, purchasing an automated crushing device is much more cost-effective for them than for individual fillers.

Solvent Reuse

Several aerosol fillers who were surveyed by the SRRP staff reuse their cleaning solvents. In some cases, solvent that is used to clean equipment after certain product batches is segregated, stored and blended into the product when the next batch of it is processed. In other cases, the solvent is simply used over and over again for cleaning until it has become too dirty. A representative at one facility indicated that his plant has a dedicated, closed loop solvent cleaning system. Solvent is used to clean equipment until it is contaminated. It is sent to an off-site recycler and recycled solvent is purchased for cleaning use.

PRODUCT SUBSTITUTION

Virtually all solvent emissions from aerosols occur as the products are dispensed in use. This may be in an industrial setting or in the home. Control of solvent vapors from aerosol product use is, for all practical purposes, impossible to implement. In fact, chlorinated solvents are present in aerosol products because they enhance and influence how the active ingredients are dispensed. At the use level, then, solvent emission reductions can only practically be achieved by not using aerosol products. Instead, products can be purchased and used in other packaging forms.

Previous studies have evaluated the availability and, to a lesser extent, the cost of non-aerosol alternatives (Westat, 1987; ICF, 1987b). Since this information is available, it is not recreated here for individual market

segments and products, but rather discussed the benefits and limitations of product substitution. Some examples are presented for illustrative purposes.

Many consumer products are available in spray pump containers. When the nozzle of a spray pump is manually depressed, pressure is exerted on the liquid in the container, forcing it out of the spray nozzle. Less versatility in spray patterns is available with pump sprays. No propellant is used in spray pumps. This reduces performance demands on the solvent, which means that a wider variety of solvents may be appropriate for the formulation. The choice of solvent still depends very much on the active ingredients in the product. A product purchased in a spray pump package can be less expensive than the same product in an aerosol container.

Among the many products that are available in pump sprays are hair sprays, cleaners, furniture polishes, fabric protectors and laundry prewash sprays.

Atomizers are another package form in which the product is dispensed as a spray. Colognes are commonly packaged in atomizer containers. Like pump sprays, no propellant is required. Atomizers work by mixing air with the liquid phase as the nozzle is manually depressed. With this design, solvent requirements may be less stringent, depending on the solubility of the active ingredients. For both spray pumps and atomizers, it may be necessary to retain the chlorinated solvent in the formulation in order to suppress flammability or to completely solubilize and dilute the active ingredients. For products in which a chlorinated solvent is the active ingredient, the solvent must be retained in the formulation, unless alternative, more benign chemicals are available.

Other product substitution options are also available. For instance, drain openers can be purchased in solid rather than aerosol form. Furniture polishes and other cleaners are available as creams or waxes. Solids, creams and waxes may not contain any chlorinated solvents.

There are a number of non-aerosol type insecticides on the market. These include liquids, powders and cakes. Nonchemical options include traps, baits and sticky tapes. The non-aerosol alternatives work differently than aerosol products. In some cases, they are intended for different purposes and do not truly replace the aerosol types. In households where small children are present, it may be unsafe to leave traps or solid insecticide cakes where children can reach them.

There are three general disadvantages associated with the replacement of aerosol products by other packaging types. The first is the loss of convenience offered by aerosol containers. Consumers have shown that they are willing to pay for the added convenience of products packaged in aerosol form. The dosage and direction of product released is well controlled. When a product such as a cleaner is supplied in a cream, wax, liquid or solid form, it must be poured or otherwise manually applied to a surface. Then it must be physically removed. This can be messy, and can generate additional waste. Non-aerosol fabric protector is an example. In its aerosol form, a fabric protector is sprayed directly on the item or part of an item to be treated. The product is dispensed as a mist or spray and the solvent and propellant components evaporate. In liquid form, the product must be poured or brushed onto the item, or the item can be dipped into the liquid. In either case, the product is likely to be "wetter" than the aerosol version. It can run, drip, be messy to apply and take longer to dry. To treat an upholstered chair, for instance, the aerosol

product offers easier handling, more direct control of application, and, in general, added convenience.

The second limitation to non-aerosols relates to safety. Aerosols completely contain hazardous products like pesticides, caustic cleaners and flammable materials. Spills and leaks are less likely to occur than with glass or plastic bottles, jars or other containers. With few exceptions (in the case of leaking aerosol cans), the product is only released intentionally (i.e. when the valve is manually activated), minimizing accidental exposure of consumers.

The third problem with non-aerosol products relates to their efficacy. Some non-aerosols do not perform as well as aerosol versions of the same products.

According to testimony submitted to Congress, pump type products cannot replace aerosol products in many applications. In some cases where pump sprays can substitute for aerosols, consumers have indicated less acceptance of the non-aerosol form. The testimony also pointed out that elderly and arthritic individuals may have difficulty using a pump type product (Aerosol Age, 1988a).

Nonaerosol products that can be used in place of aerosol products often contain chlorinated solvents. Examples are liquid and paste spot and stain removers that contain TCA (Westat, 1987). A review of the Westat data indicates that liquids without chlorinated solvents are available, but no data were obtained as to the applicability of the alternate products. Aerosol tire cleaners are another product type for which non-aerosol alternatives exist. METH and TCA are used in the aerosol version because they swell the rubber and make cleaning easier. Chlorinated solvents have been removed from the non-aerosol pump spray type container and replaced with alcohols and 2-butoxyethanol.

Flying insect killers are sprayed directly at live insects to kill them. To be effective, the product must be dispensed as very small particles suspended in a fine mist. Pump sprays are reported to be ineffective in producing the fine particle size required.

There are other packaging technologies under development. One company has introduced a mechanical spray system that is reported to perform like an aerosol, but without the use of a chemical propellant. As noted above, the removal of the propellant may increase the number and type of solvents that can be used. The device has a twist cap that is connected to an expandable rubber bladder. The product is pulled into a chamber under the cap when the cap is twisted to the left. When the cap is twisted to the right, the product is forced under pressure down into the rubber bladder. Then, when the valve stem is depressed, the product is dispensed as a continuous spray. The system is said to be compatible with any size or shape container. The developer plans to license the technology for use with consumer products (Geigel and Miller, 1985).

CHEMICAL SUBSTITUTION

There are five ways by which reformulation can be implemented to reduce chlorinated solvent usage in aerosol products. The first two approaches are to simply substitute another solvent or water for the chlorinated solvent portion of a blend. The third option is to replace the active ingredient in a blend so that another solvent can be used. The fourth option is to use recycled solvent in place of virgin solvent. The fifth option is to switch to a propellant that has different, or less stringent, solvency requirement and permits the replacement of the chlorinated solvent with another solvent. Each of these approaches has been adopted, at least to some extent, by the aerosols industry. All five alternatives

present difficulties that must be overcome if they are to be successfully implemented. There are some aerosol products for which these chemical substitution options are not viable.

There are previous studies that have examined the potential for chemical substitution in aerosol products; among them are Geigel and Miller (1985) and ICF (1987a and 1989). Some earlier studies listed formulations in terms of weight percent of different components and, perhaps, compared costs of the different blends. In this section general considerations of chemical substitution are discussed, with focus on solvent replacement and active ingredient reformulation in specific product segments where chlorinated solvent usage is highest. Also discussed is the possibility of replacing virgin solvent with recycled solvent and the use of new propellants and propellant blends that can be adopted by the industry.

