EPA-453/R-94-066-A

STUDY OF VOLATILE ORGANIC COMPOUND EMISSIONS FROM CONSUMER AND COMMERCIAL PRODUCTS

REPORT TO CONGRESS

March 1995

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EXECUTIVE SUMMARY

The purpose of this report is to respond to the Clean Air Act (Act) requirement to report to the Congress on consumer and commercial products as contributors to ozone nonattainment. The report is primarily technical in nature and does not conclude which products may warrant federal regulation. Such decisions will be addressed when EPA publishes a regulatory schedule. The requirements of the Act concerning consumer and commercial products are discussed below.

Section 183(e) of the 1990 Amendments to the Act requires the EPA to conduct a study of emissions of volatile organic compounds (VOC) into the ambient air from consumer and commercial products. As stated in §183(e), the objectives of the study are (1) to determine the potential of consumer and commercial product VOC emissions to contribute to ozone levels which violate the national ambient air quality standard (NAAQS) for ozone; and (2) to establish criteria for regulating consumer and commercial products or classes or categories of products under the authority of §183(e) of the Act. The EPA is required to submit a report to Congress that documents the results of the study.

Upon submission of the report, the EPA is required to list those categories of products that are determined, based on the study, to account for at least 80 percent of the total VOC emissions, on a reactivity-adjusted basis, from consumer and commercial products in areas that violate the NAAQS for ozone. The EPA is required to divide the list into 4 groups to establish priorities for regulation. Beginning no later than 2 years following publication of the list and regulatory schedule, the EPA is required to regulate one group every two years until all 4 groups are regulated.

Although §183(e) addresses VOC emissions from "the use, consumption, storage, disposal, destruction, or decomposition" of consumer and commercial products, the EPA does not intend to regulate the users of the products. Furthermore, in developing regulations under §183(e), the EPA will duly consider the impacts of such rules on product performance and cost to the consumer, and will strive to minimize any adverse impacts of such regulations. In developing specific regulations, the EPA will evaluate new information on cost-effectiveness as well as other criteria and may, in the process, reassess the product listing and schedule.

In establishing criteria for regulating consumer and commercial products, §183(e) requires consideration of factors which are broader than the EPA usually considers in developing regulations. Under §183(e), the EPA is required to take into consideration (1) the uses, benefits, and commercial demand of consumer and commercial products; (2) any health or safety functions served by the products; (3) those consumer and commercial products that emit highly reactive VOC into the ambient air; (4) those products that are subject to the most cost-effective controls; and (5) the availability of any alternatives to such consumer and commercial products that are of comparable costs, considering health, safety, and environmental impacts. The EPA believes that consideration of these factors will ensure that consumer needs and demands continue to be met.

Within a short time after submitting this report to Congress, the EPA will publish in the *Federal Register* a schedule for regulation of products under §183(e). The initial publication of the list and schedule for regulations will not be considered final Agency action. Accordingly, the four groups may be modified such that a product category may be moved to a different group, delisted altogether, or added to the list. The EPA will make appropriate adjustments to ensure that it continues to meet the statutory requirements of §183(e) to regulate categories which account for at least 80 percent of baseline emissions.

Should a product be listed for regulation, the extent to which the product is affected will be determined at the time of rulemaking. As part of the rulemaking process, the EPA will consider public comments at the time each product is considered for regulation.

The persistence of the ground-level ozone problem has caused State and local air pollution agencies to seek emission reductions beyond those which have been obtained through regulation of the conventional mobile and stationary sources of emissions. As a result, several agencies are adopting rules to regulate various household consumer products. Individual State and local regulations for consumer products could have significantly different requirements, which in turn could lead to serious disruption of the national distribution network for consumer products. In response, the consumer products industry has urged EPA to issue national rules for consumer products to provide consistency across the country. The States are also supportive of a national rule which will assist them in their efforts toward achievement of ozone attainment.

In response to these concerns, EPA consulted with consumer product manufacturers and other interested parties to determine which products would be the most amenable to an expedited regulation that could achieve significant VOC emission reductions without serious adverse effects on consumer satisfaction or price of the products. The industry identified a group of 24 consumer products that meet these criteria (see section 2.6). Both the consumer products industry and the States strongly support expedited Federal regulation of these 24 product categories. The EPA plans to promulgate the rule for these 24 categories by early 1996.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Ground-level ozone has been a pervasive pollution problem in the United States for several decades. In the upper atmosphere, or stratosphere, ozone occurs naturally and forms a protective layer to shield us from the sun's harmful ultraviolet rays. However, in the lower atmosphere, or at "ground level," man-made ozone can cause a variety of problems to human health, crops and trees. It is this ground-level ozone problem that is the focus of this report.

Ground-level ozone can cause a wide range of health effects depending upon the ozone concentration, the duration of exposure, and the activity level of the individual while exposed. Scientific evidence indicates that ambient levels of ozone affect people with impaired respiratory systems, such as asthmatics, as well as healthy, active adults and children. For example, increased ozone levels can aggravate preexisting respiratory disease, as observed in studies associating increased ozone levels with increased hospital admissions and emergency department visits for respiratory causes. In healthy adults and children, exposure to ozone for six to eight hours at moderate levels of exertion and at relatively low concentrations has been found to reduce lung function. Similar reductions in lung function result from one to three hours of exposure at heavy levels of exertion at higher concentrations. In adults these decreases in lung function are often accompanied by symptoms such as cough, chest pain, and shortness of breath, with the severity of the symptoms increasing with increasing ozone concentration. In addition, animal studies showing structural damage in the lung after months of exposure to ozone raise concerns about potential chronic effects, although attempts to associate chronic health effects in humans with long-term ozone exposure have yet to provide unequivocal evidence that such a linkage exists.

Each year ground-level ozone is also responsible for agricultural crop yield loss. This loss has been estimated to be in the range of several billion dollars annually, although the assessment of economic effects on the agricultural sector remains incomplete. Ozone also causes noticeable foliar damage in many crops and species of trees. Studies also indicate that current ambient levels of ozone are responsible for damage to forests and ecosystems.

Ground-level ozone is particularly difficult to control because it is not emitted directly into the atmosphere, but instead is formed by a complex photochemical reaction caused by primarily by volatile organic compounds (VOC), nitrogen oxides (NO_X), heat and sunlight. VOC are emitted from a variety of sources, including automobile exhaust, industrial and chemical processes, evaporating gasoline vapors, and many kinds of consumer and commercial products. NO_X is emitted from the combustion of fuels from sources like automobiles, power plants and industrial boilers.

Since the early 1970's the U.S. Environmental Protection Agency (EPA) and State and local air pollution control agencies have had programs in place to protect the public from ground-level ozone. Traditionally these programs have focused on reducing emissions from motor vehicles and a variety of industrial and chemical processes. As a result, major improvements have occurred from these kinds of sources. However, substantial increases in vehicles miles travelled and other growth factors have made ground-level ozone much more difficult to control than initially anticipated.

By 1990 there were 98 areas in the country that did not meet the EPA-established national ambient air quality standard (NAAQS) for ozone. Approximately 150 million Americans lived in these areas. That same year the Congress passed and President Bush signed into law sweeping amendments to the Clean Air Act (Act). The 1990 Amendments required a broad array of programs to further reduce emissions of VOC, NO_x and/or other pollutants from the automobile, petroleum, chemical, steel, utility, and pulp and paper industries, as well as a wide variety of other large and small sources.

In the 1990 Amendments, the Congress also required for the first time that EPA study and regulate emissions from consumer and commercial products. In putting these requirements into place, Congress recognized that national, state and local emission control programs traditionally focused on emissions from mobile (e.g. cars) and stationary (e.g. factories) sources. Although those control programs can be effective, Congress was concerned that ozone control programs were generally ignoring major components of the VOC emissions inventory which could also be effectively controlled.

In part, the Congressionally mandated program to focus on consumer and commercial products was based on a 1989 report by the Congressional Office of Technology Assessment (OTA) entitled *Catching our Breath: Next Steps for Reducing Urban Ozone*[1]. The report indicated that individually small, diverse sources of VOC (so-called "area sources") contribute significantly to the continuing ozone nonattainment problem. According to the OTA report, a major source of VOC emissions is the wide range of consumer and commercial products.

Many sectors of industry have been supportive of the requirements contained in the 1990 Amendments to establish a national program to control emissions from consumer and commercial products and other area sources. Some in industry were concerned that, unless EPA looked at the consumer and commercial product sector of the inventory, ozone control programs would have to continue to require increasingly expensive emission reductions from traditional mobile and stationary sources. Consumer and commercial products, by comparison, may represent an opportunity for much more cost-effective control. Faced with a broad array of varying State regulations controlling VOC emissions from their products, several companies that manufacture consumer and commercial products have also supported national regulations to help encourage national consistency.

1.2 REQUIREMENTS OF §183(e) -- CONSUMER AND COMMERCIAL PRODUCTS

Although control of one small source of VOC emissions may contribute little to overall ambient air quality, VOC reductions obtained through regulation of multiple small sources could have a beneficial additive effect. Section 183(e) of the 1990 Amendments requires the EPA to conduct a study of emissions of VOC into the ambient air from consumer and commercial products. The objectives of the study are (1) to determine the potential of consumer and commercial product VOC emissions to contribute to ozone levels which violate the NAAQS for ozone; and (2) to establish criteria for regulating consumer and commercial products or classes or categories of products under the authority of §183(e) of the Act. In establishing criteria for regulating consumer and commercial products, the EPA must take into consideration (1) the uses, benefits, and commercial demand of consumer and commercial products; (2) any health or safety functions served by the products; (3) those consumer and commercial products that emit highly reactive VOC into the ambient air; (4) those products that are subject to the most cost-effective controls; and (5) the availability of any alternatives to such consumer and commercial products that are of comparable costs, considering health, safety, and environmental impacts. Upon completion of the study, the EPA must submit a report to Congress that documents the results of the study.

The EPA must also list those categories of products that are determined, based on the study, to account for at least 80 percent of the total VOC emissions, on a reactivity-adjusted basis, from consumer and commercial products in areas that violate the NAAQS for ozone. The EPA must divide the list into 4 groups to establish priorities for regulation. Beginning no later than 2 years following publication of the list, the EPA must regulate one group every two years until all 4 groups are regulated.

1.3 SCOPE OF CONSUMER AND COMMERCIAL PRODUCTS UNDER §183(e)

According to §183(e), "the term 'consumer or commercial product' means any substance, product (including paints, coatings, and solvents), or article (including any container or packaging) held by any person, the use, consumption, storage, disposal, destruction, or decomposition of which may result in the release of volatile organic compounds. The term does not include fuels or fuel additives regulated under section 211, or motor vehicles, non-road vehicles, and non-road engines as defined under section 216."

The EPA believes that the statutory definition of consumer or commercial product is much broader than just the traditional "consumer" products (e.g., personal care products, household cleaning products, household pesticides, etc.). Instead, consumer and commercial products include all VOC-emitting products used in homes, businesses, institutions, and a multitude of commercial manufacturing operations. Among these products are a wide range of surface coatings, metal cleaning solvents, graphic arts inks, adhesives, asphalt paving materials, and many other products used in manufacturing processes or commercial operations, many of which have been previously regulated by the EPA and/or by the States.

Throughout this document, "consumer products" refers to those products used in and around the home, office, institution, or similar settings. The commercial and institutional use of these or similar products is also included under "consumer products." For example, a floor wax applied to the floor of the cafeteria of a factory would be considered a consumer product. The term "commercial products," on the other hand, generally refers to products used in manufacturing operations or in other commercial activities such as garment drycleaning, publication printing, and roadway paving. A more thorough discussion of the scope of §183(e) is presented in Section 2.2. Categories of consumer and commercial products and estimates of their VOC emissions are presented in Section 2.3 and in Chapter 5.

1.4 EPA'S CONSUMER AND COMMERCIAL PRODUCTS STUDY

The primary objectives of the study and report to Congress are to educate the EPA and Congress on consumer and commercial products as contributors to ozone nonattainment, to identify opportunities for reduction of VOC emissions from the use of these products, to establish criteria for regulation of consumer and commercial products, and to provide information which can be used in conjunction with the criteria to list and schedule categories for regulation.

1.4.1 Organization of the Consumer and Commercial Products Study

The consumer and commercial product study was a comprehensive, integrated effort directed toward meeting the objectives listed above and in §183(e)(2)(A). This Report to Congress presents an overview of the findings of the individual studies carried out by the EPA. Volumes which comprise the consumer and commercial products study are:

(EPA-453/R-94-066-a)	Report to Congress
(EPA-453/R-94-066-b)	Comprehensive Emissions Inventory
(EPA-453/R-94-066-c)	Fate of Consumer Product VOC in Landfills
(EPA-453/R-94-066-d)	Fate of Consumer Product VOC in Wastewater
(EPA-453/R-94-066-e)	Economic Incentives to Reduce VOC Emissions from Consumer and Commercial Products
(EPA-453/R-94-066-f)	Aerosol Products and Packaging Systems

1.4.2 Contents of the Report to Congress

This Report to Congress contains eight chapters, including this introduction. Chapter 2 presents a summary of findings of the EPA's study of consumer and commercial products and addresses such topics as (1) scope of products covered by §183(e); (2) emission estimates for all categories of products subject to §183(e); (3) the role of consumer and commercial products in the ozone nonattainment problem; (4) control measures and systems of regulation available under §183(e); (5) the regulatory environment surrounding consumer products; and (6) opportunities for emission reductions from regulation of specific categories of consumer products.

Chapter 3 addresses the issue of relative photochemical reactivity as it relates to consumer and commercial products and includes (1) a description of the reactivity-related requirements of §183(e); (2) a discussion of the science of photochemical reactivity; (3) an explanation of the role of relative reactivity in developing ideal ozone control strategies; and (4) methodologies which could be used now, based on the current uncertainties and limitations associated with reactivity, to fulfill the requirements of §183(e).

Chapter 4 presents a detailed discussion of the criteria developed by the EPA for regulating consumer and commercial products under §183(e), describes how the criteria are being used, and lists the considerations on which the EPA will base the selection of categories for regulation.

Chapter 5 through 8 present in-depth summaries of each of the supporting volumes of the consumer and commercial products study. Virtually all the substantive information contained in the five volumes is presented in these summaries. They address the comprehensive emissions inventory (Chapter 5); the fate of VOC in consumer products which are disposed of in landfills or enter the wastewater stream (i.e., are the VOC emitted to the air, or are they changed or otherwise kept from being emitted through some physical or chemical process?). (Chapter 6); economic incentive programs which could be used to reduce VOC emissions from consumer and commercial products (Chapter 7); and aerosol products and packaging systems (Chapter 8).

1.5 REFERENCES

1. U.S. Congress, Office of Technology Assessment, *Catching our Breath: Next Steps for Reducing Urban Ozone*, OTA-O-412, Government Printing Office, Washington, D.C., July 1989.

CHAPTER 2

FINDINGS OF THE CONSUMER AND COMMERCIAL PRODUCTS STUDY

This chapter presents the findings of the EPA's 4-year, comprehensive study of consumer and commercial products. The objectives of this chapter are to (1) present a concise synopsis of the EPA's findings; (2) give the reader an appreciation of the breadth of products considered to be consumer and commercial products; (3) explain the role consumer and commercial products play in the nation's ozone nonattainment problem; (4) list the control measures and systems of regulation authorized under §183(e) to control VOC emissions from these products; (5) describe the current regulatory environment surrounding consumer products; and (6) identify opportunities for VOC reductions which could be obtained through federal regulation of specific categories of consumer products.

2.1 SUMMARY OF FINDINGS

A summary of the EPA's findings is presented below. Each of these findings is supported by the EPA's study of consumer and commercial products. The findings are keyed to other sections of this report to Congress as indicated by numbers appearing at the end of each entry.

- Failure to meet the national health standard for ozone is a persistent problem. Ozone is the least understood of the criteria pollutants and is the most intractable to date. Although some progress has been made through past regulatory efforts, large areas of the country continue to exceed the health-based national ambient air quality standard (NAAQS) for ozone. The extent and complexity of the ozone nonattainment problem has caused attention to be turned toward emission sources beyond the conventional stationary and mobile sources. In addition, such circumstances have led the EPA to consider innovative approaches such as seasonal and market-based strategies to obtain emission reductions. (1.1, 2.2)

- To be the most effective, ozone control strategies ideally should be based not only on mass VOC and NO_x emissions but should consider the relative photochemical reactivity of individual species, the VOC-to-NO_x ratios prevalent in specific airsheds, and other factors which could work together to minimize the formation of ozone with minimum adverse impacts. Reactivity data on VOC, especially those compounds used to formulate consumer and commercial products, is extremely limited. Better data, which can be obtained only at great expense, is needed if the EPA is to consider relative photochemical reactivity in any VOC control strategy. In the meantime, a practical approach is to act on the basis of mass VOC emissions. (3.0)

- Consumer and commercial products, while individually small sources of VOC emissions, contribute significantly to the ozone nonattainment problem. In 1990, consumer and commercial products emitted approximately 3.3 million tons of VOC in ozone nonattainment areas, or about 6 million tons of VOC nationwide. This is approximately 28 percent of all man-made VOC. (2.3, 5.0)

- The scope of consumer and commercial products subject to §183(e) is very broad and includes not only household consumer products but many products used commercially and in industrial manufacturing operations. This vast universe of products ranges from underarm antiperspirants and deodorants to coatings used in the manufacture of automobiles. (1.2, 2.2)

- Partially spent consumer products which are disposed of in landfills eventually release their residual VOC content. Unless the particular landfill has emission controls applied, this VOC ultimately enters the ambient air. The EPA was unable to determine what the extent to which consumer products are disposed of in landfills with controls in place. Consequently, no adjustment to emission estimates could be made for fate of consumer product VOC in landfills. (6.1)

- In many cases, VOC contained in consumer products enter the wastewater stream and are, to varying extents, biodegraded instead of being emitted to the ambient air. For example, ethanol is almost completely biodegraded, while Stoddard solvent undergoes no biodegradation and is emitted to the air. (6.2)

- Opportunities for emission reductions do exist. With regard to consumer products, California and other States have issued regulations which limit the VOC content of approximately two dozen categories of products. These regulations were developed over several years with extensive interaction with the consumer products industry. The EPA has estimated that the VOC content limitations imposed by the California regulations, if applied nationwide, may result in an overall VOC reduction of approximately 25 percent from the 1990 baseline for those categories. (2.6)

- In developing control measures for consumer products, emission reductions must be balanced with product efficacy, consumer acceptance, and consideration of which products are subject to the most cost-effective controls. Reformulation of consumer products may require lead time and expense for research, product development, testing, and regulatory agency approval (Food and Drug Administration, Department of Transportation, Federal Trade Commission, etc.) -- all of which add to the cost of compliance. Accordingly, the EPA recognizes these requirements and will duly consider them at the time of rulemaking. (2.4)

- Consumer education will be essential to successful implementation of control measures for many consumer and commercial products. Education can be employed alone or in combination with other control measures. (2.4)

- Economic incentive programs appear to be viable alternatives to command and control strategies to reduce VOC emissions from consumer and commercial products. Optimal selection of an economic incentive regulatory strategy depends upon the objectives of the program. Certainty of emission reductions, minimization of control and/or implementation costs, technological innovation, and flexibility afforded by the program are all objectives which must be considered in selecting a strategy. Tradeoffs are intrinsic to regulatory policy design. Consequently, the best regulatory strategy for consumer and commercial products depends upon the particular universe of products being regulated and the priority of objectives. (2.4, 7.0)

- A widely held misconception is that most aerosol products employ chlorofluorocarbons (CFC's) as propellants and contribute to stratospheric ozone depletion. In 1978, the EPA banned the use of CFC's in virtually all aerosol products, the exceptions being medical products, military specification products, and aviation products. Hydrocarbons (propane, butane, and isobutane), which are VOC, are currently the predominant propellant compounds. (8.2)

- Aerosol products function as systems composed of the product, the propellant, the valve, and the container. Hydrocarbon propellants not only expel the product from the container but serve as diluents in the product formulation. Consequently, seemingly expeditious measures to reduce VOC content (e.g., changing from an aerosol to a pump spray, switching to a non-VOC compressed gas propellant, etc.) may not achieve the desired VOC reduction. (8.2)

2.2 SCOPE OF PRODUCTS SUBJECT TO §183(e)

In order to comply with the requirements of §183(e), the EPA identified the range of consumer and commercial products to address in the study. Section 183(e) defines "consumer or commercial product" to mean "any substance, product (including paints, coatings, and solvents), or article (including any container or packaging) held by any person, the use, consumption, storage, disposal, destruction, or decomposition of which may result in the release of volatile organic compounds. The term does not include fuels or fuel additives regulated under section 211, or motor vehicles, non-road vehicles, and non-road engines as defined under section 216."

Initially, the EPA considered a narrow interpretation of the statutory definition. According to this interpretation, only household consumer products, including commercial and institutional uses, would be addressed by the study under §183(e). These are the products that are considered by the general public to be "consumer products." They include personal care products, household cleaning products, household pesticides, aerosol spray paints, and other products used in or around homes, offices, schools, etc. Products used in industrial manufacturing operations were not included.

However, the statutory definition and legislative history of the 1990 Amendments indicate that a broader interpretation is warranted. Thus, the EPA currently interprets "consumer or commercial product" to include all VOC-emitting products used in homes, businesses, institutions, and a wide range of industrial manufacturing operations. In addition to "consumer products," the scope of §183(e) includes many "commercial products." These products are generally not used in or around the home, office, or institution, but in industrial applications such as metal degreasing, garment drycleaning, publication printing, roadway paving, shipbuilding and repair, and the manufacture of numerous products including automobiles, fiberglass boats, fabric, large appliances, wood furniture, and many others.

Given the breadth of the statutory definition, there is a need for a clear understanding of what is meant by ". . substance, product . . or article . ." for purposes of identifying target entities for developing emission estimates and for listing categories for regulation. This interpretation is complicated by the fact that products are manufactured using other products and substances. For example, the manufacture of automobiles (products), involves the use of coatings (products). These coatings are manufactured using pigments, resins, solvents, and other ingredients (products). In order to avoid duplicate counting and redundant regulation of consumer and commercial products, only one stage in this process should be associated with the term "product" under §183(e).

In establishing boundaries for the meaning of "product," a key question is, "where along the chain of predecessor products and substances should one go to establish a target entity for regulation under §183(e)?" The following characteristics were developed to aid in identifying consumer and commercial "products" to be included in the scope of §183(e):

- The "product" must be an entity which has definition and is clearly identifiable with regard to the specific function(s) it performs.

- The "product" must be identified in such a manner that it is distinguishable from other products for the purpose of applying the criteria developed pursuant to §183(e). Specifically, a product must be able to be compared with other products with regard to uses, benefits, commercial demand, health and safety functions, nature and magnitude of emissions, cost-effectiveness of controls, and availability of alternative products.

- The "product" must be capable of being evaluated such that a determination of "best available controls" can be made, in the event the product is targeted for regulation.

- The "product" must not be an ingredient of another formulated product. However, a "product" can be something used in the manufacture of an article not considered a "product" under §183(e). For example, a solvent used in the formulation of paint should not be considered a "product," but the paint, when applied to an automobile [not itself a product under §183(e)], should be a "product" within the scope of §183(e).

2.3 ROLE OF CONSUMER AND COMMERCIAL PRODUCTS IN THE OZONE NONATTAINMENT PROBLEM

As stated in §183(e)(2)(A)(i), one of the objectives of the consumer and commercial products study was to "determine their potential to contribute to ozone levels which violate the national ambient air quality standard for ozone." The purpose of this section is to examine how these products collectively contribute to the ozone nonattainment problem. This relationship is dependent on (1) the mass VOC emissions from consumer and commercial products; (2) the relative share of all VOC emissions which can be attributed to these products; and (3) how individual species of VOC emitted from these products participate in the photochemical reactions which result in ozone formation. Each of these topics is discussed below, followed by the EPA's conclusions regarding the role of consumer and commercial products in ozone nonattainment.

2.3.1 Emission Estimates

A major component of the study was development of a comprehensive inventory of emissions from consumer and commercial products. The inventory study is summarized in Chapter 5. The EPA found that VOC emissions from consumer and commercial products in ozone nonattainment areas totalled approximately 3.3 million tons in 1990. Table 2-1 presents emission estimates for the principal categories of consumer and commercial products.

TABLE 2-1

VOC EMISSIONS FROM CONSUMER/COMMERCIAL PRODUCTS IN OZONE NONATTAINMENT AREAS (1990)

Product Category		Emissions Nonattainment Areas (tons/yr)
"Consumer Products" (EPA Survey)		**597,209**
Personal care products	174,115	
Household products	55,095	
Automotive aftermarket products	106,469	
Adhesives and sealants	45,467	
FIFRA products (pesticides, etc.)	121,464	
Coatings & related (except AIM)	89,405	
Remaining products surveyed	5,194	
Architect & Indust Maint (AIM) Coatings		**315,000**
Commercial Adhesives		**230,092**
Tire manufacturing cements	26,400	
Platen adhesives (textile industry)	2,092	
Miscellaneous industrial adhesives	201,600	
Commercial Solvents		**290,323**
Metal cleaning (degreasing) solvents	36,000	
Industrial cleaning (cleanup) solvents	150,000	

Product Category		Emissions Nonattainment Areas (tons/yr)
Petroleum drycleaning solvents	54,600	
Synthetic fiber spinning solvents	46,200	
Textile industry equipment cleaning	68	
Textile industry spot cleaners	848	
Automotive repair - parts washers	2,607	
Commercial Coating Operations		**1,713,300**
Autobody refinishing	55,000	
Aerospace coatings	107,500	
Wood furniture manufacture	60,000	
Ship building and repair	15,100	
Metal furniture coating	63,000	
Flat wood paneling coating	20,000	
Large appliance coating	15,600	
Magnet wire coating	4,800	
Metal can coating	45,000	
Metal coil coating	21,600	
Miscellaneous metal product coating	218,400	
Auto and light truck assembly	75,000	
Paper, film, and foil coating	65,000	
Magnetic tape coating	5,500	
Auto & business machine plastic parts	22,000	
Flexible package printing	150,000	
Rotogravure publication printing	20,000	
Lithographic printing	600,000	
Letterpress printing	28,200	
Fabric coating	21,000	

TABLE 2-1 (Continued)

VOC EMISSIONS FROM CONSUMER/COMMERCIAL PRODUCTS IN OZONE NONATTAINMENT AREAS

Product Category		Emissions Nonattainment Areas (tons/yr)
Fabric printing	25,200	
Mold release agents	75,400	
Commercial Paving and Roofing		**147,285**
Cutback asphalt paving materials	128,400	
Asphalt concrete paving materials	360	
Roofing - built-up	7,126	
Roofing - elastomeric	9,123	
Roofing - modified bitumen	2,276	
Other Products and Activities		**29,721**
Fiberglass boat manufacturing	12,100	
Kerosene space heaters	39	
Camp stoves and lanterns	6	
Artificial fireplace logs	154	
Agricultural pesticide application	15,000	
Commercial explosives	2,422	
TOTAL FOR ALL §183(e) CATEGORIES		**3,322,930**

2.3.2 Consumer and Commercial Product Emissions in Perspective

In order to assess the extent to which consumer and commercial products contribute to ozone nonattainment, the VOC contribution of these products must be put into perspective relative to all man-made sources of VOC emissions. Based on the results of the inventory study, VOC emissions from consumer and commercial products in 1990 were estimated to be 3.6

million tons in ozone nonattainment areas, or about 6 million tons nationwide. This is approximately 28 percent of all man-made VOC emissions. The principal source categories and their mass VOC emissions are presented in Table 2-2.

TABLE 2-2

SOURCES OF VOC EMISSIONS IN 1990 (NATIONWIDE)

Emission Source Category	Nationwide Emissions (tons/yr)	Share of Total (percent)
Mobile Sources (Automobiles, etc.)	7,920,000	36.9
Consumer/Commercial Products	6,000,000	28.0
Petroleum Marketing	2,460,000	11.5
Fuel Combustion (Stationary Sources)	2,300,000	10.7
Forest, Agricultural, and Other Burning	990,000	4.6
Petroleum Refineries	820,000	3.8
Organic Chemicals Manufacturing	550,000	2.6
Industrial Manufacturing	400,000	1.9
TOTAL FOR ALL SOURCES	**21,440,000**	**100.0**

2.3.3 Potential of Consumer and Commercial Products to Contribute to Ozone Nonattainment

Although magnitude of mass VOC emissions is an important consideration, the EPA acknowledges that, ideally, a rigorous determination of the potential of consumer and commercial products to contribute to ozone nonattainment should also consider the propensity of individual ingredients to react photochemically with NO_x in the atmosphere to form ozone. Two possible methods of accounting for photochemical reactivity in making this determination are presented below.

2.3.3.1 *Reactivity Scale Method*

The potential to contribute to ozone nonattainment could be expressed as the amount of ozone formed by VOC emitted from consumer and commercial products relative to the ozone formed by the VOC otherwise present (i.e., how the ambient ozone concentration is affected by addition of VOC from consumer and commercial products). Using the reactivity scale method, this relationship can be expressed mathematically as:

$$CCP\ Ozone\ Potential = \frac{\sum CCP(VOC)_i r_i}{\sum AMB(VOC)_j r_j} \qquad (1)$$

where $CCP(VOC)_i$ and r_i are the weight-fraction and reactivity, respectively, of consumer and commercial product VOC species i, and $AMB(VOC)_j$ and r_j are the weight-fraction and reactivity, respectively, of ambient VOC species j. The reactivity factors r_i and r_j refer to the ozone yield (i.e., the amount of ozone produced per amount of VOC present).

The reactivity scale method is simple but requires that reactivity data exist for every VOC species emitted from consumer and commercial products. Consumer and commercial product VOC emissions, unlike mobile source (automotive) emissions, generally have not been the subject of atmospheric studies. Consequently, existing reactivity data on these compounds are either largely incomplete or uncertain. The method also suffers from uncertainties, mainly in the reactivity data themselves -- the reactivity chemistry for most of these species is not well known -- and in the linearity assumption used in equation (1). Overall, the reactivity scale method, even with adequate data on reactivity, should be viewed as providing only approximate results.[2]

2.3.3.2 *Air Quality Simulation Model Method*

The potential of consumer and commercial products to contribute to ozone nonattainment can also be estimated through air quality simulation model (AQSM) computations of ozone formed in the presence, and in the absence, of the consumer and commercial product VOC, for any set of ambient conditions. Such estimates are clearly more reliable and useful than those derived by the reactivity scale approach presented above. However, they, also, are not without significant uncertainties, and are extremely costly to obtain. Uncertainties lie in the chemistry, dispersion, and emissions components of, or inputs to, the models. To reduce such uncertainties requires costly research, efforts to obtain reliable and complete input data, and field-testing of the models. Finally, for universal use, estimates of these products' potential to contribute to nonattainment should be based on model computations for several "representative" ozone nonattainment urban atmospheres.[2]

2.3.4 EPA's Conclusions Regarding the Role of Consumer and Commercial Products

Because of the uncertainties, inconsistencies, and lack of reactivity data on individual compounds, the EPA concluded that a rigorous determination of the potential of consumer and commercial products to contribute to ozone nonattainment is not possible at this time. In order to fulfill the requirements of the Act, the EPA was forced to make the determination that since consumer and commercial products collectively account for approximately 28 percent of all man-made VOC emissions, they contribute significantly to ozone formation in nonattainment areas.

This approach, while not a robust evaluation of the causal relationship between consumer and commercial product emissions and ozone nonattainment, represents the EPA's best effort, given the uncertainties and inconsistencies of reactivity, to determine the role of consumer and commercial products in ozone nonattainment. If, in the future, sufficient information or new methodologies become available, the EPA may reevaluate this finding.

2.4 CONTROL MEASURES AND SYSTEMS OF REGULATION UNDER §183(e)

Section 183(e) presents specific control measures and systems of regulation to be used by the EPA to reduce VOC emissions from consumer and commercial products. The term, control measures, refers to techniques which are applied to products and/or processes to prevent or reduce emissions. Systems of regulation are various mechanisms by which the appropriate control measures can be implemented. The following sections describe the control measures available to the EPA in regulating consumer and commercial products, the systems of regulation which may be employed to implement these measures, and who may be subject to the regulations.

2.4.1 General Constraints

2.4.1.1 *Regulated Entities*

Regulated entities are those persons on which regulations may be imposed in order to implement the various control measures. Section 183(e)(1)(C) defines regulated entities to be "(i) manufacturers, processors, wholesale distributors, or importers of consumer or commercial products for sale or distribution in interstate commerce in the United States, or (ii) manufacturers, processors, wholesale distributors, or importers that supply the entities listed under clause (i) with such products for sale or distribution in interstate commerce in the United States."

2.4.1.2 *Best Available Controls*

In regulating consumer and commercial products to reduce VOC emissions, the regulations must require best available controls. Section 183(e)(1)(A) defines best available controls to be "the degree of emissions reduction that the Administrator determines, on the basis of technological and economic feasibility, health, environmental, and energy impacts, is achievable through the application of the most effective equipment, measures, processes, methods, systems or techniques, including chemical reformulation, product or feedstock substitution, repackaging and directions for use, consumption, storage, or disposal."

2.4.1.3 *Use of Control Techniques Guidelines*

Under Section 183(e)(3)(C), the EPA may issue control techniques guidelines (CTGs) in lieu of regulations where the Administrator determines that the CTGs will be substantially as effective in reducing VOC emissions in nonattainment areas. In many cases, CTGs can be effective regulatory approaches to reduce emissions of VOC in nonattainment areas -- with the advantage of not imposing control costs on attainment areas, where benefits of reducing VOC emissions may be far less or zero. In the case of, for example, small volume consumer products that are widely used (e.g., personal care products), a CTG might not be effective at reducing VOC emissions because of difficulties in enforcement. However, for other cases (and for a potentially large share of nonattainment area VOC emission sources), enforcement and compliance can effectively be focused at the source of the VOC emissions, be it the point of manufacture, the point of end-use, or both. For example, VOC emissions from commercial products used in industrial settings could be controlled effectively with a CTG that targeted emissions at the point of end-use, as the population of end users is likely to be readily identifiable.