General Issues

When a chlorinated solvent is present in a blend solely because of its solvent properties, it may be relatively easy to replace it with another solvent. Even when another solvent can be used, it is rarely a direct 1:1 replacement. The concentrations of other components in the blend are likely to change as well. It is uncommon that a chlorinated solvent is selected only because of its solvent characteristics. As discussed in Section II, METH and TCA in particular are often used in household, automotive and industrial products because of their other unique characteristics as well. When a solvent contributes other properties to a product, it becomes more difficult to replace. Furthermore, if the chlorinated solvent is the active ingredient in a blend, it becomes very difficult to find a substitute for the solvent and achieve a comparable level of product performance.

When reformulation of a product is considered, it is necessary to evaluate the compatibility of the new blend with existing valve hardware and the container itself. For example, METH chemically attacks certain types of plastics that are often used for making valve hardware. Aerosol products containing METH are fitted with hardware made from plastics known to be resistant to METH. If METH is removed from a blend and replaced by another solvent, it may be necessary to use different hardware. For instance, the existing hardware might react with the new solvent. It might be unnecessarily expensive for the new blend, or it may not provide the desired spray pattern. When a formulation is changed, the way a product is dispensed is likely to change as well. The evaporation rate of the product may be different. Spray characteristics are very dependent on the composition and concentrations of ingredients in the blend. The spray pattern may be affected, as well as the "wetness" or "dryness" of the spray.

Product performance, stability and aging effects are among the other factors that must be tested before a new product can be introduced to the market. Products that are regulated by a government agency may need to be reviewed by that agency prior to sale. The Food and Drug Administration (FDA) regulates pharmaceuticals, foods and cosmetics, though these are not significant uses of chlorinated solvents. Pesticides are regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which is administered by EPA. Aerosol disinfectants are included in this category. If these types of products are reformulated, they must be reregistered. State agencies have their own registration programs as well.

In the subsections below, chemical substitution of TCA, METH, PERC and CFC-113 is discussed. For many products, use of hydrocarbon solvents may be a chemically viable substitution option. These solvents are flammable and their use in aerosol

products poses increased risk of fire or explosion. There are three areas where fire hazards need to be considered. The first is during use, especially for personal care and household products, and for products that may be used near a source of ignition (near electrical equipment, for example). Second, and of importance to manufacturers, distributors and retail marketers is the risk of fire where flammable aerosol products are stored or displayed in bulk. An increased volume of flammable products in storage may require installation of additional fire suppression and firefighting equipment. Third, handling of flammable materials presents problems for aerosol fillers.

It should be noted that chemical substitution can result in increased manufacturing costs. There may be associated equipment changes for process equipment or for storage tanks. Additional fire suppression systems or explosion proof equipment may be required.

Personal Care Products

Chlorinated solvents are no longer widely used in personal care products. However, a review of the history of chemical substitution in hair spray products is useful as an illustration of the critical interrelationships between product ingredients, hardware selection and product performance.

When CFC propellants were removed from hair sprays in the 1970s, they were replaced by flammable hydrocarbon propellants, often in combination with alcohol. METH was included in the newer formulations to reduce flammability. It also served as a drying aid and cosolvent to solubilize the polymer resins used in hair sprays. METH has been removed from essentially all hair sprays, resulting in increased flammability and lower polymer solubility. New hair spray resins have been

developed that are more compatible with the hydrocarbon/alcohol blends. Also, water has been added to hair spray formulations as a cosolvent to further improve resin solubility (Rouse and Novack, 1988). It has been reported that the ethanol/water blends dried more slowly than the METH-based hair sprays (Geigel and Miller, 1985). This has been corrected by incorporating a different valve system that changes the evaporation rate of the product as it is dispensed.

The fact that hair spray sales exhibited strong growth in 1987 and 1988 indicates consumer confidence in the reformulated products. That growth is also considered by industry sources to reflect changes in hair style preference.

Household Products

There are a variety of household products that contain chlorinated solvents. In many of these, METH, TCA or PERC serve as active ingredients. Chemical substitution in these products is more complex. With household products, toxicity is an important consideration because there is a greater chance of exposure to products used in the home. For household products, then, chemical substitutes must be carefully evaluated in terms of toxicity, chemical reactivity and product safety.

An ICF report (1989) identified three household aerosol products that contain TCA for which no chemical substitutes are available. The products are spot removers, water and oil repellants, and suede protectors. Aerosol spot removers are powder sprays used to remove spots and stains from clothing and fabrics instead of laundering. PERC, METH and TCA have been used in spot removers as active ingredients. Reports vary as to the extent to which PERC and METH are used. The ICF report states that TCA is the only chlorinated solvent in spot removers. Later in the same report, though, it is stated that

PERC, in combination with TCA, has largely replaced METH as the primary active ingredient. It appears that the use of METH in spot removers is declining. It remains uncertain whether PERC or TCA are replacing METH, or if the two are used in combination.

The degreasing action of METH, PERC and TCA make them good cleaners in spot removers. As ICF reported, there appears to be no chemical substitute for chlorinated solvents in aerosol spot removers. Flammable hydrocarbon solvents are undesirable for two reasons. First, they don't clean as well as the chlorinated solvents. Second, their flammability poses dangers.

Water and oil repellant applications are also identified as essential uses of TCA (ICF, 1989). Water and oil repellants are used primarily for protecting textiles and upholstery. Their use and composition differs from "water repellants" used for waterproofing shoes, textiles and other products. Water and oil repellants are composed of 90 percent or more TCA. To replace the TCA with flammable hydrocarbon solvents would increase risk of fire. This is especially dangerous near combustible textiles and furniture.

Suede protectors are the third product type that contain TCA for which chemical substitution is especially difficult. High concentrations of TCA are reported in aerosol suede protectors (Westat, 1987; ICF, 1989). Some spray shoe polishes contain TCA or METH. There are aerosol shoe polishes without chlorinated solvents. No information as to the alternative solvents used is available. Many other aerosol household products have brands that contain chlorinated solvents and brands that do not. The question to be resolved is whether the products can be used interchangeably for the same purposes, with comparable performance.

Automotive and Industrial Products

Automotive and industrial cleaning products in aerosol form often contain chlorinated solvents as the primary active ingredient. In these products, where TCA, PERC, or METH is used not just to solubilize other components, it is more difficult to find nonchlorinated solvent replacements.

The ICF (1989) report identified three automotive and industrial aerosol product categories that contain TCA and for which no chemical substitute is available. The three product segments are electric motor cleaners, mold releases and brake cleaners. As in household products, chlorinated solvents are often present as active ingredients.

PERC and TCA are good degreasing and cleaning agents. They are used in aerosol products to remove grease and dirt from electric motors and other electrical equipment. Most brands on the market contain both PERC and TCA to take advantage of PERC's strong degreasing action and slow evaporation rate. Products that contain only TCA are used for smaller cleaning jobs where faster evaporation is less of a problem. No alternative active ingredients/solvents that can be used in aerosol products of this type have been identified. CSMA reports that one of the reasons TCA is so useful in engine cleaners is because its high dielectric strength and nonflammability allow motors to be cleaned while running (CSMA, 1989b).

Brake cleaners are another aerosol product category traditionally utilizing TCA and PERC as active cleaners. Usually the two solvents are used in combination. Chemical substitutes must have good cleaning and degreasing properties, should be nonflammable and work quickly. No solvent cleaners that can replace TCA and PERC in aerosol brake cleaners have been identified. Xylene and alcohol solvents have been tested,

but they do not provide the same degree of cleaning capability (ICF, 1987a).

CFC-113 is used in aerosol cleaners for the electronics industry. It is also used in mold release products. ICF reports that METH and TCA are the two chlorinated solvents used in mold releases. Aerosol mold releases are sprayed onto molds to release products formed in those molds. High concentrations (40 to 50 wt. %) of TCA and METH have been reported in aerosol mold releases. The chlorinated solvents are favored for this application in industrial facilities because of their nonflammability. There are currently no substitutes for CFC-113 in aerosol electronic cleaners, mold releases and other industrial applications (Strobach, 1988).

Other aerosol products used in automotive and industrial applications contain chlorinated solvents. With the exception of the three products noted above, there are existing aerosol product alternatives formulated without chlorinated solvents. Once again, the flammability and efficacy of these products must be evaluated for specific desired end uses. Sometimes the alternative formulations exhibit better performance. Examples of successful chlorinated solvent replacement include aerosol lubricants, carburetor and choke cleaners and some adhesives. METH is used in some spray adhesives because of its very good solvency and fast evaporation rate. It also defines the spray pattern of the dispensed product. The alternatives to METH, usually acetone, xylene and MEK, don't have comparably good solvency characteristics.

Paints and Finishes

There are adequate alternatives to chlorinated solvents used in aerosol paints and finishes. Products formulated with exhibit acceptable quality spray patterns and product solubility

characteristics. There has been rapid substitution of METH in spray paints since 1985. In some simpler paint formulations, METH has been replaced with acetone. The products are reported to be more flammable, less dense and slightly runnier on application (ICF, 1987a). For some uses, these drawbacks may be acceptable. Solvent blends made with acetone and TCA are also utilized. For applications that require better quality paints, aerosol formulators have developed spray paints based on acetone/ester solvent combinations.

Water is an acceptable solvent in some spray paints. There are problems that arise whenever water is used in aerosol containers. Water can cause corrosion, so containers are generally lined with a protective coating. Water is not necessarily a very good solvent for all of the types of ingredients found in aerosol products. Hydrocarbon propellants, for instance, are generally insoluble in water. Water based spray paints containing water insoluble propellants are reported to have some performance problems, such as low hiding power, chemical or mechanical instability, poor finish, and foaming (Bartlett, 1988). A later subsection on new propellants discusses how this problem has been overcome. We are not aware of any aerosol paints or finishes for which chemical substitution cannot be accomplished.

Aerosol paint strippers contain significant amounts of METH. One industry report indicates that no solvent alternatives are available for aerosol strippers (ICF, 1988).

Insecticides

The four major types of insect sprays that contain chlorinated solvents are foggers, house and garden insect sprays, flying insect killers and residual insecticides. We have already discussed in Section II the specialty use of

CFC-113 on flying insect sprays used near high voltage electric lines. This is considered an essential use of CFC-113. A chemical substitute for CFC-113 for this application has not been found. CSMA reports a similar use of TCA in insect sprays applied near transformers and other electrical equipment (CSMA, 1989b).

Reformulation of aerosol pesticides is estimated to take 3 years or more before the products can be marketed. Research and development takes a lot of time, followed by product development, product testing and EPA registration procedures. Significant costs can be incurred in each step of the reformulation process.

In some insect sprays, chlorinated solvents sometimes are added as active ingredients. TCA is one of them. It is an active ingredient not because of its toxicity, but because it evaporates quickly and rapidly cools an insect's body. TCA is considered a knockdown agent in this application. CSMA states that it is the most effective knockdown agent available for hornet and wasp sprays (CSMA, 1989b). Water can be used as a solvent for flying insect killers, but not in products that may potentially be dispensed near electrical equipment. Water has been used in some aerosol pesticides since the 1960s. It costs less to use than other solvents, is less irritating if inhaled and is nonflammable. It does not, however, serve as a knockdown agent, but only as a solvent.

Because of regulatory pressures and concerns over the health effects of METH, pesticide manufacturers are removing METH from formulations. Total release foggers traditionally contained high concentrations of METH or TCA. Petroleum distillates have been tested as replacement solvents. They were determined not to be good alternatives for two reasons. First, the products become flammable and dangerous for use. Second,

the petroleum distillates can damage fabrics such as carpets, upholstery and drapes. Total release foggers based on water are being researched. When water is used, a propane and isobutane mixture is used as the propellant. This tends to make the product flammable. Water based total release foggers have excessive fallout. That is, too much of the product drops out and settles right around the container. It doesn't get propelled throughout the room to be treated, and therefore is inefficient to use. Water based total release foggers are still being researched. Research efforts are directed at product storage stability, physical characteristics of the spray and hardware systems, and biological efficacy of the product.

Residual insecticides are applied to areas where insects are located. They are generally not sprayed directly at insects to kill them. Residual insecticides contain a high percentage of base oils and solvents with 1.0 to 2.0 percent toxicant. Chlorinated solvents are not used as knockdown agents or active ingredients in these products. Rather, they are present only as solvents (ICF, 1987a). Desired characteristics of residual insecticides are low odor, little or no tendency to stain, and good effectiveness. As was discussed, solvent substitution is easier to achieve in products where the chlorinated solvent is not present as an active ingredient. Residual insecticides are examples of this kind of substitution. There are two solvent alternatives. The first alternative is petroleum distillates, which are used in some formulations. Water is the other alternative. It can be used in two different ways. The first way is in combination with a new propellant, DME. This use is discussed in a later subsection. The other alternative is to use water as the solvent in aerosol foams. The foams are reported to be safer, more efficient, and less expensive to use. They can be difficult to apply in hard to reach areas because a foam will not travel as far as a sprayed mist or stream (ICF, 1987a). On

the plus side, water based products have less odor and are unlikely to cause staining.

Use of Recycled Solvent

The use of recycled chlorinated solvent represents a viable source reduction option. On a technical level, there is no reason why recycled solvents cannot be used in most aerosol products. Recycled solvents are not widely used in the industry because of institutional, rather than technical problems.

Ten survey respondents answered a question about their purchases of recycled solvents. Seven said that they do not purchase recycled solvents and three said that they do. Information from the surveys and site visits indicates that recycled chlorinated solvents are sometimes used in industrial and automotive products and in spray paints. One survey respondent said that recycled solvents are used in their household aerosol products as well.

Respondents cited three reasons why recycled solvents aren't used more often in aerosol products. First, they said that products that must be registered by the U.S. EPA or FDA cannot contain recycled solvents. This would include products such as pharmaceuticals and pesticides. It appears to SRRP, however, that the regulations may not specifically prohibit the use of recycled solvents.