2.4.2 Control Measures

Under §183(e), several control measures are available to EPA in reducing VOC emissions from consumer and commercial products. Although specific measures are listed in the Act, the EPA is not limited to those measures alone.

2.4.2.1 *Reformulation*

Reformulation of consumer and commercial products as a means of reducing VOC emissions involves replacing one or more VOC ingredients with either non-VOC ingredients or VOC ingredients of such low volatility that they have little propensity to enter the ambient air to react to form ozone. Replacement ingredients must be physically and chemically compatible with the remainder of the formulation and must function in a manner similar to the original constituent to maintain product integrity and efficacy. Ingredient interactions can complicate reformulation efforts. For example, replacing a single compound can sometimes affect the performance of other ingredients. Even the order in which ingredients are combined can affect the efficacy of some formulations.

Reformulated products must undergo a series of tests before marketing can be considered. The reformulation process begins by identifying appropriate replacement compounds (in this case, non-VOC or low-volatility compounds). Alternative ingredients are tested for suitability based on efficacy of the product, compatibility with other ingredients, shelf life and stability, feasibility of mass production, and packaging needs. All of these tests, which are considered essential for product development, are done by the formulator and are not required or monitored by any regulatory agency.

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) requires pesticide products to be registered with the EPA. Under FIFRA, a product is defined as a pesticide if it is intended to prevent, destroy, repel, or mitigate any "pest," including any fungus, bacterium, virus, or other microorganism found on inanimate surfaces. Consumer and commercial products that claim to be antimicrobials (e.g., disinfectants, sterilants, etc.) are also considered to be pesticides, and are therefore subject to FIFRA registration. Under FIFRA, formulators of pesticides are required to demonstrate that the product does not cause "unreasonable adverse effects on the environment." Reformulation of a FIFRA-registered product would therefore require registration of the new product.

Consumer products may also be regulated by the Food and Drug Administration (FDA). The FDA has specific requirements which apply to products classified as cosmetics and over-the-counter (OTC) drugs. The OTC drugs must comply with a monograph issued as part of the FDA's *Over the Counter Drug Review* or be subject to a new drug application (NDA). Because the NDA process is extremely time and resource intensive, compliance with the FDA monograph is the more practical means of meeting the FDA requirements. The monograph defines those ingredients which are safe and effective for use in personal care products classified as OTC drugs (e.g., underarm antiperspirants). The FDA requires that each OTC drug active ingredient meet monograph specifications and compendial specifications, and that each active and inactive ingredient must be safe, not interfere with product efficacy, meet compendial specifications, and comply with color additive requirements. Furthermore, each final product formulation must meet monograph effectiveness requirements.

Also subject to FDA regulation are cosmetics. Cosmetics are not required to undergo premarket approval by the FDA. However, the law requires that the manufacturer of a cosmetic product ensure that the safety of each ingredient, as well as the final product formulation, is substantiated prior to marketing. Furthermore, if the product contains color additives, each such ingredient must be the subject of an existing FDA color additive regulation approving the use of the ingredient. The FDA has authority to seize or enjoin the sale of any product that does not comply with these requirements. Although the manufacturer of a cosmetic bears much of the responsibility for ensuring safety, a change in formulation necessitates a lengthy and expensive process of safety evaluation that is very similar to that required by FDA for an OTC drug.

In developing regulations for consumer and commercial products, the EPA will consider the additional regulatory requirements which may be triggered by product reformulation.

2.4.2.2 *Product Substitution*

Product substitution is a control measure that involves replacement of existing products or processes with available substitutes which result in reduced VOC emissions. Within the context of §183(e), product substitution implies moving from one product to a different product, process, or application method. An example of product substitution would be replacement of an aerosol spray paint with a brush-on paint. Substitution may or may not be a more onerous control measure than reformulation, depending on whether there would be plant closures, layoffs, or other adverse impacts resulting from the prohibition of a product or process.

2.4.2.3 *Repackaging*

Product repackaging is listed as one of the control measures available to the EPA in reducing emissions from consumer and commercial products. Repackaging is the placement of an existing product (i.e., the product formulation would not be changed in any way) into packaging designed such that spillage, leakage, and evaporation are minimized. An example of repackaging would be replacement of a screw cap container for a cleaning solvent with a squeeze bottle or other dispenser which would help prevent spillage if the container is upset, and would minimize evaporation of the solvent while the container is open. Repackaging alone would not necessitate reformulation of the product.

2.4.2.4 *Directions for Use, Consumption, Storage, and Disposal*

This measure consists of providing the users of the products specific directions for handling, using, and disposing of the products in a responsible manner. This technique could be employed to reduce VOC emissions from the use, consumption, storage, and disposal of high-VOC products for which there are no lower-VOC alternatives (e.g., paint thinners, cleaning solvents, rubbing alcohol, etc.). Although it would be impossible to predict the VOC reductions achieved by providing the consumer with directions for use, consumption, storage, and disposal of a product, this approach could result in some degree of reduction, especially in the case of high-volume, high-VOC products.

An extension of this control measure would be consumer education. Education concerning the use of consumer and commercial products may be an important and necessary adjunct to reformulation, product substitution, repackaging, and directions for use, consumption, storage, and disposal. Because of the inability to control consumer use, handling, and disposal patterns once the product is purchased, lack of awareness on the part of consumers can result in unnecessary or excessive use of some VOC-containing products. Education that informs and influences consumers to practice low-VOC emission measures, including informed selection and proper use, handling, and disposal of consumer and commercial products, is essential as a control in itself and in conjunction with other control measures to augment their effectiveness. This measure could be implemented through product labeling, via public information media, and/or by dissemination of information to other federal agencies and State and local agencies involved with consumer product safety, recycling, waste disposal, etc.

2.4.3 Systems of Regulation

Section 183(e) gives the EPA a choice of systems of regulation which could be used to implement the various control measures. These approaches range from product registration to product prohibition. Economic incentives are also available and could be used alone or in conjunction with other approaches and may provide flexibility while promoting development of lower-VOC-emitting products and/or processes.

2.4.3.1 *Product Registration and Labeling*

Product registration consists of companies providing information to the appropriate regulatory agency concerning the products manufactured or marketed by the companies. This information could range from merely the names of the products and manufacturers to information on the product formulations, VOC content, and quantity produced. Registration could enable regulatory agencies to identify the vast universe of manufacturers, processors, and distributors subject to a specific rule and would facilitate compliance assurance. Another application of registration would be to provide the regulatory agencies with information which could be used to establish baseline VOC allocations which could then be used in the implementation of an economic incentive regulatory approach.

Product labeling is one approach to implementing the control measure described as "directions for use, consumption, storage, and disposal" of products. Reductions could be brought about in two ways: (1) product labeling which allows the consumer to make environmentally informed purchasing decisions; and (2) product labeling which includes instructions for use, consumption, storage, and disposal of the product in a manner which would minimize VOC emissions.

Product labeling has been demonstrated to be an effective means of affecting the environmental purchasing decisions of consumers. A national survey conducted in 1989 by the Gallup Organization found that 96 percent of women and 92 percent of men said they would make a special effort to buy products from companies trying to protect the environment. Eighty-seven percent of consumers have also stated they were willing to spend 5 to 15 percent more for environmentally preferable products or packaging.

Environmental labeling has already been employed by some manufacturers to promote the sale of their products. This "green labeling," however, sometimes tends to mislead the consumer regarding the true environmental impacts of products. Consequently, the Federal Trade Commission (FTC) continues to monitor "green labeling" activities and is developing specific guidance on permissible labeling practices. Accordingly, any rulemaking requiring or allowing environmental labeling should be carried out with close coordination with the FTC.

2.4.3.2 *Self-Monitoring and Reporting*

Successful implementation of any control measure requires some degree of compliance assurance. Because of the vast array of products and regulated entities potentially subject to §183(e), self-monitoring and reporting by the manufacturers, processors, and/or distributors of the products may be an effective means of establishing baselines and tracking compliance. This approach could be complemented by compliance checks and/or audits performed by the enforcing authorities.

The primary objective of self-monitoring is to make available any information necessary to determine compliance with an implemented control measure. Self-monitoring in the context of §183(e) could consist of the regulated entities keeping records of product formulations, quantities of products sold, types and amounts of feedstocks purchased, names of suppliers and/or downstream distributors supplied, or combinations of these or other types of information. The collected information could be accessed by the enforcing agency through requirements for self-reporting and/or through on-site compliance audits.

In the context of §183(e), reporting could involve submission of information concerning the identity of a regulated entity, information collected through self-monitoring, or any information held by a regulated entity which would facilitate compliance assurance. For example, the most elementary form of reporting would be a requirement for all parties subject to a particular rule to identity themselves as regulated entities. A more substantive requirement would be for each regulated entity to report annual sales and formulations for each product subject to a rule. The content and frequency of required reports would be based on the enforcement considerations associated with a specific rule.

Because self-monitoring and reporting requirements would require expenditure of time and resources on the part of the regulated entities, this approach should be applied judiciously. The burden imposed on the regulated community should be considered carefully. On the other hand, certainty of compliance and government resources required for enforcement activities are also valid considerations. Consequently, successful implementation of any control measure must be based on consideration of enforcement needs, certainty of compliance, cost to the government, and burden imposed on the regulated entities.

2.4.3.3 *Prohibitions*

Prohibition of certain high-VOC products could also be adopted as a means of reducing VOC emissions. Because prohibition may have more severe adverse economic impacts than other systems of regulation, prohibition of individual products, product types, or product forms should be considered only after other approaches have been exhausted.

2.4.3.4 *Limitations*

Many existing regulations affecting consumer and commercial products are based on VOC content limits. For example, coatings are generally limited to a certain number of grams VOC per liter of coating. Most consumer product regulations promulgated by the States impose specific limits for percent VOC content by weight.

2.4.3.5 *Economic Incentives*

Economic incentives are listed among the systems of regulation available under §183(e). Specifically mentioned are marketable permits and auctions of emission rights. In some cases, economic incentive programs may be superior to VOC content limitations as strategies to reduce emissions from consumer and commercial products. In other situations, a combination of VOC content limitations and economic incentive approaches may provide significant advantages.

The optimal selection of a regulatory strategy depends on the specific characteristics of the universe of sources being regulated. Potential abatement cost savings, administrative and monitoring costs, and distributional implications of employing economic incentive strategies to regulate different consumer and commercial product industries may vary significantly.

Selection of a regulatory strategy also depends upon the program's objectives. For example, to stimulate technological advancement, a marketable permit program using auctions may be preferable. Alternatively, if distributional considerations are important, a permit program with freely granted permits, or perhaps a fee program with rebates, might be preferable. Similarly, if certainty of emission reductions is a primary objective, (especially if product efficacy problems exist), marketable permit programs may be preferable, but might be an undesirable approach if protecting consumers from potential future product price increases is a primary goal.

Emission fee programs can be used to obtain real and quantifiable reductions in the emissions of VOC from consumer and commercial products. The basic rationale for these programs (and economic incentive programs in general) is to bring the full "social cost" of using VOC into the economic system. A fee on the emission of VOC would increase the cost of using the atmosphere as a waste sink. The fee would have the same effect as the prices for the goods and services exchanged in conventional markets: for example, manufacturers would economize on their use of VOC because the "price" of using VOC would be higher, just as they would economize on the use of labor if wage rates were to increase. Such a fee system would act as an incentive for manufacturers to reduce the VOC content of products. This is one of several economic incentive approaches that may be used under §183(e).

Designing a fee program to reduce VOC emissions from consumer and commercial products presents many choices. Many of these design options are summarized in Chapter 7. Tradeoffs are intrinsic to regulatory policy design. The best regulatory strategy for consumer and commercial products depends upon the particular universe of products being regulated and the priority of objectives. The EPA will weigh the desirability of economic incentive approaches in the context of individual rulemakings, in light of public comments and consultation with interested parties.

2.5 REGULATORY ENVIRONMENT SURROUNDING CONSUMER PRODUCTS

Household consumer products as sources of VOC emissions have been subject to increasing scrutiny over the past several years. This is due primarily to the intractability of the ozone nonattainment problem, and the resulting need to focus attention on even the least of VOC emission sources. Consumer products are recognized as a potential source of emission reductions by not only the Clean Air Act Amendments of 1990 but by several State and local air pollution agencies.

2.5.1 The Clean Air Act Amendments of 1990 -- Rate of Progress Requirements

The Act, as amended November 1990, classifies areas that exceed national health-based air quality standards based on the severity of their pollution problem. Specifically, §182(b) prescribes increasingly stringent measures that must be implemented and sets deadlines for achieving the standards. The Act also establishes specific interim emission reduction requirements to ensure than progress toward attainment is sustained. By November 15, 1993, each area of the country designated as moderate or above for ozone nonattainment was required to submit to the EPA an implementation plan demonstrating how VOC emissions will be reduced by 15 percent (from the 1990 baseline) by November 1996. Areas which fail to submit or implement an approvable plan within the applicable time frame are subject to sanctions in the form of withheld federal highway funds or requirements for new industrial sources to offset emissions. Currently, there are 55 areas across the country which are classified as moderate or above for ozone nonattainment and, therefore, are subject to the 15 percent rate of progress requirement.

This requirement of the Act has prompted State and local agencies to seek out VOC emission reductions beyond those which have been obtained through regulation of the conventional mobile and stationary sources of emissions. Consequently, consumer products are being targeted for regulation by State and local air pollution authorities.

2.5.2 State and Local Regulation of Consumer Products

Several State and local agencies have adopted rules to regulate various consumer products. New York's first consumer products rule, 6 NYCCR 235, covering consumer insecticides, air fresheners, and disinfectants, was adopted in September 1988. Subsequently, New York adopted a regulation to limit the VOC content of antiperspirants, deodorants, and hair sprays. Since the late 1980's, Texas has limited the VOC content of windshield washer fluids in Dallas and Tarrant Counties; other areas of Texas have recently become subject to that rule.

Because of the severity of its ozone nonattainment problem, California has led the nation in the move to reduce VOC emissions from consumer products. The California Air Resources Board (CARB) adopted its regulation for antiperspirants and deodorants in 1990, and has expanded the consumer products program to include regulations which now cover 27 categories of products. California's South Coast Air Quality Management District (SCAQMD) and Bay Area Air Quality Management District (BAAQMD) have implemented local rules for charcoal lighter fluids and aerosol spray paints, respectively. The SCAQMD charcoal lighter fluid emission standard and test method are used in the CARB rule. Currently, CARB is nearing completion of an aerosol spray paints rule.

The Clean Air Act rate of progress requirements have caused several other States to adopt or begin development of consumer products rules. In September 1993, the State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO) published a guidance document entitled *Meeting the 15-Percent Rate-of-Progress Requirement Under the Clean Air Act: A Menu of Options* to enable the State and local agencies to develop regulatory programs to meet the November 1996 rate of progress milestone. Included in the document are chapters covering consumer products and aerosol spray paints. The STAPPA/ALAPCO recommendations for VOC standards for consumer products are based on the CARB regulations. The spray paint recommendations are based on the BAAQMD rule.

Generally, the CARB rule, as presented in the STAPPA/ALAPCO guidance, has been used as a model by other States in developing their own rules. As of December 1994, States which had adopted or were in the process of developing consumer products regulations included Arizona, Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Texas, and Wisconsin.

2.6 SPECIAL CONSIDERATIONS CONCERNING CONSUMER PRODUCTS

States have moved to develop rules because consumer products as a group contribute significantly to the unhealthy levels of ozone pollution that exist in many parts of the country. In response, industry representatives have urged the EPA to issue national rules limiting VOC content in many consumer products. Consumer products are used in every household, business, and institution in the country. Adoption of a multitude of individual State and local regulations for consumer products, each of which potentially having different applicability, content limits, labeling, reporting requirements and other features, could prove very disruptive to the national distribution network for consumer products.

Prompted by these considerations, the EPA calculated projected emission reductions that may be achievable through federal regulation of consumer products. In the near future, the EPA will decide whether to include consumer products in its list and schedule for regulations to be published pursuant to §183(e) of the Act. If a federal consumer products rule is to be of use to the States in meeting their 15 percent rate of progress demonstrations, the rule would have to be promulgated and in effect (i.e., reductions must be made) no later than November 15, 1996.

In order to develop an estimate of VOC emission reductions which may be obtained through implementation of a federal rule for consumer products, determinations must be made on (1) which product categories might be included in a rule which could be effective by November 1996; and (2) VOC content limitations for the respective categories covered by the rule. As an example, the EPA estimated the effectiveness of extending existing State consumer product rules to nationwide applicability.

For purposes of this demonstration, the product categories selected for inclusion are based on the STAPPA/ALAPCO guidance (i.e., the CARB rule) and include only those categories for which the CARB standards will be effective by November 1996. Nationwide emission reductions were estimated for the product categories covered by the CARB rule by using the 1990 formulation and sales data collected through the EPA's consumer products survey (discussed in Section 5.1) combined with the VOC content limits listed in CARB's table of standards. For each product category covered by the survey, the distribution of product sales (tons of product) versus VOC content (percent VOC) was plotted on a histogram. Emissions were corrected for fate in wastewater and percent market share captured by the survey as explained in Section 5.3. For two categories (floor polishes and waxes, and household adhesives), estimates of emission reductions could not be made because of either inconsistencies in categorization between the CARB rule and the EPA survey data or limitations of the histograms. In one case (charcoal lighter materials), the CARB rule is based on an emission standard (mass of VOC emitted per start) rather than a VOC content limitation.

The first step in performing the emission reduction calculation was to determine each category's nationwide baseline emissions from the survey data. Then, using the histogram, all products in that category with VOC contents above the standard were moved into compliance (i.e., product tonnage was multiplied by the content standard) to yield a new emission estimate. Products originally at or below the CARB standard were not moved up to the limit; only noncomplying products were changed.

After applying the above procedure to the 21 categories which could be assessed, emission reductions were estimated to range from zero percent (for nonaerosol antiperspirants and deodorants) to 73 percent (for lawn and garden insecticides). The overall, weighted average reduction was approximately 25 percent. (For the purpose of making a preliminary estimate of the effectiveness of a federal rule, a similar overall percent reduction for the remaining five categories was assumed.) As a result, annual nationwide emission reductions through implementation of a hypothetical federal rule covering all 24 categories was estimated to be approximately 121,000 tons per year, or about one pound per capita (based on a 1990 U.S. population of 248 million). Table 2-3 presents the results of this assessment.

2.7 REFERENCES

1. U.S. EPA Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, *Alternative Control Techniques - Control Techniques for Volatile Organic Compound Emissions from Stationary Sources* (EPA-453/R-92-018), December 1992.

2. Dimitriades, B., *Scientific Bases of the VOC Reactivity Issues Raised by Section 183(e) of the Clean Air Act Amendments of 1990*, U.S. Environmental Protection Agency, Office of Research and Development, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina, 1994.

TABLE 2-3

ESTIMATED EMISSION REDUCTIONS FROM CONSUMER PRODUCTS

Product Category	VOC Limit (percent)	Baseline Emissions (tons/yr)	Controlled Emissions (tons/yr)	Emission Reduction (tons/yr)	Emission Reduction (percent)
Aerosol Cooking Sprays	18	2,720	1,768	952	35
Air Fresheners [1] (single phase)	70	8,078	6,139	1,939	24
(double phase)	30	12,372	10,764	1,608	13
(liq. & pumps)	18	8,029	8,029	0	0
(sol. & gels)	3	397	151	246	62
Auto Windshield Washer Fluids [2]	10, 35(cold)	80,522	53,145	27,377	34
Bathroom and Tile Cleaners [3]	5, 7(aero)	1,356	949	407	30
Carburetor and Choke Cleaners	75	5,873	4,522	1,351	23
Charcoal Lighter Materials [4]	see note	3,961	2,971	990	25 *
Dusting Aids (aerosols)	35	345	169	176	51
(other forms)	7	276	185	91	33
Engine Degreasers [5]	75	2,860	2,317	543	19
Fabric Protectants	75	1,097	878	219	20
Floor Polishes and Waxes [6]		3,860	2,895	965	25 *
(Flexible)	7				
(Nonresilient)	10				
(Wood)	90				
Furniture Maintenance Products	25	3,585	3,083	502	14
General Purpose Cleaners	10	1,413	579	834	59
Glass Cleaners [7]	8, 12(aero)	15,461	6,648	8,813	57
Hair Sprays	80	179,613	150,875	28,738	16
Hair Mousses	16	2,421	1,743	678	28
Hair Styling Gels	6	622	174	448	72

TABLE 2-3 (Continued)
ESTIMATED EMISSION REDUCTIONS FROM CONSUMER PRODUCTS

Product Category	VOC Limit (percent)	Baseline Emissions (tons/yr)	Controlled Emissions (tons/yr)	Emission Reduction (tons/yr)	Emission Reduction (percent)
Household Adhesives [8]		67,608	50,706	16,902	25 *
(aerosol)	75				
(contact)	80				
(constr/panel)	40				
(gen purpose)	10				
Insecticides (crawling bug)	40	17,179	7,215	9,964	58
(flea and tick)	25	3,739	1,196	2,543	68
(flying bug)	35	5,753	2,646	3,107	54
(foggers)	45	3,663	2,234	1,429	39
(lawn/garden)	20	8,799	2,376	6,423	73
Laundry Prewash (aer & solid)	22	529	354	175	33
(other forms)	5	337	337	0	0
Laundry Starch Products	5	6,033	3,740	2,293	38
Nail Polish Removers [9]	85	6,287	5,595	692	11
Oven Cleaners [10]	5, 8(aero)	1,825	1,022	803	44
Shaving Creams	5	95	60	35	37
Underarm Antiperspirant [11] (aero)	60	5,456	5,347	109	2
(others)	0	18,264	18,264	0	0
Underarm Deodorant [11] (aero)	20	1,364	1,146	218	16
(others)	0	4,566	4,566	0	0
ALL CATEGORIES		**486,358**	**364,788**	**121,570**	**25**

* These categories were assessed assuming a reduction of 25 percent based on reduction calculations for the remaining categories. See text for explanation.

Footnotes continue on the following page.

TABLE 2-3 (Continued)
ESTIMATED EMISSION REDUCTIONS FROM CONSUMER PRODUCTS

1. Air fresheners category does not include toilet deodorant blocks.

   Current CARB standard for single-phase air fresheners is 70 percent; standard is reduced to 30 percent 1/1/96, but reductions were calculated based on 70 percent limit.

2. Windshield washer emission reduction estimate was calculated assuming that half of the products are formulated for "cold" areas or seasons. Either a geographic or seasonal applicability provision would need to be developed.

3. Bathroom and tile cleaners histogram does not specify product form.

4. The CARB charcoal lighter emission standard is 0.020 pounds VOC per start, based on test method specified in South Coast Air Quality Management District Rule 1174, February 27, 1991. No estimate of emission reductions was made.

5. Current CARB engine degreaser current standard is 75 percent. This limit is reduced to 50 percent 1/1/96, but reductions were calculated based on 75 percent standard.

6. EPA survey data on floor waxes and polishes is not separated by type of flooring. No estimate of reductions was made.

7. Glass cleaners histogram does not specify product form. CARB standard for nonaerosol glass cleaners is reduced to 6 percent 1/1/96, but reductions were calculated based on currently effective 8 percent limit.

8. EPA survey data on adhesives is separated into 10 categories which do not correspond with CARB categories. No estimate of reductions was made.

9. Current CARB standard is 85 percent. Standard is reduced to 75 percent effective 1/1/96, but calculation was based on 85 percent. Acetone, the principal ingredient, is currently being considered by EPA for exemption from the VOC definition.

10. Oven cleaners histogram does not specify product form.

11. The CARB standards for underarm antiperspirants and deodorants refer to content of "high volatility organic compounds" (i.e., those VOC with a vapor pressure of greater than 80 millimeters of mercury (mmHg) at 20°C). Because aerosol propellants are the only ingredients of these products with such high vapor pressures, this measure is, in effect, a limitation on the propellant content of the products.

CHAPTER 3

PHOTOCHEMICAL REACTIVITY

Section 183(e) of the 1990 Amendments requires the EPA develop a control strategy for VOC emissions from consumer and commercial products, taking into account the photochemical reactivities of such emissions. Specifically, the Administrator is required to (1) determine the potential of VOC emissions from consumer and commercial products to contribute to ozone levels which violate the NAAQS for ozone; (2) consider those products which emit "highly reactive" species of VOC; and (3) list those consumer and commercial products that account for at least 80% of the VOC emissions on a "reactivity-adjusted" basis in ozone nonattainment areas. To meet these requirements, the Administrator must have either appropriate, quantitative data on the ozone-forming potentials, commonly referred to as "reactivities," of all VOC emission species associated with consumer and commercial products, or some other method for characterizing the impact of such VOC emissions on ambient ozone. Such data and methods currently exist but are known to have uncertainties and other limitations.

The purpose of this chapter is to present, explain, and discuss the validity, uncertainties, and overall utility of existing reactivity data and methods in relation to the requirements of §183(e). This chapter first discusses the chemistry underlying the reactivity property of VOC. Limitations of existing reactivity data and the use of such data are discussed, including those related to the reactivity concept itself, and those associated with experimental error. Finally, different existing and proposed VOC reactivity classification schemes and reactivity estimation methods are described and discussed with respect to their relative usefulness in meeting the requirements of §183(e).

This discussion, which is simplified to the greatest extent possible, is intended to present the EPA's understanding of the current science in as readable a way as possible for the benefit of those interested in the reactivity issues related specifically to consumer and commercial products. Therefore, the emphasis is on pertinent conclusions and on uncertainties inherent in the scientific evidence underlining those issues, rather than on in-depth and comprehensive description of the "reactivity" science. This results in occasional simplifications of scientific concepts.

3.1 *THE CHEMISTRY OF "REACTIVITY"*

In the presence of oxygen (O_2), and with the stimulus of sunlight radiation, nitrogen oxides ($NO+NO_2$ or NO_x) react in the atmosphere to form ozone (O_3) and nitric oxide (NO)[1] through reactions (1) and (2) below. Resultant ozone, however, is rapidly destroyed by reacting with NO and converting it back to NO_2, reaction (3). Sources of NO_x include combustion associated with stationary sources (e.g., power plants) and mobile sources (e.g., automobiles).

$$NO_2 + \text{sunlight} \rightarrow NO + O \qquad (1)$$

$$O + O_2 \rightarrow O_3 \qquad (2)$$

$$O_3 + NO \rightarrow NO_2 \qquad (3)$$

Ozone, therefore, cannot be accumulated in the atmosphere unless NO is converted back to NO_2 through some other process. Such a process exists, and occurs when VOC pollutants are present. In the presence of VOC, NO is converted into NO_2 through the chain reaction process shown below[1], where "η" is the number of NO_2 molecules formed for each VOC molecule consumed in reaction (3).

$$\text{ubiquitous OH radicals} + \text{VOC} \rightarrow RO_2 \text{ radicals} \qquad (4)[1]$$

$$RO_2 \xrightarrow[\text{(step 1)}]{NO} NO_2 + R'O_2 \xrightarrow[\text{(step 2)}]{NO} \ldots\ldots \xrightarrow[\text{(step } \eta)]{NO} \eta NO_2 + OH + \text{products} \qquad (5)$$

The ultimate amount of accumulated ozone depends on the nature and concentration of VOC present and the concentration of NO_x. In VOC-deficient and NO_x-rich atmospheres ozone formation is inhibited by NO_x due to ozone- and radical-scavenging reactions [mainly reactions (3) and (6)], and very little ozone ultimately accumulates. Ozone formation is favored in VOC-rich atmospheres where the η molecules of NO_2 could result in as many as η molecules of ozone.

$$NO_2 + OH \rightarrow HNO_3 \qquad (6)$$

Different VOC species have different ozone-forming potentials or reactivities[2] for four reasons:

(a) their **kinetic reactivities** differ, that is, the rates, k_{OH}, at which they react in the atmosphere [reaction (4)] differ (see footnote 1);

(b) their **mechanistic reactivities** differ, that is, the amounts of NO_2 (and consequent amounts of ozone) they yield through reaction (5) [and follow-up reactions (1) and (2)] differ;

(c) they increase or reduce the ambient OH pool to different degrees, thus causing the other VOC present in air to participate more or less vigorously in the ozone-forming process; and

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[1] Besides the reaction with OH, some VOCs are consumed also, to widely varying degrees, through photolysis and reactions with O_3, O-atoms, and NO_3 -- processes which also result in RO_2 radicals. The propensity of a VOC species for such reactions is often referred to as "kinetic reactivity". However, for the bulk of the VOC species encountered in polluted atmospheres, the reaction with OH is the main RO_2-producing process, and, for this reason, the term "kinetic reactivity" is used here to denote the rate of reaction, K_{OH}, for reaction (4).

(d) they deplete the reaction system of the NO_x reactant to different degrees.

Mechanistic reactivity refers to the amount of ozone produced through reaction of a given amount of a VOC species (i.e., the yield). Many VOC species, such as long carbon-chain compounds, benzaldehyde, phenol, and others, react relatively fast with HO radicals, but are of low mechanistic reactivity. Others, such as C_4 - C_6 paraffins are of relatively low kinetic reactivity but produce NO_2, and potentially ozone also, in high yields. Olefins, polyalkyl-substituted benzenes, and aliphatic aldehydes are highly reactive in both respects. Low reactivity VOC can still be significant ozone producers if they occur at high concentrations, and under favorable conditions [e.g., carbon monoxide (CO)].

The kinetic reactivity of a VOC species (i.e., the rate of reaction) is an intrinsic property of the molecule, unaffected by other pollutants in the atmosphere. In contrast, the mechanistic reactivity, and, ultimately, the ozone-forming potential of a VOC species is strongly influenced also by other VOC and the VOC-to-NO_x ratio in ambient air, and other conditions.[2] In general, conditions that affect the influence of the VOC factor in the ozone-forming process also affect the mechanistic reactivities and, ultimately, the ozone-producing potentials of VOC. Specifically, lower VOC-to-NO_x ratios and lower-reactivity ambient VOC mixtures tend to enhance a given VOC species' ozone-forming potential. These effects have two significant implications:

(1) The concept of VOC reactivity has practical utility only in VOC-limited atmospheres, that is, in atmospheres in which the influence of the VOC factor on the ozone-forming process is stronger than that of the NO_x factor, and for which atmospheres, therefore, VOC control is the optimum approach to ozone reduction. Such atmospheres are, for example, those above the center-city sections of most urban areas. In VOC-rich atmospheres, the application of reactivity, or any other VOC control measure, will be less effective than NO_x control. VOC-rich atmospheres are, for example, those within "aged" urban plumes, depleted of NO_x, and atmospheres above densely vegetated urban areas.

(2) The ozone-forming potentials of VOC species vary, both absolutely and relative to each other, with ambient conditions. Thus, reactivity-related VOC-control measures cannot be expected to have the same impacts in all atmospheres. This is a limitation of the reactivity concept, but not necessarily a prohibitive one. This is because, for atmospheres for which VOC control is the optimum approach to ozone reduction, the *effect of variation of* ambient conditions on reactivity is small compared to the reactivity differences among different VOC species.

3.2 THE MEASUREMENT OF REACTIVITY

In early studies, gross measures of reactivity of VOC were obtained through smog chamber tests in which the various VOC species were tested individually under irradiation conditions simulating a single solar day.[3] Such reactivity data presently exist for a significant number of VOC species. Later developments led to the requirement to test a VOC species more realistically, that is, in the presence of an "urban VOC mix", and under irradiation conditions simulating both single-day and multi-day transport of pollutants in the atmosphere. Such smog chamber tests generally provide reasonably reliable and useful data, but are tedious, costly, and unreliable for low reactivity VOC. For these reasons, only very few VOC have been tested to date in this fashion. Furthermore, complete reactivity characterization of a VOC species requires several smog chamber tests covering the range of VOC-to-NO_x ratios, VOC composition, and radiation conditions occurring in the various nonattainment atmospheres.

These difficulties and requirements led to development of what is referred to as the "k_{OH} method"[4], a method now normally used for identifying negligibly reactive VOC, and the "Incremental Reactivity" (IR) method[5], more appropriate for rating reactive VOC. The "k_{OH} method" entails experimental measurement of the rate at which the VOC is consumed in reaction with OH. The method is commonly used for measurement of a VOC's reactivity relative to that of a reference VOC species. In this method, it is assumed -- not always a valid assumption, as explained later -- that k_{OH} is an indicator of the VOC species' ozone-forming potential. The IR method entails laboratory studies of the VOC species to derive a mechanistic model describing the species' atmospheric chemistry, and the use of a computer model to compute an estimate of the species' contribution to ambient ozone for any set of atmospheric conditions.

Of the two recent reactivity measurement methods, the k_{OH} method entails measurement of K_{OH} that can be made very accurately. The method's accuracy, however, with respect to determining the effect of VOC on ambient ozone is limited due to the fact that k_{OH} does not reflect ozone potential for all VOC. Specifically, long carbon-chain VOC, some aromatic oxygenates, and hydroxylamines have relatively high k_{OH} values but disproportionately low, even negative, ozone-forming potentials. The IR method is conceptually more valid in this latter respect, but it also has its drawbacks. Specifically, the accuracy of the IR method, first, depends on how well the atmospheric chemistry of the VOC is known. Such chemistry has been judged by University of California at Riverside (UCR) experimentalists to be relatively well known for only 13 VOC -- out of some 328 species or groups of species considered.[6] In addition to the chemistry uncertainties, the IR data suffer also from a conceptual uncertainty arising from the fact that ambient conditions affect absolute and relative incremental reactivities. To illustrate this latter effect, "Maximum Incremental Reactivities" (MIR), derived by UCR for generally low VOC-to-NO_x ratio conditions, were compared with "Maximum Ozone (yield) Incremental Reactivities" (MOIR), derived for generally higher ratio conditions. Results showed that the MIR and MOIR values correlate well but not without significant scatter. It should be stressed, however, that this conceptual uncertainty of the IR method, first, as already mentioned, is not of serious consequence, and, second, it arises from the chemistry of the ozone process, and, hence, affects all methods for measuring ozone-potential reactivities.