The second reason why fillers are reluctant to use recycled solvent is because solvent purity a high priority. This is especially true when the solvent is an active ingredient in pharmaceuticals and personal care products. There is a general concern among aerosol fillers that the purity and quality of recycled solvent is questionable. One way to implement recycled solvent use in plants with this concern is to

employ them, at least at first, in the less critical operations. If reliable recycled solvent meeting the specifications of critical operations could be regularly obtained, its use could then be expanded to more operations in the plant.

The third reason that those surveyed resist recycled solvent use is based on cost. Several respondents indicated that recycled solvents cost almost the same as virgin, and so there is little economic reason to change. In order to achieve the purity required for aerosol applications, recyclers must process the used solvent more so than they might if it was going to be used in a gross metal cleaning application. The further processing increases the cost of the recycled material.

Alternative Propellant Technologies

Another way to approach chemical substitution is to change the propellant in an aerosol formulation. The use of a different propellant system changes the solvent characteristics of the product, and may permit the replacement of chlorinated solvent with another solvent or water. The development of alternative propellant technologies has been driven primarily by the phase out of CFCs. There are few aerosol products sold in the U.S. that still contain CFC propellants. A consumer preference for less flammable products has also been a driving force to new propellant development.

Much of the new technology consists of replacements for CFC-11 and CFC-12. There is considered to be no alternative for CFC-113 used as a propellant (Strobach, 1988). In this subsection we discuss four propellants that are being used more often. The four are dimethyl ether (DME), HCFC-22, HFC-152 and HCFC-142b. An emerging new aerosol technology that physically separates active ingredients and propellants is also described in the subsection.

Table 3.2

PROPELLANT PROPERTIES

Chemical	DME	HCFC-142b	HFC-152a	CFC-22	Propane	Iso-butane	N-butane
Formula	CH ₃ OCH ₃	CH ₂ CClF	CH ₂ CHF	CHClF	C ₃ H ₈	i-C ₄ H ₁₀	N-C ₄ H ₁₀
Molecular Weight	46.1	100.5	66.1	86.5	44.1	58.1	58.1
Boiling Point (°F)	-12.7	14.4	-13.0	-41.4	-43.7	10.9	31.1
Density (g/cc @ 70°F)	0.66	1.12	0.91	1.21	0.50	0.56	0.58
Solubility in Water wt % @ 70°F)	34	0.5	1.7	3.0	0.06	17	20
Kauri-Butanol Value	60	20	11	25.0			
Flash Point (°F, Closed Cup)	-42	0	0	None	-156	-120	-100

Chlorinated solvents are often used in aerosol products because they reduce flammability which arises when flammable hydrocarbons are used as propellants. If nonflammable propellants can be used, the need for chlorinated solvents can be reduced or avoided. The solvency characteristics of the reformulated product must be considered. It is sometimes necessary to include chlorinated solvents in blends because of their good solvent properties. The ideal propellant system, then, is one that reduces product flammability and solubilizes the components, or permits a different solvent blend to be used. The four propellants listed above are used because they are nonflammable or are less flammable than propane, n-butane and isobutane. Properties of these four are listed in Table 3.2. Properties of the traditional hydrocarbon solvents and the chlorinated solvents are provided for comparison.

Dimethyl Ether The use of DME as a propellant was commercialized in Europe and Japan in the 1970s. It had been tried in the U.S. during the 1940s, but there were problems with its use and it was discontinued. DME is a strong solvent. When initially tried, it caused most valves not to function properly (Strobach, 1988). Since its reintroduction in the 1970s, protective internal liners and new hardware materials that can withstand the strong solvency of DME are available. DME is less flammable than traditional hydrocarbon propellants. A primary advantage of DME is its water solubility. It is 35 percent soluble in water at 70 degrees F. Most other propellants have very limited water solubility. Its flammability, therefore, is offset by the ability to formulate DME with water as the solvent, resulting in products that are less flammable.

DME/CFC-11 blends are used in hairsprays, deodorants, and antiperspirants. (Under the Montreal Protocol, the use of CFC-11 will be phased out. As noted above, however, replacements for CFC-11 are available). Because of its high

solvency, DME solubilizes many resins used in paints and adhesives. It can function as the propellant and solvent in some types of products. A system consisting of DME propellant and hydrocarbon solvent replaces a hydrocarbon propellant and METH solvent based system in an aerosol adhesive application. The new adhesive is reported to be safer (uses less toxic ingredients), faster drying, and economically competitive (Dunn, 1988).

DME/water blends have been developed for total release insect sprays. These products replace the more flammable hydrocarbon solvent based formulations. Water dropout has been reported to be a problem with the new products. Water can be damaging to carpets, furniture or other surfaces on which the container is placed. Substitution with propane or ethanol in place of a small amount of the DME reduces dropout (Bartlett, 1989). Other insect sprays formulated with hydrocarbon propellants and chlorinated solvents can be replaced using DME. Blends of DME with hydrocarbon propellants or with CFC-22 propellant eliminate the need for another solvent in some products.

Water based paints have been developed that contain DME as a propellant and hydrocarbon solvents to improve solubility of water insoluble components. The presence of hydrocarbon solvents and DME enhances the evaporation of water from sprayed paint. Slow drying of water based paints is commonly cited as a reason why they are not more widely used. The addition of DME is also reported to reduce foaming, another common problem of aqueous spray paints.

DME is used in other aerosol products that traditionally contain chlorinated solvents. Because of its high solvency, it is used in laundry prespotters, leather and fabric protectors, flying and crawling insect killers, flea sprays,

paint foams, primers, and sprayable polyurethane (Bohnenn, 1988).

The use of DME is not without its drawbacks. DME is a flammable liquified gas. Process equipment used with DME must be classified as Class I, Division I, Group C. Pump gaskets and seals must be made from materials that can tolerate DME's solvency. The cost to convert an existing fitting line to accommodate DME (that is, from Group D to Group C) can range from \$1,500 to \$15,000, excluding the cost to retrofit pumps, heat exchangers and other ancillary equipment (Johnsen, 1988). DME is photochemically reactive. It is often used in combination with hydrocarbon solvents that may also be photochemically reactive. The use of VOCs is discouraged and regulated in many parts of the country.

Other Propellants HCFC-22 (chlorodifluoromethane) is a nonflammable propellant. It can be used alone or in blends with other propellants to reduce product flammability. It has been used in total release foggers in place of TCA. HCFC-152a (1,1-difluoroethane) is moderately flammable. It has also been used in total release foggers to reduce the flammability of the product. HCFC-142b is considered to be almost nonflammable or very slightly flammable. The problem with all three of these alternatives is that they have very limited water solubility and are poor solvents. Hydrocarbon solvents are usually used in combination with these propellants to improve solubility. Consequently, the VOC content of the final product may be higher than a comparable product formulated with chlorinated solvents. Once again, there is a tradeoff. In this case, source reduction of chlorinated solvents is achieved by increasing the use of photochemical smog precursors. The new alternative propellants cost much more than propane and butane.

Future Alternatives HCFC-141b (1,1-dichloro-1-fluoroethane) and HCFC-123 (1,1,1-trifluoro-2,2-dichloroethane) are two new solvents developed by U.S. CFC manufacturers. They have very low ozone depletion potential and are not regulated under the Montreal Protocol as are the fully halogenated CFCs. They are currently undergoing animal toxicity testing, and will not be commercially available until the test results have been evaluated. HCFC-123 is nonflammable. HCFC-141b is considered marginally flammable. It is not clear at this time what potential these solvents hold for the aerosols industry.

Barrier Packs

Barrier packs are compartmented pressurized containers in which the product is physically separated from the propellant. There are several types, but the two major types are piston containers and bag-in-can containers. In a piston container, the propellant is stored below the piston and forces product above it out of the can when the dispensing valve is depressed. With the bag-in-can arrangement, the product is retained inside a flexible pouch in the can. Propellant surrounds the pouch and pushes the product out of the can. The product in this case does not contact the container at all. This technology can be used with products that would corrode the inside of the can or that are highly viscous.

Shaving gels and caulking compounds are two products most commonly packaged in barrier packs. There are two advantages to the use of barrier packs. First, viscous products that cannot be dispensed with traditional aerosol systems can be packaged in barrier packs. The second advantage is that product can be dispensed while holding the container in any position. Barrier packs provide an opportunity for more kinds of products to be packaged as aerosols. They do not really reduce the use of CFC propellants. They do not result in solvent usage

reduction. In fact, the adoption of barrier packs is not recommended as a means to reducing VOC solvent consumption (Lim, 1989). With barrier packs, it may be necessary to use more solvent in a product because the propellant normally in contact with components of a blend has been removed, and additional solvent may be required to keep solid components within an acceptable range. The use of barrier packs can increase the container costs by as much as two times.

IV. ANALYSIS OF SOURCE REDUCTION OPTIONS

The aerosols industry annually consumes a little more than 57 thousand metric tons of chlorinated solvents. In Section III, alternative processes and techniques that have the potential to reduce solvent consumption and releases were identified. In this section, these options are classified into three categories. Within each category, the options are analyzed in terms of implementation costs and source reduction potential.

CLASSIFICATION OF OPTIONS

Each option from Section III has been classified into one of the three categories. The classification of options is summarized in Table 4.1. In column one are listed the options for which no further analysis is done. There are three reasons why options are placed in this category. First, in some cases cost information is insufficient to perform the analysis. A second reason is that certain options, though technically feasible, would result in very small reductions in solvent use or releases if implemented. A third reason is that the applicability of an option is very product specific. Analysis would require a product by product approach. For the hundreds of product types available, this would involve analysis beyond the scope of this report.

The second category includes alternatives for which limited analysis can be carried out. For these options, some cost information is available, and a rough estimate of source reduction potential can be made. For the third category of options, a more detailed analysis in the form of case studies was carried out.

Table 4.1

CLASSIFICATION OF SOURCE REDUCTION OPTIONS

<u>No Further Analysis</u>	<u>Limited Analysis</u>	<u>Case Study Analysis</u>
Improved maintenance Practices	Liquid solvent Recovery and use of recycled solvents	Hydrocarbon solvents
Refrigerated condensation	Non-aerosol packaging	Alternative propellants
Carbon adsorption		Correction of over and under filling
Water-based formulations		
Alternative active ingredients		

NO FURTHER ANALYSIS OPTIONS

Four options are included in the no further analysis category. Improved maintenance practices can potentially reduce solvent releases by practices such as identifying and controlling fugitive emission sources. The exact nature of maintenance improvements adopted and subsequent emission reductions will vary from plant to plant. Although it is a relatively simple option to implement, actual source reduction achieved will be small. This option was not further analyzed.

Refrigerated condensation and carbon adsorption are two vapor collection and recovery techniques that are widely used in other industries, but they are not appropriate for the aerosols industry. The amount of solvent lost to the atmosphere during product filling is much less than the amount emitted during product use. The solvent concentration in filling plant exhaust streams is very low. Neither vapor recovery technique would be cost-effective under these conditions. Also, very little solvent could actually be recovered.

There are two reformulation strategies that can potentially reduce chlorinated solvent requirements. The first option is to replace solvent with water as the carrier. The second option is to reformulate the active ingredient component of a product. Both of these reformulation strategies are complex, because they impact propellant and hardware selection and can significantly change the way a product is used. In addition, product reformulation is very product specific. In order to estimate the source reduction potential of these options, it would be necessary to analyze in detail each type of product that contains chlorinated solvents, identify alternative formulations, and develop product efficacy, toxicity and consumer preference information.

This analysis is not attempted in this report. A more detailed discussion of reformulation costs is, however, provided in a subsection to follow. One of the options evaluated is a water based formulation, combined with DME propellant.

LIMITED ANALYSIS OPTIONS

There are two options for which we have enough information to perform a limited cost analysis and develop a rough estimate of source reduction potential. The options analyzed in this subsection are the use of recycled solvent, and liquid solvent recovery.

Recycled Solvent

As noted in Section III, most aerosol fillers do not use recycled chlorinated solvents in their products with the exception of some paints, automotive and industrial products. At least one filler surveyed also uses recycled solvents in household products. In general, though, there is reluctance throughout the industry to replace virgin solvent with recycled. Aerosol fillers require a high purity grade of solvent. In order to provide this, solvent recyclers must process recovered solvent more than they need to in order to sell the same solvent into the metal cleaning industry. It costs more for them to do the additional processing. As a result, the recycled solvent that aerosol manufacturers purchase costs about the same as, or a little less than, virgin solvent. There is little economic incentive for them to choose recycled solvent over virgin. Also, because of their concerns about solvent purity, some fillers feel that it is necessary to test the quality of every incoming batch of recycled solvent before it can be used in product formulations. When this is done, any cost savings that might result from purchasing recycled material are offset by laboratory costs to conduct the analyses.

It is known that some of the virgin chlorinated solvent used in aerosols has already been replaced by recycled, to what extent this has occurred is difficult to estimate. In the SRRP staff assessment, 91 percent of the total virgin TCA and 90 percent of the total virgin METH consumed in the aerosols industry could potentially be replaced by recycled solvent. The details of this estimation are provided in Appendix A. This replacement could occur without any additional cost to the industry (not considering added costs for laboratory analysis). It would reduce virgin solvent requirements by 18 thousand mt for METH and 30.9 thousand mt for TCA. This represents a combined savings of 48.9 thousand mt, or 85 percent of the virgin chlorinated solvent demand in the aerosols industry.

While this reduction in virgin solvent demand is technically achievable, and could cost the industry nothing to implement, the switch to recycled solvent is not likely to occur. The largest markets for recycled chlorinated solvents are the metal cleaning and electronics industries. If recycled solvents are diverted away from these markets via purchases by aerosol fillers, these industries will be forced to increase their consumption of virgin solvents. It would cost them more to use virgin material than to use recycled. Also, there would be a net increase in virgin solvent production to meet demand of these two large markets.