Given these relative strengths and limitations of the k_{OH} and IR reactivity methods, it is of interest to know how data by the two methods compare. Such a comparison indicates some correlation but with a large amount of scatter. It should be noted here that Carter's IR data compared well with ozone-potential data computed through use of photochemical grid models.[7] The overall judgment adopted here, and favored by some (McNair)[7] -- but not all (Jeffries & Crouse)[8] -- experts, is in favor of the IR data, mainly because such data provide the most appropriate means for quantifying the effect of VOC on ambient, episodic ozone through use of reactivity methods. The need, however, for continuing research to obtain more reliable MIR data for VOC emitted from consumer and commercial products is, clearly, an important and urgent one.

The protocol presently favored -- but not officially endorsed -- by EPA for reactivity testing of a VOC species, calls, first, for a measurement of the species' k_{OH} reactivity relative to that of ethane -- a species whose reactivity, as explained below, is unofficially used by EPA as the borderline separating reactive from negligibly reactive organics. If such reactivity is found to be equal to or lower than that of ethane on a per-gram-of-VOC basis[2], and there are no other VOC-loss reactions, it is concluded that the VOC species can only have negligible O_3 potential, and no further testing is required. If its k_{OH}-reactivity is greater than that of ethane, then the EPA will assume the VOC species to be reactive unless other evidence is obtained that shows lower ozone- potential relative to ethane. k_{OH}-reactivity data have been obtained or estimated for nearly all VOC species of interest.[6,9] Incremental Reactivity data have been obtained, estimated, or surmised by UCR researchers for some 328 VOC species or groups of species.[6] IR data were also compiled by Hartwell Laboratory investigators in England[10], and by the Swedish Environmental Research Institute.[11] These European data, however, were derived for northern Europe conditions, and, therefore,are less appropriate for use in the U.S..

3.3 REACTIVITY SCALES

Of the various reactivity scales used or proposed in the past, EPA adopted first, in 1977, a three-class scale ("negligibly reactive", "low-reactive", "reactive")[12], and later the two-class scale ("negligibly reactive", "reactive") implied by the "VOC" definition put into effect in 1992.[13] In both cases, "negligibly reactive" VOC are certain listed species judged by EPA -- based mainly on smog chamber and/or k_{OH} data -- to have insignificant ozone-forming potentials. "Reactive VOC" are all those judged to be clearly more reactive than ethane -- the most reactive member of the "negligibly reactives" class. Finally, "low-reactive" VOC are all those of borderline reactivity, i.e., those for which existing data do not clearly support inclusion in either the class of negligibly reactive or the class of reactive VOC. These group-reactivity scales are practical, but their usefulness is severely limited by the inherent assumption that all species within the class of "reactives" are of equal reactivity when, in fact, their reactivities differ by more than an order of magnitude.

In contrast to those first reactivity scales, the more recent k_{OH} and IR scales entail very little grouping of VOC, i.e., the various VOC species are assigned reactivity ratings mostly individually. Assuming that these ratings are accurate, this is yet another advantage of the k_{OH} and IR scales over the earlier scales.

3.4 APPROACHES TO DEVELOPING REACTIVITY-BASED CONTROL STRATEGIES

There are two proposed approaches to developing reactivity-based control strategies: through use of reactivity scales such as those described above, and through application of an air

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[2] Comparison of VOC species reactivities to that of ethane can be made either on a per-gram-of-VOC basis or a per-mole-of-VOC basis. Given the relatively low molecular weight of ethane, use of the per-gram basis, obviously, tends to result in more VOCs (high-molecular-weight ones) falling into the "negligibly reactives" class, relative to the per-mole basis. EPA's Office of Air Quality Planning and Standards (OAQPS), with responsibility for regulatory actions in this area, has unofficially adopted the per-gram basis.

quality simulation model (AQSM). In the reactivity scale approach, ozone-forming potentials of different VOC emission mixtures are estimated from mixture composition and species reactivity data through simple linear summation calculations. Of the two approaches, this is the simpler but also less credible one, and is of limited geographical scope.

The AQSM approach entails use of airshed models to compute impacts on ambient ozone -- throughout the urban area -- of modifications of the VOC emission mixture. It is the more credible approach, but is also extremely complex and costly. Both approaches suffer from uncertainties and other limitations, the seriousness of which depends on the specifics of the control strategy needed. Application of the two approaches in meeting the three specific requirements of §183(e) is discussed below.

3.5 MEETING THE REQUIREMENTS OF §183(e)

Reactivity and the causal relationship between VOC emissions and ozone formation is addressed three times in §183(e), although reactivity is mentioned explicitly only twice. The following sections present approaches to meeting the reactivity-related requirements of the Act.

3.5.1 Role of Consumer and Commercial Products in Ozone Nonattainment

One objective of the study of consumer and commercial products, as stated in §183(e)(2)(A)(i) is to "determine their potential to contribute to ozone levels which violate the national ambient air quality standard for ozone . . "

Although reactivity is not mentioned explicitly here, such potential is understood to be the ozone contribution of the consumer and commercial product VOC relative to that of the ambient VOC in their totality. A measure of this potential can be obtained from concentration and reactivity data for all VOC species in the nonattainment atmosphere through a linear summation calculation, i.e.,

$$CCP\text{-}0_3\text{-}Potential = \frac{\sum CCP(VOC)_i r_i}{\sum AMB(VOC)_j r_j} \qquad (7)$$

where $CCP(VOC)_i$ and r_i are the weight-fraction and reactivity, respectively, of CCP VOC species i, and $AMB(VOC)_j$ and r_j are the weight-fraction and reactivity, respectively, of ambient VOC species j. This reactivity scale method is simple but requires that reactivity data exist for all VOC emission species emitted by consumer and commercial products. The consumer and commercial product emissions, however, unlike, e.g., automotive emissions, do not have a history of studies, and existing reactivity data, therefore, are either largely incomplete or uncertain. The method also suffers from uncertainties, mainly in the reactivity data themselves -- the reactivity chemistry for most of these species is not well known -- and in the linearity assumption used in equation (7). Overall, the reactivity scale method should be viewed as providing only approximate results.

The CCP-O_3-Potential can also be estimated through AQSM computations of ozone formed in the presence and in the absence of the consumer and commercial product VOC, for any set of ambient conditions. Such estimates are clearly more reliable and useful than those derived by the reactivity scale approach. However, they, also, are not without significant uncertainties, and are extremely costly to obtain. Uncertainties are in the chemistry, dispersion, and emissions components of or inputs to the AQSM models, and, to reduce such uncertainties, requires costly research and efforts to obtain reliable and complete input data and to field-test the models. Finally, for universal use, estimates of CCP-O_3-Potential should be based on model computations for several "representative" nonattainment urban atmospheres.

3.5.2 Highly Reactive Compounds

In establishing criteria for regulating consumer and commercial products, §183(e)(2)(B) requires that the EPA take into consideration each of five factors, including "(iii) [t]hose consumer and commercial products which emit highly reactive volatile organic compounds into the ambient air."

In the absence of pertinent guidelines from the Act, the distinction between "reactive" and "highly reactive" VOC can only be made with considerable arbitrariness. For the classification to be effective and practical, the "highly reactive" VOC should be considerably more reactive than the "reactive" ones, and it should be feasible to selectively control such VOC more cost-effectively than through indiscriminate VOC control. Lacking detailed information related to the latter criterion, such a classification could not be and was not developed as part of this report to Congress. Instead, the EPA used the best judgement to develop a rational and practical classification.

Specifically, "highly reactive" VOC are proposed to be those with MIR > 4, and include: Ethyl- and trimethyl-amines, methyl nitrite, unsaturated C_3- and C_4-esters, furan, aliphatic saturated $C_{<6}$-aldehydes, unsaturated C_3-aldehydes and dialdehydes except glyoxal, $C_{<14}$-polysubstituted naphthalenes, polyalkyl-benzenes, terminal $C_{<7}$-olefins, internal $C_{<11}$-olefins, and methyl- and ethyl-acetylenes. If the MOIR rather than the MIR scale is used, the "boundary" MOIR value corresponding to MIR = 4 is estimated to be approximately MOIR = 1.75. Use of this latter value as the MOIR "boundary" results in a "reactive"-vs-"highly reactive" classification almost identical to that based on MIRs. This suggests that even moderately large changes in VOC-to-NO_x ratio would not invalidate this classification.

Using the same reasoning as with the MIR data, a classification based on use of K_{OH}-reactivity data was derived. "Highly reactive" VOC in this case are proposed to be those with $K_{OH} > 50{,}000$ ppm^{-1} min^{-1} (the K_{OH} value corresponding to MIR = 4, approximately), and include: Ethyl- and trimethyl-amines, 2-(2-ethoxyethoxy)-ethanol (carbitol), alkyl-styrenes, polyalkyl-benzenes with 3 or more alkyl substituents, alkyl-phenols, and $C_{>4}$-olefins.

The above MIR- and K_{OH}-reactivity classifications of VOC are in disagreement with respect to the reactivity assignments of carbitol, furan, $C_{<6}$-aldehydes, alkyl-styrenes, dialkyl-benzenes, alkyl-phenols, and methyl- and ethyl-acetylenes. To resolve these conflicts, the reactivities of the "disagreement-VOC" were reassessed in the light of the latest evidence regarding atmospheric photochemistry of those VOC, and results were used to develop a compromise classification, as explained next.

Smog chamber evidence has established that longer carbon-chain paraffins[5], and by reasonable implication, longer carbon chain VOC in general, and carbitol [14], tend to have lower ozone-producing potentials than suggested by their k_{OH} values. Existing smog chamber data also suggest that alkyl-styrenes [15], furan [16], $C_{<6}$-aldehydes [17], and dialkyl-benzenes[17] have ozone-potentials comparable to those of "highly reactive" VOC. Furthermore, phenol is known to have a propensity for scavenging radicals and, hence, have low, in fact, negative ozone potential despite its high k_{OH}. Such evidence is judged to support the MIR-derived reactivity assignment for phenol and alkyl phenols. On the other hand, in the almost total lack of experimental ozone-potential data for and methyl- and ethyl-acetylenes, these species were assigned reactivity ratings consistent with the k_{OH} data. Finally, the existing reactivity data or judgments on specific VOC species were used through extrapolations -- when such extrapolations could be made reasonably -- to derive reactivity ratings for families or groups of VOC.

As a result of the above considerations, a compromise classification was derived that identifies "highly reactive" and "reactive" VOC as follows:

Highly Reactive VOC: Nitrites, $C_{<8}$-alkyl-amines, unsaturated esters, furan, $C_{<6}$-aldehydes, $C_{<14}$-poly-substituted naphthalenes, alkyl-styrenes, polyalkyl-benzenes, and $C_{<10}$-olefins.

Reactive VOC: All VOC other than the "highly reactive" ones (listed above) and the "negligibly reactive" ones (identified in the EPA's definition of VOC[13]).

3.5.3 Adjustment of Emissions Inventory Data to Account for Relative Reactivity

The third reactivity-related requirement concerns adjustment of emissions data to account for relative reactivity. Section 183(e)(3)(A) states that "the Administrator shall list those categories of consumer or commercial products that the Administrator determines, based on the study, account for at least 80 percent of the VOC emissions, on a reactivity-adjusted basis, from consumer or commercial products..."

This requires that the various consumer and commercial product categories be assessed relative to each other with respect to the levels of "highly reactive" or "reactive" VOC emissions with which they are associated. Such an assessment can be accomplished reasonably well through use of a somewhat simplistic methodology based on the "highly reactive" and "reactive" definitions developed and described above.

In order to make the required adjustment to emissions data for a given product category, the emissions of each "highly reactive" compound could be weighted through application of a reactivity adjustment factor. This adjustment factor could be equal to the ratio of the MIR of the highly reactive compound to some reference MIR as shown in equation (8),

$$\textit{Reactivity Adjustment Factor}_i = \frac{MIR_i}{MIR_{ref}} \tag{8}$$

where MRI_i is the MIR of the highly reactive species, and MIR_{ref} is the MRI used as the reference.

In developing this methodology, the EPA considered three choices for MIR_{ref}. Recall that "highly reactive" VOC have been defined above as compounds with MIR > 4. If MIR = 1 were to be selected as the reference MIR, the adjustment factor would be equal to the MIR of the species, and even emissions of "reactive" VOC would be subject to adjustment. This would result in over-adjustment of the "highly reactive" VOC. Another possible reference considered was the MIR of the most reactive of the "reactive" VOC, or MIR = 4. That choice would result in too little adjustment, since even emissions of "highly reactive" compounds would receive only small adjustments. The EPA eventually selected the mid-point MIR of the "reactive" compounds as a reference, or MIR = 1.875. As a result, the reactivity adjustment factor for any highly reactive VOC can be expressed as shown in Equation (9).

$$\textit{Reactivity Adjustment Factor}_i = \frac{MIR_i}{1.875} \tag{9}$$

The emission estimate for a given product category could then be weighted to account for relative reactivity by applying the adjustment factor to the mass emissions of highly reactive VOC ingredients as shown in Equation (10).

$$\textit{Adjusted Emissions} = \textit{Reactive Mass Emissions} + \sum (HRC_i\ \textit{Mass Emissions})(RAF_i) \tag{10}$$

where HRC_i is an individual highly-reactive compound, and RAF_i is the reactivity adjustment factor corresponding to that particular compound.

For example, a product category has annual VOC emissions of 100 tons. Included in the 100 tons are 20 tons of formaldehyde (HRC_1) and 10 tons of o-xylene (HRC_2). The remaining 70 tons is composed of "reactive" emissions. The MIR of formaldehyde and o-xylene are 7.2 and 6.5, respectively. Based on a reference MIR of 1.875, the reactivity adjustment factors for the two compounds are $RAF_1 = 3.84$ and $RAF_2 = 3.47$. To calculate adjusted emissions, the formaldehyde tonnage is multiplied by 3.84, the o-xylene tonnage is multiplied by 3.47, and the three terms ("reactives", formaldehyde, and o-xylene) are then added as shown below.

$$\textit{Adjusted Emissions} = 70 + (20)(3.84) + (10)(3.47) = 181.5\ \textit{tons} \tag{11}$$

The hypothetical product category would have a reactivity-adjusted emissions estimate of 181.5 tons per year. As a result, the emissions from this category would be weighted almost double compared to a category with similar mass emissions but with no emissions of highly reactive compounds.

The methodologies presented in this chapter concerning (1) the potential of consumer and commercial product VOC to contribute to ozone nonattainment; (2) identification of "highly reactive" compounds; and (3) adjustment of mass emission estimates to account for relative reactivity represent the EPA's best effort and are believed by the EPA to be the most appropriate way to meet the statutory requirements, given the limitations and uncertainties surrounding the reactivity issue. Should additional information become available, the methodologies and other information presented in this report to Congress may change.

3.6 REFERENCES

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CHAPTER 4

CRITERIA FOR REGULATING PRODUCTS UNDER §183(e)

4.1 INTRODUCTION

One objective of the study was to establish criteria for regulating consumer and commercial products under the Act. The Act lists five factors that must be considered in developing the criteria. This chapter presents the EPA's interpretation of the meaning and intent of each of the five factors and develops criteria which address each factor. In addition, two criteria (magnitude of annual emissions and regulatory efficiency) are presented which are not directly associated with any of the factors required to be considered, but are believed by the EPA to be important in establishing the schedule for regulations. Throughout this discussion, *factor* refers to one of five considerations which the Act requires the EPA to take into account in establishing the regulatory criteria. *Criterion* refers to a parameter by which each product category is to be assessed in order to establish that category's relative priority for regulation. A summary of the five factors and the corresponding criteria is presented in Table 4-1.

Application of some of the criteria requires that subjective decisions be made, although others are based on more objective decisions. Where quantitative evaluation is not feasible, qualitative methods are employed. The use of subjective judgement, because it raises questions concerning consistency and equity, has been avoided to the greatest extent possible. The following sections describe the methodology for applying the criteria and for eventually assigning a rank or score for each product category within the scope of §183(e).

Please note that throughout this chapter a **higher score** for a given criterion generally indicates that the product category tends to have **higher priority** for regulation with respect to that criterion. Furthermore, a very high or very low score for a single criterion does not necessarily predict the outcome of the ranking; the composite score obtained from application of all the criteria will be the primary basis for a category's priority for regulation. It should also be noted that the EPA plans to establish priorities for regulation based on the criteria presented in this report to Congress. However, the priorities established may change at any time prior to the decision to regulate a particular product category if warranted.