Liquid Solvent Recovery

If aerosol fillers do not use recycled chlorinated solvents in their products, there is still an opportunity to achieve on-site source reduction. Fillers can evacuate unusable cans on-site in a self-designed unit or in a purchased unit. Liquid contents are collected and reused on-site, or sent off-site to a cement kiln, incinerator or solvent recycler. In

this analysis, we will determine the costs to crush waste cans on-site with a purchased unit, and either reuse the solvent or send it off-site. We use two plants to evaluate the cost-effectiveness of this option. Plant A is a very large facility that generates three hundred unusable cans per day. Plant B is a much smaller facility that generates ten unusable cans per day.

The cost to purchase a fully contained can evacuator ranges from \$55,000 to \$60,000 for a smaller unit and \$75,000 to \$80,000 for the larger unit. The smaller unit processes 600 to 1,000 cans per hour. Plant B only generates 250 cans per year. Clearly, the can crushing unit would not be appropriate for Plant B. Plant A does not generate enough waste cans to operate the unit for one hour a day. In a five day workweek, Plant A generates 1,500 reject cans, enough for two cycles. We assume that the unit is operated one day a week for, at most, two hours. In one year the unit will process 75,000 cans. Assuming a ten year equipment life, a 10 percent cost of capital, and a unit costing \$57,500 installed the annual capital cost of the unit amounts to \$9,315. The per can cost is \$0.124, significantly less than the cost of off-site can disposal.

This cost does not include the cost of a pressurized storage vessel for the liquid concentrate and propellant collected from the cans. Maintenance and operating costs are not included either. Operating costs would include electricity and a source of air pressure. Maintenance would entail periodic replacement of seals that can be damaged by repeated contact with propellants and solvents. The equipment supplier we spoke with did not have detailed operating and maintenance costs available, since they were still evaluating the details of their systems.

The liquid concentrate and propellant drain from the crusher and are stored in a pressurized vessel. The material is likely to contain many constituents unless some effort is made to separate and crush similar products in each cycle. In either case, it is unlikely that the filler will want to reuse this material. One reason is that the mixture contains flammable liquified propellants. If the material is open to the atmosphere, some of the propellant will evaporate, resulting in a potentially hazardous work environment and the release of VOC's to the atmosphere. Most likely, Plant A will send the material to an off-site treatment storage and disposal facility. The solvent portion can be recovered, the combustible and flammable portion can be used as supplemental fuel. The remaining material consisting of miscellaneous product active ingredients will be incinerated. Many waste treatment companies charge generators for the waste they take, but give a credit for the recoverable solvent portion of the waste.

It is difficult to estimate how much it would cost to send the waste liquid off-site because the waste will vary in composition depending on what products are processed, and will contain many different components. To illustrate how a charge/credit arrangement might work, we assume a waste stream of fixed composition. Not all of the waste cans generated will contain chlorinated solvents. Economically, it would be better for the filler to segregate the waste that does not contain chlorinated solvents from the waste that does. If half the cans are filled with chlorinated solvent based products, that amounts to 150 cans per day. We assume an average can size of ten ounces, twenty percent solvent concentration and an average liquid density of 8 pounds per gallon. Recyclers charge and credit schemes vary, but for this case we assume a charge of \$1.65 per gallon of nonrecoverable material and a credit of \$1.25 per gallon for recoverable solvent. Considering only that

portion of waste that contains chlorinated solvents (that is, 150 units per day) it costs Plant A \$7,809 per year to dispose of the waste as summarized in Table 4.2. This includes a credit for recoverable solvent. As noted above, it does not include maintenance costs for operating the can evacuator, nor does it include the capital cost of two storage tanks for collection and segregation of the recovered liquid or for disposing of the crushed cans as solid waste. It also does not include the cost for disposing of the waste cans that do not contain chlorinated solvents.

Different waste disposal costs have been reported by others. Waste treatment companies that collect intact waste cans charge as much as one dollar per can. Another filler has estimated a cost of \$0.83 per can for incineration and solvent recycling (Flanner, 1988). Our example contains a number of assumptions that may not be accurate for a given plant, but it illustrates that it may be possible to recover chlorinated solvents and reduce disposal costs at the same time.

Non-aerosol Packaging

Many types of aerosol products are available in non-aerosol form. Some of the alternate products and packages were discussed in Section III. The aerosol can and other hardware account for approximately 35-50 percent of the cost of an aerosol product (Geigel and Miller, 1985; ICF, 1987a). When a product is packaged in non-aerosol form, these costs can be greatly reduced. There is no need for a valve system in a liquid, solid or paste product. Non-aerosol spray pumps are much simpler than the aerosol delivery systems. Container and valve costs for non-aerosol sprays are significantly reduced when packaging in non-aerosol form.

Table 4.2

ANNUAL COSTS TO COLLECT LIQUID AND SEND OFF-SITE

	<u>Cost</u>
Can Crushing (@ \$1.24/can)	\$4,650
Nonrecoverable to Incineration (@ \$1.65/gal)	3,878
Solvent Recovery (credit @ \$1.25/gal)	(719)
	<hr/>
	\$7,809

Assumptions:

Average can size = 10 oz.

Average liquid density = 8 lb/gal.

150 units per day containing chlorinated solvents.

250 operating days per year.

Switching to a non-aerosol package can change a product's solvent requirements. There may be a wider choice of solvents that can be used than when the same product is packaged as an aerosol. It is difficult to estimate the impact this change might have on product cost and the source reduction potential. Once again, the analysis is very product specific. The only conclusion that can be drawn is that non-aerosol products are, in general, less expensive than their aerosol counterparts. It should be noted that this is not a universally accepted conclusion, however. Whether the aerosol products are more expensive or not, their continued growth reflects the fact that consumers like to use aerosol products.

Earlier studies have compared the costs of aerosol and non-aerosol products. A study published in 1984 examined the economic effects of banning CFC propellants in aerosols. In most product categories evaluated in that report, aerosol products cost more than non-aerosol products, on the basis of cost per ounce of active ingredient (ICF, 1984). The average aerosol premium ranged from 10 percent for women's hairsprays to 60 percent for spray starch. An exception to this trend was aerosol insect repellent, which was more expensive in non-aerosol form by an average of 67 percent. It should be noted that this study made no attempt to look at chlorinated versus nonchlorinated solvent usage. For that reason, and because the study is more than five years old, it is of limited use in assessing product costs today from the perspective of chlorinated solvent use reduction.

A more recent study was conducted by Westat in 1987 (Westat, 1987). The objective of this study was to gather data on the concentration and incidence of chlorinated solvents in household products. Aerosol products were analyzed along with liquids, pastes, pump sprays and powders. The cost of each

product, where available, was reported along with container size and solvent concentration. This study is also of limited use for our purposes. There is insufficient information to determine whether the aerosol and non-aerosol products have equivalent amounts of active ingredients, or whether they are designed to perform the same function. Also, since the focus of the study was chlorinated solvent exposure, there was no attempt to compare chlorinated solvent based aerosol products with nonchlorinated solvent, non-aerosol products, which is the ideal source reduction option for our study.