4.2 FACTOR 1: USES, BENEFITS AND COMMERCIAL DEMAND

4.2.1 Key Terminology

Use: The purpose for which the product exists.

Benefit: Value from use; usefulness; something for the good of a person or thing.

Commercial Demand: The quantity of a commodity bought at a specific market price.

TABLE 4-1

SUMMARY OF FACTORS AND CRITERIA

Factor 1: The uses, benefits, and commercial demand of consumer and commercial products.

- **Criterion 1 - Utility**
- **Criterion 2 - Commercial demand**

Factor 2: The health or safety functions (if any) served by such consumer and commercial products.

- **Criterion 3 - Health or safety functions**

Factor 3: Those consumer and commercial products which emit highly reactive VOC into the ambient air.

- **Criterion 4 - Emissions of "highly reactive" compounds**

Factor 4: The availability of alternatives (if any) to such consumer and commercial products which are of comparable costs, considering health, safety, and environmental impacts.

- **Criterion 5 - Availability of alternatives**

Factor 5: Those consumer and commercial products which are subject to the most cost-effective controls.

- **Criterion 6 - Cost-effectiveness of controls**

Additional Considerations

- **Criterion 7 - Magnitude of annual VOC emissions**
- **Criterion 8 - Regulatory efficiency**

4.2.2 Criteria 1 and 2

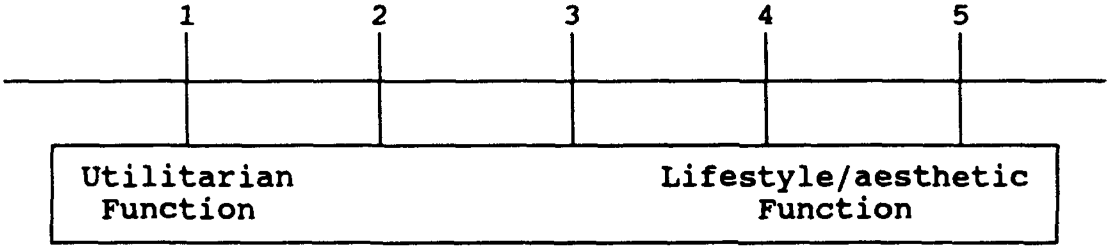
Two criteria result from the interpretation of Factor 1. Criterion 1 addresses the uses and benefits portion of Factor 1. Criterion 2 addresses the commercial demand portion of Factor 1.

4.2.2.1 *Criterion 1 - Utility*

The terms "use" and "benefit" have similar connotations but distinct meanings. The "use" or "purpose" is a way to describe or classify a product. Once the purpose of a product is known, benefits can be assessed. The development of comparative measures for "use" does not appear to be practicable. It is, however, possible to qualitatively measure or compare the benefits derived from the use of products. Therefore, because uses can only be measured or compared in terms of the benefits they provide, Criterion 1 addresses both uses and benefits through application of the concept of **product utility**.

Criterion 1 provides a measure of the comparative utility of products. Inherent to the utility scale is the concept of **essentiality**, that is, how indispensable a product is to the consumer. Less essential products rank higher on the scale and more essential products rank lower. The utility scale is presented below.

Criterion 1: Utility



4.2.2.2 *Criterion 2 - Commercial Demand*

Commercial demand can be interpreted as the amount of a product society wishes to purchase at a specific price at a specified time. A high commercial demand and market share may indicate that a product is valued highly by a large portion of the population, or that it has an attractive price; a low commercial demand indicates that a product is valued to a lesser extent, or that its price makes it less attractive. Annual dollar sales is the measure typically used by economists to indicate commercial demand for a product.

Other indicators of commercial demand that were considered include the total volume or weight sold, the number of units sold, and price per unit. A measure of total volume or weight sold may indicate the relative importance of the product to consumers, as does the total annual dollar sales. However, products that are used in larger quantities may be given undue emphasis.

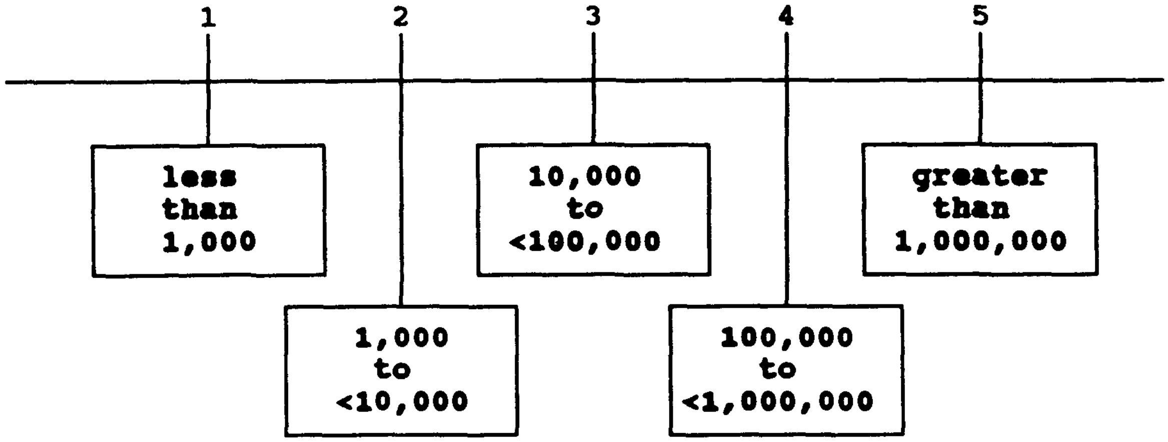
Similarly, a measure of the number of units or the price per unit may, in some cases, indicate the relative value consumers place on a particular product. The number of units may be a useful indicator of how widespread the demand is for a product. In general, the greater the number of units sold, the greater the number of people that use and value a product. However, this is not always accurate, because the number of units sold depends on the number of units that are typically used in one year as well as the number of consumers. Furthermore, both number of units and price per unit may merely reflect the number of applications that can be conveniently packaged. An additional complication in applying this factor is that for some products, such as asphalt concrete, the meaning of a "unit" is not clear.

Initially, the EPA determined that Criterion 2 should represent the commercial demand of a product using total annual dollar sales of the product. This preliminary decision was based on the consideration of total annual dollar sales as a composite measure of units purchased and price per unit. However, some concerns were raised regarding application of this measure. The primary point of contention was related to whether a product with high annual sales should receive low priority for regulation (i.e., higher annual sales may indicate a highly-valued product which should not be tampered with), or a higher priority for regulation (i.e, high annual sales may indicate a product with high volume usage resulting in high levels of VOC emissions). Furthermore, Criterion 2 (dollar sales) may either offset or over-emphasize Criterion 7 (magnitude of VOC emissions) depending on how the EPA applied Criterion 2. For example, consider a product with high annual sales combined with high annual VOC emissions. Depending on the "polarity" of Criterion 2 (dollar sales), the effect of Criterion 7 (high emissions ⇒ score of 5) either would be offset by Criterion 2 (high sales ⇒ score of 1) or would be duplicated by Criterion 2 (high sales ⇒ score of 5). Clearly, a means of tempering this effect was needed.

One modification of Criterion 2 was suggested by the consumer products industry.[1] The industry proposed that it might be better to consider commercial demand based on a proxy, which is the apparent price consumers are willing to pay for the VOC contained in a product. This approach could be implemented by expressing commercial demand for a product as dollar sales per tonnage of VOC emissions. This modification was suggested again and received general acceptance at a July 1994 meeting of the National Air Pollution Control Techniques Advisory Committee (NAPCTAC) in Durham, North Carolina.

Criterion 2, as modified, reflects commercial demand expressed quantitatively as annual product sales ($ thousands) divided by annual VOC emissions (tons).

Criterion 2: Demand for VOC-Containing Products ($K sales/ton VOC emitted)



4.3 FACTOR 2: HEALTH OR SAFETY FUNCTIONS

4.3.1 Key Terminology

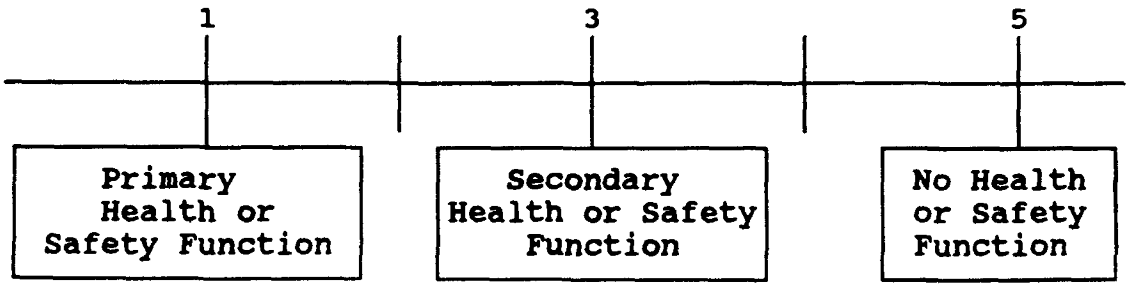
Health: Condition of being sound in body; freedom from disease or ailment.

Safety: Condition of being free from undergoing hurt, injury, or loss.

4.3.2 Criterion 3 - Health or Safety Functions

The EPA believes that the intent of Factor 2 is to recognize health or safety benefits derived from the use of consumer and commercial products and to ensure that these benefits are not unduly or unnecessarily compromised. Criterion 3 is designed to lower the priority for regulation of products that contribute to the protection of health or safety. A product with no health or safety function is assigned a maximum score (higher priority for regulation); a product marketed primarily for its health or safety functions receives a minimum score. A product whose health or safety functions are secondary is assigned a mid-range score.

Criterion 3: Health or Safety Functions



4.4 FACTOR 3: PRODUCTS WHICH EMIT HIGHLY REACTIVE COMPOUNDS

4.4.1 Key Terminology

Photochemical Reactivity: A compound's potential to undergo chemical reaction to form photochemical oxidants in the atmosphere.[2]

Highly Reactive Compound: A compound which falls within one of the ten chemical classes identified by the EPA to be highly photochemically reactive under most conditions.[3]

4.4.2 Criterion 4 - Emissions of Highly Reactive Compounds

Tropospheric (ground level) ozone is formed through a series of complex chemical reactions involving VOC and oxides of nitrogen (NO_x) in the presence of sunlight. This phenomenon has been subject to continuing scientific investigation since well before the mid-1970's when the EPA adopted its present scheme of classifying compounds as **reactive** or **negligibly reactive** for the purpose of defining VOC.

However, in order to address the statutory requirement to consider relative reactivity in developing criteria for regulating consumer and commercial products, the EPA developed a list of 9 classes of compounds that are considered to **be highly reactive** under most conditions. A discussion of photochemical reactivity and rationale for the list of highly reactive compounds is presented in Chapter 3. Table 4-2 presents EPA's list of highly reactive compounds.

Criterion 4 places higher priority for regulation on those products which emit highly reactive compounds. A score of 5 (higher priority) is assigned to products which emit greater than 1,000 tons per year of one or more highly reactive compounds in ozone nonattainment areas. A product whose emissions of highly reactive compounds are less than one ton per year receives a score of 1 (lower priority). A product for which the magnitude of emissions of highly reactive compounds is unknown receives a score of 1.

Criterion 4: Emissions of Highly Reactive Compounds (Tons/yr)

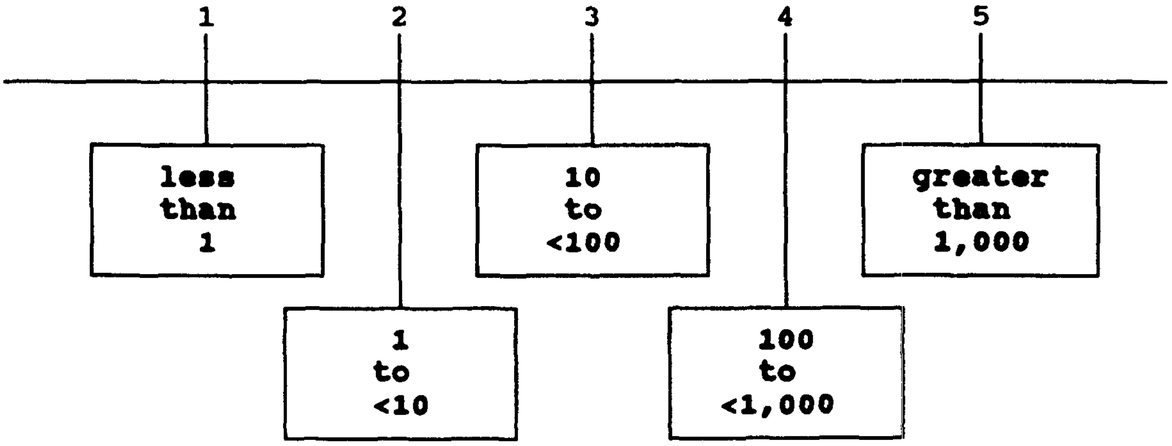


TABLE 4-2

CLASSES OF "HIGHLY REACTIVE" COMPOUNDS[3]

Nitrites

$C_{<8}$-Alkyl-amines

Unsaturated Esters

Furan

$C_{<6}$-Aldehydes

$C_{<14}$-Poly-substituted Napthalenes

Alkyl-Styrenes

Polyalkyl-benzenes

$C_{<10}$-Olefins

Alkyl-phenols

4.5 FACTOR 4: AVAILABILITY OF ALTERNATIVES

This factor pertains to available, lower-VOC-emitting products and product reformulations. The language in §183(e)(2)(B)(v), "...available alternatives at comparable cost," implies that consideration is to be given to products on the market or developed to such a degree that alternatives are of reasonably acceptable efficacy and have no adverse health, safety, or environmental impacts.

4.5.1 Key Terminology

Alternative: Something that performs the same function. Alternatives include reformulated products and substitute products and/or processes.

Comparable costs considering health, safety, and environmental impacts: At this point, the EPA does not have information on the cost of alternative products. Until more information becomes available, the EPA has adopted **consumer acceptance** as a surrogate measure of cost comparability. Consumer acceptance of consumer products will be determined based on 1990 market share derived from the results of the EPA's 1993 census survey of consumer product manufacturers discussed in Sections 2.1 and 5.3. If cost information becomes available, the EPA will include such costs in its consideration of the availability of alternatives and the priority for regulation. Furthermore, cost of alternatives will be considered as part of the rulemaking process for categories listed for regulation under §183(e).

Consumer acceptance: A product commands a "significant" market share. The market percentage which constitutes a significant market share will vary for each product category. For example, within a product category containing a great number of products, a small share of that market may be considered significant. Conversely, the same small share of a category containing few products may not be significant.

Reformulated Product: A product with the same form and function, but with one or more ingredients changed to achieve lower VOC emissions.

Substitute: A product of a different form with lower VOC emissions, but that retains the same function as the original product. A substitute can also be an alternative process or method of application that performs the same function as the original process but results in reduced VOC emissions (e.g., brush-on application of paint substituted for aerosol spray painting; high-volume, low-pressure spray application substituted for conventional spray application; etc.).

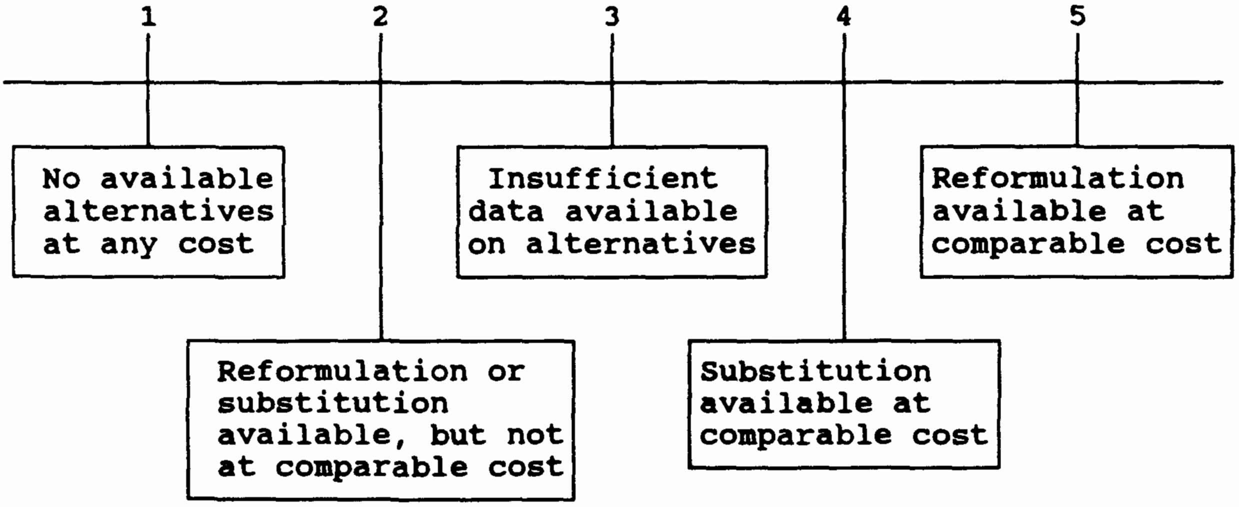
4.5.2 Criterion 5 - Availability of Alternatives

This criterion considers both substitutes and reformulated products that are currently available. Information on VOC emissions and relative market shares, available from product category studies and from the inventory, is used to identify available substitutes and/or lower VOC formulations. In assessing the availability of acceptable alternatives, all known impacts (e.g., product efficacy, health and safety, environmental impacts) are considered.

In developing Criterion 5, the EPA recognized that there is a "hierarchy of control measures" in which some measures are believed to be more onerous than others. Specifically, reformulation is viewed as less onerous than substitution (i.e. product prohibition). Accordingly, available reformulation at comparable cost warrants a higher priority for regulation than does available substitution at comparable cost. The difference in priority between reformulation and substitution is not meant to imply that reformulation is more cost-effective than substitution (the issue of cost-effectiveness is addressed under Factor 5, Section 4.6). Rather, the EPA believes that because reformulation involves alternatives within the same product form and market channels, it is therefore less disruptive to the affected industry and to the consumer. Since substitution involves replacing entire product forms through product prohibition, the potential exists for greater economic dislocation. While possibly causing no net loss in sales or employment across the industry, substitution may reduce demand for certain products while increasing demand for others.

Based on this "hierarchy of control measures," the scale for Criterion 5 assigns the lowest score (lower priority for regulation) to those products for which no known alternatives exist. The highest score (higher priority) is assigned to products for which reformulation is possible (i.e., a lower-VOC product is available, is accepted by the consumer as indicated by a significant market share, and has comparable efficacy, health effects, and environmental impacts). Products for which insufficient data exists to make this determination are assigned a mid-range (neutral) score. The scoring partitions for Criterion 5 are presented below.

Criterion 5: Availability of Alternatives



4.6 FACTOR 5: COST-EFFECTIVENESS OF CONTROLS

4.6.1 Key Terminology

Control: Measure applied to eliminate or reduce VOC emissions to the ambient air.

Best Available Controls: "...equipment, measures, processes, methods, systems or techniques, including chemical reformulation, product or feedstock substitution, repackaging, and directions for use, consumption, storage, or disposal." [§183(e)(1)(A)]

Cost-effectiveness: Unit cost per unit of benefit; cost of control per unit of VOC reduction ($/ton). Most cost-effective means the least cost per ton of VOC reduction.

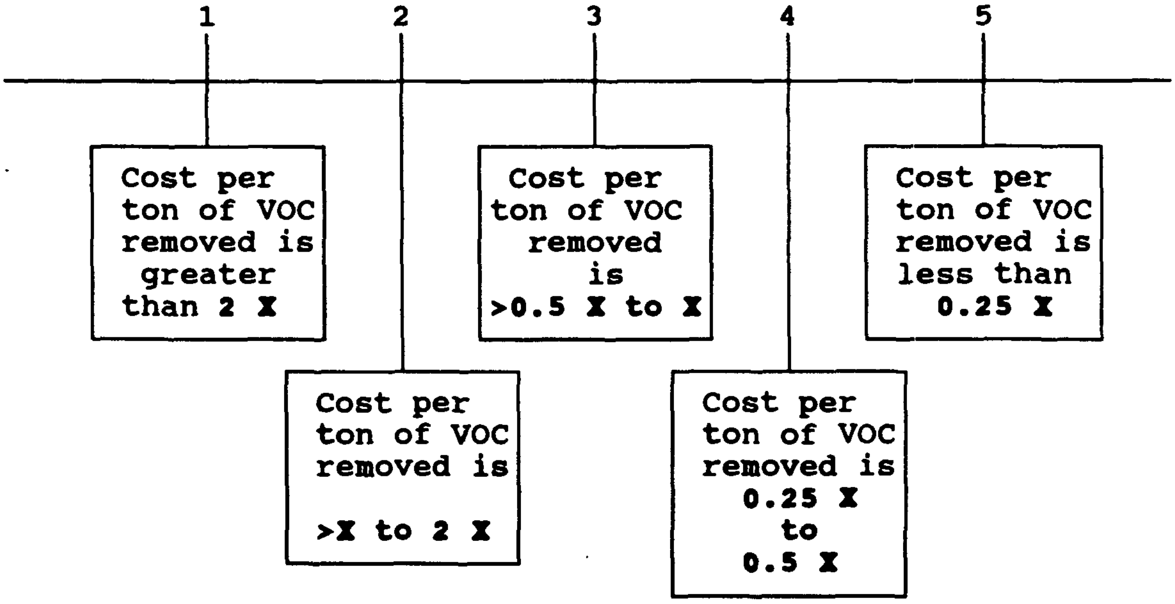
4.6.2 Criterion 6 - Cost-Effectiveness of Controls

Each product category receives a score of 1 to 5 based on application of one of two possible rating methods. Categories for which the cost-effectiveness value is known are assigned a score using **Method 1**. Categories for which cost-effectiveness data are unavailable are evaluated by implementing **Method 2**. Each product or product category will be evaluated using either Method 1 or Method 2 as determined by the availability of cost-effectiveness data.

4.6.2.1 *Method 1 (Known Cost-Effectiveness Value)*

In using Method 1, categories for which the cost of control is very high receive a 1 (low priority). Categories for which controls are very cost-effective are assigned a 5 (high priority).

Criterion 6: Cost-Effectiveness of Controls (Method 1)



Where X is equal to $2,000, the existing EPA-accepted cost-effectiveness value for VOC emissions.

4.6.2.2 *Method 2 (Cost-Effectiveness Value Unknown)*

For categories for which cost-effectiveness data are unavailable, scores are assigned by considering a category's (1) annual VOC emissions and (2) available control alternatives. How each of these considerations may help predict cost-effectiveness of controls is discussed below.

(1) Annual VOC Emissions

Even without much information about a given category, one would expect that greater emission reductions could be achieved for a category with a larger magnitude of uncontrolled emissions. Accordingly, controls for a category with high VOC emissions would tend to be more cost-effective and would warrant a higher priority for regulation.

(2) Availability of Alternatives

As explained in Section 4.5.2, EPA has adopted a "hierarchy of control measures" in which some measures are believed to be more onerous than others. A category for which control measures are least onerous (e.g., reformulation) would warrant a higher priority for regulation than a category for which the available controls are more onerous (e.g., product substitution).

Combining (1) and (2) to Obtain a Score

The score for Criterion 6 is obtained by combining the two above considerations by employing a matrix which incorporates magnitude of emissions (Criterion 7) as the Y-axis and availability of alternatives (Criterion 5) as the X-axis. The highest score (higher priority) is assigned to a product with high annual emissions (Criterion 7 = 5) and for which reformulation is available at comparable cost (Criterion 5 = 5). The lowest score (lower priority) is assigned to a product with low annual emissions (Criterion 7 = 1) and for which there is no available alternative (Criterion 5 = 1).

Criterion 6: Cost-Effectiveness of Controls (Method 2)

		Criterion 5 Score (Availability of Alternatives) <Reformulation Available No Available Alternatives>				
		5	4	3	2	1
Criterion 7 Score (Emissions)	5	5	4	4	3	3
	4	4	4	3	3	2
	3	4	3	3	2	2
	2	3	3	2	2	1
	1	3	2	2	1	1

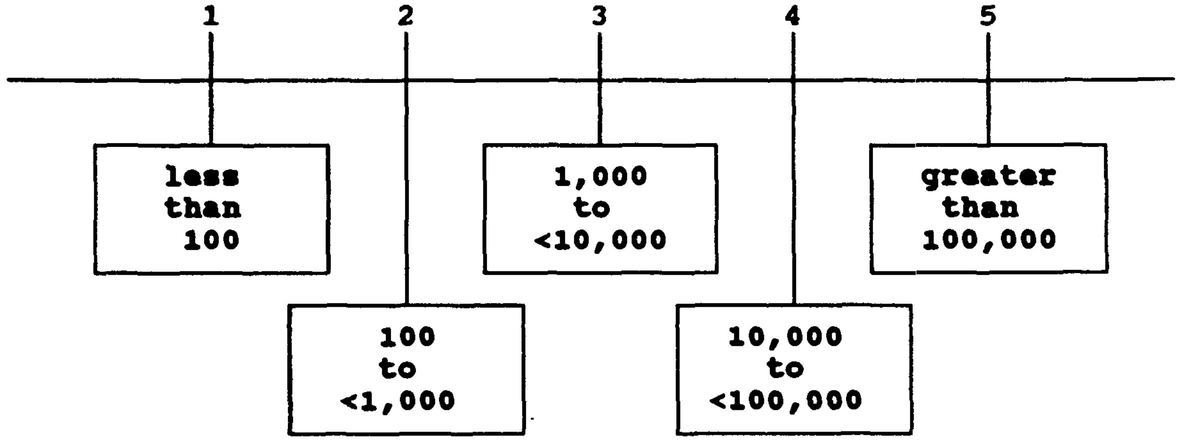
4.7 ADDITIONAL CONSIDERATIONS

Section 183(e) states that the EPA must consider the five factors listed, but does not limit the EPA's discretion to consider other relevant factors. Two additional considerations were identified by the EPA and are discussed in the following sections.

4.7.1 Criterion 7 - Magnitude of Annual VOC Emissions

Criterion 7 does not specifically address any of the five factors listed in §183(e). However the EPA believes magnitude of emissions to be an important consideration. Products with greater VOC emissions would be tend to be targeted for earlier regulation, and would be assigned a high score. The scoring partitions are presented below.

Criterion 7: Magnitude of Annual VOC Emissions (Tons)



4.7.2 Criterion 8 - Regulatory Efficiency and Program Considerations

The EPA intends to exercise discretion in adjusting the product category rankings, if necessary, to achieve an equitable and practical regulatory program. For example, certain types of health use products may be considered for exemption if there is no suitable substitute as provided for in §183(e)(3)(A); adjustments in priority rank may be made for products that are covered by existing regulations or by regulations under development; or certain products or product categories may be grouped in the interest of regulatory efficiency. The eight criteria are designed to produce a regulatory agenda based on all relevant parameters. The purpose of Criterion 8 is to provide for adjustments to the rankings in the interest of regulatory efficiency and/or program considerations.

4.8 USE OF THE CRITERIA TO DEVELOP THE SCHEDULE FOR REGULATIONS

The eight criteria developed by the EPA and discussed above are the primary bases for EPA's 8-year regulatory program for consumer and commercial products under §183(e). The criteria will be employed in three stages: (1) Criteria 1 through 7 will be exercised for each of the product categories within the scope of §183(e) to yield a numerical score for each category; (2) Criterion 8 will be applied to yield the list of categories which account for at least 80 percent of the VOC emissions from consumer and commercial products in ozone nonattainment areas; and (3) the listed categories will be placed into Groups I through IV of the schedule for regulations which will be published in the *Federal Register* following submittal of this report to Congress.

The output of the numerical scoring exercise will be a list of all categories within the broad scope of §183(e) ranked by numerical scores assigned through application of Criteria 1 through 7. The list of product categories which will be scheduled for regulation under §183(e) will be a subset of the categories scored. Actual selection of categories for regulation and placement of these categories in the four groups will be performed based on consideration of Criterion 8 (Regulatory Efficiency) which was introduced in Section 4.7.

The approach for exercising Criterion 8 to place categories in Groups I-IV for regulation includes several considerations. A primary consideration will be to list those product categories that account for at least 80 percent of baseline VOC emissions, on a reactivity-adjusted basis, in ozone nonattainment areas. An effort will be made to adhere to the numerical ranking scheme, but the EPA is prepared to override the numerical ranking based on program considerations. Furthermore, consideration will be given to listing for early regulation those categories affected by ongoing rule or control techniques guideline (CTG) development.

The initial publication of the list and schedule for regulations will not be considered final Agency action. Accordingly, Groups I-IV may be modified such that a product category may be moved to a different group, delisted altogether, or added to the list. The EPA will make appropriate adjustments to ensure that we continue meet the statutory requirements of §183(e) to regulate categories which account for at least 80 percent of baseline emissions. With respect to the priority for regulation assigned to each product, the EPA will consider public comments at the time each product is considered for regulation in a rulemaking process.

4.9 REFERENCES

1. Letter from R. Engel, Chemical Specialties Manufacturers Association, to B. Jordan, U.S. Environmental Protection Agency, August 31, 1993. Comments on draft criteria.

2. U.S. Environmental Protection Agency, *Requirements for Preparation, Adoption, and Submittal of Implementation Plans; Approval and Promulgation of Implementation Plans*, Federal Register, 57 FR 3941, February 3, 1992.

3. Dimitriades, B., *Scientific Bases of the VOC Reactivity Issues Raised by Section 183(e) of the Clean Air Act Amendments of 1990*, U.S. Environmental Protection Agency, Office of Research and Development, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, North Carolina, 1994.

CHAPTER 5

COMPREHENSIVE EMISSIONS INVENTORY

This chapter presents a detailed summary of the EPA's inventory of VOC emissions from consumer and commercial products. The purpose of the inventory effort was to develop estimates of annual VOC emissions in ozone nonattainment areas for every consumer and commercial product category subject to §183(e). These estimates, along with other information, were used to develop a prioritized list of categories to be regulated as required by §183(e). Eight criteria for regulating consumer and commercial products were developed based on the factors listed in §183(e). Three of these criteria (emissions of highly reactive compounds, availability of lower-VOC alternatives, and annual VOC emissions) were evaluated based on the inventory data. These criteria are discussed in detail in Chapter 4. The emission estimates and *per capita* emission factors developed by the EPA can also be used by State and local agencies in developing emission inventories for specific mixes of products and categories within their jurisdiction.

5.1 ELEMENTS OF THE INVENTORY

Because of the wide variety of products subject to §183(e), emission estimates were developed independently for three major subdivisions of the universe of consumer and commercial products.

5.1.1 Consumer Products (including commercial and institutional uses)

These are products which most people associate with the term "consumer products." This group includes such products as personal care products, household cleaning products, household pesticides, automotive maintenance and detailing products, and many others. Institutional and commercial uses of these or similar products are also considered within the scope of traditional consumer products. Emission estimates for these categories were obtained through a 1993 census survey of consumer product manufacturers. This segment of the inventory is summarized in Section 5.3.

5.1.2 Industrial Products Affected by Existing Federal Regulatory Programs

The statutory definition of "consumer or commercial product" is much broader than just the traditional consumer products and includes virtually all VOC-emitting products used in the home, by businesses, by institutions, and in industrial manufacturing operations. This segment of the consumer and commercial products inventory includes those products which are used industrially and are affected by existing or ongoing regulations developed by the EPA and/or by the States. These products include a wide range of surface coatings, metal cleaning solvents, adhesives, inks, agricultural pesticides, asphalt paving materials, and a host of others. Estimates of VOC emissions from these products were obtained from background documentation developed for the respective regulations or guidance documents. Emission estimates for previously regulated categories are based on "residual" emissions (i.e., emissions which continue after controls have been applied). Estimates for categories associated with ongoing standards development are 1990 "baseline" emission estimates from those categories (i.e, emissions before any controls have been applied). This segment of the inventory is summarized in Section 5.4.

5.1.3 Products Addressed by Special Studies

Many consumer and commercial products fall outside the scope of the consumer products survey and the categories affected by existing or ongoing regulatory programs. This third segment of the inventory is comprised of products which do not fall within the first two segments. It includes such products as foods, beverages, and tobacco; small combustion sources such as kerosene heaters, camp stoves, and artificial fireplace logs; products used in the roofing and textile industries; and a wide range of miscellaneous products including but not limited to, mold release agents, automotive parts washers, and products used in the manufacture of fiberglass boats. Emission estimates for these products were obtained through special studies conducted by the EPA. These studies were limited to searches of the literature for relevant scientific investigations in which VOC emissions from these products were characterized and quantified. This segment of the inventory is summarized in Section 5.5.

5.2 ADJUSTMENTS TO INVENTORY DATA

In accordance with §183(e), an effort was undertaken to develop estimates of VOC emissions from consumer and commercial products in ozone nonattainment areas. Because the "raw" data from the consumer products survey and the other sources were primarily for nationwide mass emissions based on the VOC content of the products, the following factors were considered in an effort to develop realistic estimates which could be used to satisfy the requirements of §183(e).

5.2.1 Adjustments for Fate of VOC in Landfills and in Wastewater

Historically, inventories of VOC emissions from consumer and commercial products have been based on the assumption that all VOC contained in these products eventually volatilize, enter the ambient air, and are thus available to react to form ozone. However, the VOC in some products such as soaps, laundry detergents, household cleaners, mouthwashes, disinfectants, etc. may be combined with water during and/or following use and enter the wastewater stream. In order to ensure that the inventory results reflected actual VOC emissions rather than VOC content, the EPA initiated an investigation to identify information on the fate of consumer product VOC that enter the wastewater stream. This study is summarized in Chapter 6. Based on this information, and information provided by the major consumer product industry trade associations [1,2,3,4,5], final emission estimates for several product categories reported in this inventory (primarily household cleaning and laundry products) reflect a "percent VOC content emitted" of somewhat less than 100 percent.