In terms of source reduction potential, a switch to non-aerosol products could significantly reduce solvent consumption. The potential is greatest for non-aerosol products that do not contain chlorinated solvents at all, such as solids, pastes, solventless liquids or water based products. For aerosol products that contain chlorinated solvents as active ingredients, a switch to non-aerosol products may not result in solvent savings. The non-aerosol versions on the market are likely to contain chlorinated solvents as well. Because of the product specific nature of the aerosols industry, it is very difficult to estimate the source reduction potential that might be achieved.

CASE STUDY ANALYSIS

In this subsection, two reformulation strategies are examined that might be implemented to reduce chlorinated solvent consumption in aerosols. First, general cost considerations related to product reformulation are discussed, and then a hypothetical case is examined in which a flammable hydrocarbon solvent blend replaces chlorinated solvent in a spray paint. Secondly, a DME propellant/water based spray paint is evaluated. Also evaluated in this section is the option of correcting over- and under-filled cans.

General Cost Considerations

Product reformulation costs fall into three areas--research and development (R&D) costs, manufacturing capital costs, and marketing/distribution costs. R&D efforts include laboratory work to develop and evaluate alternative formulations, product efficacy testing, stability testing to determine if can corrosion or leakage will occur, hardware/container, stability testing and product toxicity testing. Prior to full scale manufacturing of a new product blend, it might be necessary to do some market testing to assess consumer acceptance of the product. Manufacturing costs may include retrofitting existing process and storage equipment or new equipment purchases. Depending on what materials are handled by a facility, the introduction of new or more flammable chemicals might require the installation of additional vapor detection and/or fire control equipment. Pumps, gaskets, seals and hoses may have to be replaced if they are incompatible with new materials, such as stronger solvents that may not have been previously handled. If water is going to be added to product, it may become necessary to replace existing transfer and storage equipment with corrosion resistant equipment.

If the reformulated product is more flammable than before, distribution and warehousing costs increase. Fire codes stipulate how flammable aerosol products can be stored and require certain levels of fire suppression equipment for different classes of flammable and combustible products.

One of the advantages to using chlorinated solvents in blends is that their higher relative densities add weight to aerosol packages. When other solvents are used in place of chlorinated solvents, the final product will likely weigh less. Consumers choose among products on the basis of product weight (among other factors). In response to this aerosol

manufacturers often increase the container size, adding more product than before, so that the relative product weight remains the same.

When different size cans are used, or if the reformulated product has different flammability properties, the artwork and labelling on the container may have to be redesigned. The average cost to change the label for an aerosol can has been estimated at \$2,250 (ICF, 1988). This includes the fixed cost to change lithographic or paper printing plates. It does not include cost of paper or labels or other expenses related to the actual labeling process, as these costs are not expected to change. When formulations are changed, the spray pattern is affected. To obtain the desired spray pattern with a new formulation it may be necessary to change the valve system. This can add additional costs. Even more costs will be incurred if products must be reregistered with federal or state regulatory agencies.

Costs of Chemical Substitution: Replacing METH Based Spray Formulations with Hydrocarbon Solvent Blends and Alternative Propellants

In this subsection, we compare the costs of two METH based spray paints with a flammable TCA acetone solvent based formula and with a flammable TCA/acetone solvent formula and with a water/DME propellant system. Products I and II in Table 4.3 represent typical spray paint formulations based on METH. In Product III, METH is replaced with a TCA/acetone solvent blend. Product IV consists of a water based spray paint formulated with DME propellant. The composition of each product is noted in terms of weight percent of the various ingredients. For each case, the cost to formulate the product is determined by multiplying the ingredient cost in dollars per kilogram by the concentration of the ingredient in the blend. Ingredient costs are listed in Table 4.4. In order to calculate a cost per

Table 4.3

	I			II		III		IV	
	<u>\$/kg</u> (3)	<u>wt%</u> (1)	<u>\$/kg</u>	<u>wt%</u> (2)	<u>\$/kg</u>	<u>wt%</u> (2)	<u>\$/kg</u>	<u>wt%</u> (1)	<u>\$/kg</u>
Solids (resins, pigments, other additives)	0.66	12	.079	12	.079	12	.079	12	.079
METH	0.64	28	.179	35	.224	-	-	-	-
TCA	0.89	-	-	-	-	40	.356	-	-
Water	0.005	-	-	-	-	-	-	21	.001
Acetone	0.66	32	.211	-	-	20	.132	-	-
Xylene	0.27	-	-	-	-	-	-	25	.068
Toluene	0.26	-	-	25	.065	-	-	6	.016
MEK	0.66	-	-	-	-	-	-	5	.033
HC propellant	0.275	28	.077	28	.077	28	.077	-	-
DME	0.95	-	-	-	-	-	-	31	.295
Total		100%	\$.546/kg	100%	\$.445/kg	100%	\$.644/kg	100%	\$.492/kg

Notes:

- (1) Formulation taken from ICF (1988).
- (2) Formulation based on personal communication with industry representative.
- (3) Cost of solids from ICF (1988), not adjusted to 1989 dollars. Since the same weight perc each formulation, the relative cost of the solids in each product will remain the same.
- (4) SRRP estimate.

can of spray paint, it is necessary to estimate an average can size. We use an average size of 8 ounces, or 0.23 kilograms. This number has been used in earlier studies (e.g. ICF, 1988; ICF, 1987a).

From the calculations, Product II--a METH based formulation is the least expensive to produce. The TCA/acetone based paint is 40 percent more expensive than Product II. Product I, which contains both METH and TCA, costs more than the METH based paint without acetone. The DME/water based paint costs less than both the TCA/acetone and METH/acetone systems.

The cost figures in Table 4.3 represent only the costs to formulate a new product. They do not include R&D costs, manufacturing capital expenditures, or distribution costs related to the development, production and marketing of a new product. Earlier studies have estimated these costs for various types of aerosol products.

Research and development (including stability and toxicity testing) and marketing costs related to the reformulation of one spray paint has been estimated at \$7,500 in 1987 dollars (ICF, 1987b) per product. That is, each different color reformulated would represent an additional \$7,500 in development costs. In 1989 dollars, then, each new product costs \$7,970 in R&D. To assess this cost on a per can basis, we assume that an aerosol product has a five year life. We use the production rate of 43,200,000 units per year from Plant A described earlier in this section, and assume that 25 percent of Plant A's product line of paints and related products contain METH, and will therefore be replaced with other products. Therefore, the development cost per can of spray paint is \$0.008.

Table 4.4

SOLVENT AND PROPELLANT COSTS

<u>Solvents</u>	<u>\$/lb</u> ⁽¹⁾	<u>\$/gal</u> ⁽¹⁾	<u>\$/kg</u>
TCA	0.405		0.89
METH	0.29		0.64
PERC	0.31		0.68
CFC-113	1.22		2.69
Acetone	0.30		0.66
MEK	0.30		0.66
Xylene	-	0.90	0.27
Toluene	-	0.84	0.26
NMP	1.59		3.51
<u>Propellants</u>	<u>\$/lb</u>		<u>\$/kg</u>
DME	0.43 ⁽¹⁾		0.95
HC Propellants	0.10-0.15 ⁽²⁾		0.22-0.33
(Average)	0.125		0.275

Sources:

(1) CMR, 1989d.

(2) Personal Communication with Industry Representative.

Earlier studies (Geigel and Miller, 1987; ICF, 1987b) have reported that no capital costs are incurred from switching from METH to another hydrocarbon solvent. We talked with one filler, however, who replaced METH with a TCA/acetone blend in a product line. They were required by local fire codes and their insurance carrier to install sprinkler heads, separate feed lines and filling heads for the acetone because of its flammability. To allow for flexibility in the future, the company decided to upgrade three tanks, not just one, and to install the extra filling head and auxiliary equipment to three lines instead of only the one currently used for paints.

Table 4.5 lists the equipment modifications that must be considered for converting to a DME propellant to ensure compliance with the standard. Because of its flammability, substantial costs can be incurred in switching to DME propellant. Many plants, in order to handle DME safely, must upgrade portions of their facilities to the National Electrical Code (NEC) Class I, Group C equipment standards. Costs associated with this equipment conversion are estimated to be \$15,000 per line in 1988 dollars, or very close to \$15,950 in 1989. Therefore, it would cost about \$63,780 for Plant A to convert all four lines. Annualized over a fifteen year equipment life, with a 10 percent cost of capital, the annual capital cost for DME conversion is \$8,473. This cost should be averaged over the annual production volume and added to the manufacturing costs of the DME/water based spray paint. If all of the METH based paint is replaced with the DME/water blend, the added cost would be an additional \$0.008 per can. For the DME/water paint, total development costs amount to \$0.016 per can.

Table 4.5

EQUIPMENT MODIFICATIONS FOR DME STORAGE AND HANDLING

A. Electrical equipment that must conform to requirements of NFPA Class I, Group C:

- Meters, relays
- Instruments
- Wiring methods
- Conduit and cable system sealing
- Liquid or condensed vapor trap drainage
- Arcing devices such as switches, circuit breakers, motor controllers and fuses
- Motors
- Lighting fixtures
- Flexible cards
- Spare parts for all of the above

B. Materials of construction for the following must be compatible with DME:

- Tank flanges
- Valve seats, packing and seals
- Pump seals
- Hoses
- Pressure relief devices
- Filling machine gaskets and seals

C. Other considerations

- Recalibrate gas detection equipment for DME
- Check tankage, piping and other equipment for proper marking and labelling
- Ensure proper grounding of all equipment
- Check equipment against current codes (ASME, etc.)

Source: ICF, 1987a.

There are still other costs that have not been incorporated into the above. When products are reformulated and, as a result, are more flammable, warehousing and distribution costs may increase. It costs \$2,000 to add sprinklers to each storage tank and \$3,000 more to add a separate line and filler head for each filling line. If we assume that Plant A must make the same changes, and chooses to do so for each of four filling lines and three bulk storage tanks, then the total cost would be \$18,000. If this cost is spread over a ten year equipment life, the cost per can of product would be negligible. We do not add this cost to the total product reformulation costs, but note that these kinds of expenses must be considered when evaluating formulation changes.

Correction of Over and Under Filling

This option was discussed in Section III as a means of reducing the number of filled containers that must be disposed of due to defects. The approach is based on an article by Flanner (1988). In order to evaluate this options, we introduce two hypothetical plants to use as models in the cost analysis. Characteristics of these hypothetical plants are summarized in Table 4.6. Plant A is a large facility that fills 72 million units a year of paints, automotive and industrial products and insecticides. It has four high speed filling lines that each process 150 cans per minute. Plant B is a smaller facility that fills 25 cans per minute of a special use industrial product. Plant B produces 3 million units a year.

Based on discussions with industry sources and a review of survey responses, we can assume that one can in every thousand cans processed through a high speed line is unusable. (The rate for slower lines may differ, but for this analysis we use the same number). At this rate, Plant A generates 288 unusable cans a day, and Plant B generates 12 a day.

Table 4.6

CORRECTION OF PROPELLANT FILLING -
COST SAVINGS ACHIEVABLE

	<u>Plant A</u>	<u>Plant B</u>
A) Annual Production (units/yr)	72,000,000	3,000,000
B) Number of Filling Lines	4	1
C) Units/Min/Line	150	25
D) Units/Day	288,000	12,000
E) Unusable Units Generated Per Day	288	12
F) Total Disposal Cost (\$/yr)	\$64,800	\$2,700
G) Cans Corrected Per Day	173	7
H) Disposal Costs Avoided Per Year	\$38,925	\$1,575
I) Added Labor Cost Per Year	\$14,418	583
J) Direct Cost Savings, (H) - (I)	\$24,507	992
K) Savings in Product Value	\$21,625	\$ 875
L) Total Cost Savings, (J) + (K)	\$46,132	1,867

Quotes of costs to send waste cans off-site for incineration, solvent recovery or other treatment range from \$.83 to \$1.00 per can. If we take \$.90 per can as a mid-range cost and calculate the daily cost for disposing of the total volume of waste cans generated at each site, the result is \$250.20 for Plant A and \$10.80 for Plant B. In yearly costs, Plant A would spend \$64,800 and Plant B would spend \$2,700 to dispose of all rejected cans.

According to one source, more than 50 percent of the unusable cans are rejected because they had too much or too little propellant (Flanner, 1988). If we take 60 percent as our estimate, this means that Plant A has 173 cans a day and Plant B has about 7 cans a day that can be corrected. We assume that damaged cans can be identified by a quick visual inspection. If it then takes an employee two minutes to weight check the other rejected cans, add propellant to underfilled cans and release propellant from overfilled cans, Plant A requires 346 minutes of labor, and Plant B requires 14 minutes of labor each day. At a labor rate of \$10 an hour, the rework amounts to \$57.67 a day for Plant A and \$2.33 a day for Plant B. During an operating year, the labor costs to correct over and underfilling total \$14,418 for Plant A and \$583 for Plant B.

The direct cost savings to correct over and underfilling consists of the disposal costs avoided minus the labor costs incurred. Subtracting labor costs from these totals yields a direct savings of \$24,507 annually for Plant A and \$992 for Plant B. It is assumed that both plants operate one eight hour shift a day, 250 days a year.

In addition to the direct disposal costs avoided, the analysis should account for the value of each can of product that can now be sold instead of shipped out as waste. This value will, of course, vary greatly depending on the type of

product, the concentrate, container and associated hardware. To keep the analysis simple, an average value of \$.50 per can is used, in which case Plant A saves an additional \$21,625 and Plant B saves \$875 more. Total cost savings (avoidance of disposal costs and recovery of lost product minus labor costs) are \$46,132 for Plant A and \$1,867 for Plant B.

The source reduction potential of this option is more difficult to determine. In Plant A, chlorinated solvents are used in a wide variety of products. Plant A also fills a number of products that do not contain chlorinated solvents. The reduction in off-site releases from Plant A can be estimated by assuming a product mix and the concentration of chlorinated solvents in each product. The details of this calculation are provided in Appendix B. If Plant A adopts the practice of manually correcting over and under filled cans, 2,309 kg of chlorinated solvents can be prevented from going to an off-site facility for incineration, solvent recovery or use as supplemental fuel.

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