Another area of concern was that it may be possible for a portion of the unused product (and VOC content) to remain in the container packaging following disposal in landfills. A study was undertaken by EPA to determine whether some adjustment of the emission estimates should be made to account for this phenomenon. Based on the study, also summarized in Chapter 6, the EPA determined that, because of the scarcity of information and the variability of landfill operating procedures, it was not possible to adjust the emission estimates to account for fate of the VOC in landfills. Consequently, for the purpose of this inventory study, the assumption was made that any remaining VOC content in the disposed products is eventually emitted to the air.

5.2.2 Adjustment to Reflect Emissions in Ozone Nonattainment Areas

Section 183(e) primarily focuses on VOC emissions in ozone nonattainment areas. Because much of the emissions data collected reflects nationwide emissions, some adjustment was necessary to obtain estimates for nonattainment areas. Since emissions from traditional consumer products are roughly proportional to population, the nationwide estimates from the consumer products survey were scaled down based on the distribution of population in ozone nonattainment areas. In 1990, approximately 148 million of the 248 million persons in the U.S. resided in ozone nonattainment areas (59.7 percent). Based on this distribution, the nationwide emission estimates for traditional consumer products were multiplied by a factor of 0.6 to reflect emissions in nonattainment areas.

For many categories of industrial products, estimates were developed based on actual locations of emission sources. Consequently, nonattainment area emission estimates were developed for those products directly. For any categories for which specific locations of emission sources were unknown, the population scaling method discussed above was employed.

5.2.3 Adjustment for Photochemical Reactivity

Section 183(e)(3)(A) requires the EPA to "list those categories of consumer or commercial products that the Administrator determines, based on the study, account for at least 80 percent of the VOC emissions, on a reactivity-adjusted basis, from consumer and commercial products in areas that violate the NAAQS for ozone." The inventory study was directed toward developing estimates of mass VOC emissions in ozone nonattainment areas. Consequently, the relative photochemical reactivities of individual species were not applied to the inventory data until later. The methodology followed by the EPA to adjust the emission estimates for purposes of establishing the "80-percent list" is presented in Chapter 3. Application of the adjustment methodology and the preliminary category ranking which resulted is discussed in detail in Section 4.8.

5.3 CONSUMER PRODUCTS SURVEY

One important segment of the inventory of VOC from consumer and commercial products are the "traditional consumer products" described in Section 5.1.1. In order to develop an accurate, reliable emission estimate for this segment, the EPA and the consumer products industry undertook a massive effort to assemble accurate formulation and sales information for over 24,000 individual consumer products. The following sections describe the survey process and the results obtained from that effort.

5.3.1 Development of the Survey Approach and Questionnaire

In anticipation of the Clean Air Act Amendments, the EPA conducted a symposium in November 1989 on regulatory approaches for reducing VOC emissions from the use of consumer products. The purpose of the symposium was to initiate a dialogue among the EPA, the States, and industry toward working cooperatively in addressing this source of emissions. Approximately 100 companies and trade associations participated in the symposium. State environmental agencies from California, Michigan, New Jersey, New York, North Carolina, Texas, and Virginia were represented as well. The proceedings of that symposium were documented in an EPA report (EPA-450/3-90-008, January 1990).

One of the key issues raised by industry representatives at the symposium was the lack of a reliable, speciated inventory of VOC emissions from traditional consumer products. The industry demanded that the EPA employ a census survey of consumer product manufacturers and distributors to develop such an inventory.

In November of 1990 the EPA and the Cosmetics, Toiletries, and Fragrances Association (CTFA) met twice with the Chemical Specialties Manufacturers Association (CSMA) at CSMA's headquarters in Washington, D.C. to discuss the plan for developing the inventory. It was suggested that the best approach for a number of consumer product categories would be through a survey of the manufacturers of those products. Information for this consumer products survey would be collected by the EPA via questionnaires distributed under the authority of Section 114 of the CAA. This approach was suggested by the consumer products industry, specifically the CSMA.

Refinements to the survey approach were made over the next two years by the work group consisting of EPA, CSMA, CTFA, the Soap and Detergent Association (SDA), other trade associations, and representatives of several companies (L&F Products, Sherwin-Williams, Procter & Gamble, Drackett, Gillette, S.C. Johnson Wax, United Industries, Aeropres Corporation, CCL Custom Manufacturing, Helene Curtis, and Carter-Wallace). This work group met on several occasions to develop a joint protocol for the consumer products inventory effort.

In December 1991, the survey questionnaire developed by the work group was sent to nine volunteer test respondents. The responses from this test were analyzed and the results presented at a March 1992 meeting of the work group. Revisions to the questionnaire were made and sent to the work group members for final endorsement.

It was recognized early in the planning of the survey that, due to the large number of survey questionnaires necessary, Office of Management and Budget (OMB) approval would be required through the submission of an information collection request (ICR). The CSMA offered to endorse the ICR and state that the industry and EPA reached a consensus that the Section 114 approach was the most suitable vehicle for gathering the required information. The ICR was submitted to OMB in July 1992, and approval was granted by OMB in December 1992.

5.3.2 Response to the Survey

The total number of questionnaires mailed was 3,610; however, a number of companies had responses from more than one division and some companies forwarded copies to companies that were not on the original mailing list. These additional sources of survey responses brought the total number of questionnaires being tracked to 3,802.

Out of the 3,802 survey questionnaires accounted for in the tracking system, only 1,283 questionnaires (approximately one-third) are included in the No Response category. An additional 352 (9.3 percent) were returned as undeliverable by the U.S. Postal Service. Approximately one-quarter of the survey questionnaires were responded to by the company indicating that they did not manufacture, distribute, or sell any of the products found in one of the product categories (Company Sheet Only). Responses via either product sheets or data diskettes were provided by the remaining companies. Thirty responses (0.8 percent) were obviously inappropriate and could not be used in the survey without lengthy follow-up. The remaining responses were complete with product information. An additional 35 completed responses were provided for a company by a third party (*e.g.*,consulting firm, custom packager, etc.). There were, therefore, 1,173 complete responses (including product formulation data) from companies manufacturing consumer and commercial products.

Not all of the 1,173 complete responses, however, could be used in the final analysis. A number of problems were encountered when the information was attempted to be entered into the data entry system from both hard copy product sheets and data diskette submissions. In all cases, attempts were made to contact the company when problems were identified, but these attempts were not always successful. In many cases, information vital to the project was not provided, such as the pounds of product sold in 1990. In a number of other cases, products were inappropriately grouped (*i.e.*, products from more than one category were reported together). These problems and a number of others were not resolved and 96 such responses were not included in the final data set. Therefore, the final data set included 1,077 complete responses.

5.3.3 Information Obtained from the Survey

Consumer products often contain ingredients which are of extremely low volatility (i.e., some ingredients evaporate at such a low rate that they do not enter the air to any appreciable degree). These low-volatility ingredients include surfactants used in shampoos and laundry detergents, heavy oils used in lubricants, and waxes used in lip balms and underarm antiperspirants. Furthermore, if volatility is not considered, many consumer products contain 100 percent VOC by definition[6] even though portions of their contents do not become available to react with NO_x in the atmosphere to form ozone. This phenomenon would severely hinder efforts to evaluate products with to regard to availability of lower VOC alternatives, since in some cases all the products in a category (even the ones which don't enter the air) may be of equal VOC content. The EPA recognized this problem and examined the possibility of collecting information only on ingredients which readily enter the air.

Consequently, the EPA adopted a volatility threshold which applies to ingredients reported in the survey. For purposes of the survey, the term "reportable VOC" (RVOC) was coined to indicate ingredients to be reported through the survey. The term RVOC includes a subset of compounds defined by the EPA to be VOC and is not to be construed as a modification of the

EPA's definition[6]. A consumer product ingredient is an RVOC if it is a VOC by EPA's definition <u>and</u> meets one of the following criteria:

1. The ingredient compound exists as a solid at room temperature (20°C) but readily sublimes (becomes a vapor at room temperature). Examples include paradichlorobenzene, naphthalene, and camphor.

2. The ingredient compound exists as a solid at room temperature (20°C) but becomes a vapor at the temperature at which the product is used. Examples include components of hot-melt glues, plug-in air fresheners, etc.

3. The ingredient compound has a vapor pressure greater than 0.1 millimeter of mercury (mmHg) at 20°C.

4. The vapor pressure for the ingredient compound is unknown, and the compound's empirical formula contains 12 or less carbon atoms.

Several States have adopted consumer product rules which are based on these same volatility criteria. The status of State and local regulatory activities concerning consumer products is discussed in Section 2.6.

Table 5-1, the principal output of the survey, presents content and emission data for each product category surveyed. Specifically, this table provides information for each category on (1) number of products reported; (2) product sales reported (tons); (3) RVOC content reported (tons); (4) estimated market coverage (i.e. what percentage of the market for a particular category was captured by the survey); (5) adjusted product sales (reported sales scaled up based on market coverage); (6) adjusted RVOC content (reported content scaled up based on market coverage); (7) RVOC content emitted (i.e., the percentage of the product's RVOC content which enters the ambient air after fate adjustments); (8) tons of RVOC emitted nationwide; (9) pounds of RVOC emitted per 10,000 persons; and (10) RVOC emissions in ozone nonattainment areas (tons).

Items 1, 2, and 3 were obtained directly from the survey responses. Item 4 (market coverage) was estimated based on information furnished by CSMA, CTFA, and SDA following their reviews of the initial results of the survey and lists of companies responding in each category[1,2,3]. Adjusted product sales (item 5) and adjusted RVOC content (item 6) were obtained by dividing reported sales and reported RVOC content by the estimated market coverage percentage. The adjustments were made in the following manner:

$$\frac{\textit{Tonnage Reported}}{\textit{Estimated Market Coverage}} = \textit{AdjustedTonnage}$$

Percent RVOC emitted was obtained by multiplying the RVOC content by a fate adjustment factor. The adjustment factor ranged from 1 percent to 100 percent and was based on information supplied by CSMA, CTFA, and SDA[1,2,3,4,5]. The fate adjustments were made to account for products which enter the wastewater stream and subsequently biodegrade rather than being emitted to the air. A fate adjustment factor of 100 percent means that all the RVOC content of the product is emitted to the air. Conversely, an adjustment factor of 1 means that only 1 percent of the RVOC are emitted.

Probably the most useful of the items in Table 5-1 are items 9 and 10. Data on emissions in ozone nonattainment areas will be used by the EPA in determining which categories will be targeted for regulation under §183(e). The *per capita* emission factors (in this case, pounds of RVOC emitted per 10,000 persons) will enable the EPA, States, and local environmental agencies to develop emission estimates for specific combinations of products based on population. This is by far the most comprehensive and accurate set of emission factors ever developed for consumer products.

In order for the EPA to assess the availability of lower-VOC alternatives, histograms were prepared for individual product categories which show the distribution of market share (by tons of product sold) at various levels of RVOC content. On these histograms, tons of product sold is plotted against RVOC content levels in 5 percent increments. By examining the histograms, the EPA can identify the distribution of high-VOC and low-VOC products and can use this information to assess the possible emission reductions which could be obtained from a given VOC limit. This information can also enable the EPA to determine (for a given category) to what extent lower-VOC alternatives are accepted by consumers. Due to space limitations, these histograms were not included in the inventory report.

Another useful output of the survey is a compilation of formulations for every product reported. Except in the confidential files of survey responses, the formulations are not identified by product brand name or manufacturer. To further protect the confidentiality of the formulation data, the products are presented in descending order of RVOC content within each category. This compilation is quite voluminous; for example, there were over 1,100 individual formulations of aerosol spray paints reported. Consequently, these formulations could not be included in the report, but can be used during the regulatory phase.

Another important output of the survey is information on individual chemical species contained in consumer products. This information will allow the EPA to identify those products which contain highly reactive compounds, compounds which are considered to be hazardous air pollutants, and/or toxics. Speciated content data can also provide needed information to EPA offices for use in risk assessment.

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
PERSONAL CARE PRODUCTS										
Hair Care Products										
1101 Bleaches and lighteners	21	2,936	101	95	3,091	106	10	11	1	7
1102 Brilliantines	4	6	0	95	6	0	100	0	0	0
1103 Conditioners	191	124,273	847	95	130,814	892	5	45	4	27
1104 Conditioning sprays	17	1,328	13	95	1,398	14	100	14	1	8
1105 Curl activators	20	1,160	1	95	1,221	1	100	1	0	1
1106 Curl revitalizers	9	792	170	95	834	179	100	179	14	107
1107 Dyes - Permanent	35	14,880	1,463	95	15,663	1,540	10	154	12	92
1108 Dyes - Semipermanent	12	3,161	34	95	3,327	36	10	4	0	2
1109 Dyes - Temporary	9	6,317	739	95	6,649	778	10	78	6	47
1110 Finishing hair sprays	126	168,742	152,152	94	179,513	161,864	100	161,864	13,054	97,118
1111 Finishing spritzes	17	7,051	6,115	95	7,422	6,437	100	6,437	519	3,862
1112 Grooming creams	16	1,338	4	95	1,408	4	100	4	0	2
1114 Mousses	61	18,498	2,300	95	19,472	2,421	100	2,421	195	1,453
1115 Permanent wave treatments	55	50,287	232	95	52,934	244	10	24	2	14
1116 Pomades	8	1,849	3	95	1,946	3	100	3	0	2
1118 Rinses	7	927	0	95	976	0	5	0	0	0

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
1119 Setting lotions	21	1,290	237	95	1,358	249	100	249	20	149
1120 Shampoos	237	276,639	1,596	95	291,199	1,680	5	84	7	50
1121 Spray shines	12	872	558	95	918	587	100	587	47	352
1122 Straighteners	2	5	0	95	5	0	10	0	0	0
1123 Styling gels	92	12,015	591	95	12,647	622	100	622	50	373
1124 Styling sprays	35	6,006	3,638	95	6,322	3,829	100	3,829	309	2,297
1125 Styling spritzes	27	8,996	7,096	95	9,469	7,469	100	7,469	602	4,481
1126 Thickeners	4	28	0	95	29	0	100	0	0	0
1127 Tonics	11	1,383	367	95	1,456	386	100	386	31	232
1199 Other hair care products	35	2,588	48	95	2,724	51	100	51	4	31
All Hair Care Products	**1,084**	**713,367**	**178,305**		**752,801**	**189,392**		**184,516**	**14,880**	**110,707**
Deodorants and Antiperspirants										
1201 Underarm deodorants	128	24,364	8,896	100	24,364	8,896	100	8,896	717	5,338
1202 Underarm antiperspirants	88	37,755	20,752	100	37,755	20,752	100	20,752	1,674	12,451
1203 Foot deodorant sprays	6	176	167	95	185	176	100	176	14	106
1204 Feminine hygiene deodorants	4	66	32	95	69	34	100	34	3	20
1299 Other deod/antiperspirants	5	345	81	95	363	85	100	85	7	51
All Deod/Antiperspirants	**231**	**62,706**	**29,928**		**62,736**	**29,943**		**29,943**	**2,415**	**17,966**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Fragrance Products										
1301 Colognes	357	10,217	8,461	95	10,755	8,906	100	8,906	718	5,344
1302 Perfumes	139	174	153	95	183	161	100	161	13	97
1303 Toilet waters	105	902	807	95	949	849	100	849	68	509
1304 After shave treatments	181	10,619	5,987	95	11,178	6,302	100	6,302	508	3,781
1305 Body fragrance sprays	37	1,728	1,562	95	1,819	1,644	100	1,644	133	986
1306 Bath oils, beads and capsules	72	9,649	153	95	10,157	161	5	8	1	5
1399 Other fragrance products	98	3,582	741	95	3,771	780	100	780	63	468
All Fragrance Products	**989**	**36,871**	**17,864**		**38,812**	**18,803**		**18,650**	**1,504**	**11,190**
Powders										
1401 Baby powders	27	87,535	10	95	92,142	11	100	11	1	7
1402 Body powders	65	3,418	17	95	3,598	18	100	18	1	11
1403 Foot powders	14	4,226	2,497	95	4,448	2,628	100	2,628	212	1,577
1499 Other powder products	60	2,389	847	95	2,515	892	100	892	72	535
All Powder Products	**166**	**97,568**	**3,371**		**102,703**	**3,549**		**3,549**	**286**	**2,130**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Nail Care Products										
1501 Polishes	42	2,642	1,467	95	2,781	1,544	100	1,544	125	926
1502 Base coats, undercoats	32	552	419	95	581	441	100	441	36	265
1503 Polish removers	45	7,669	5,973	95	8,073	6,287	100	6,287	507	3,772
1504 Nail extenders	5	11	0	95	12	0	100	0	0	0
1505 Cuticle softeners	13	104	0	95	109	0	10	0	0	0
1506 Manicure preparations	11	53	0	95	56	0	100	0	0	0
1599 Other nail care products	46	1,077	823	95	1,134	866	100	866	70	520
All Nail Care Products	**194**	**12,108**	**8,682**		**12,746**	**9,138**		**9,138**	**737**	**5,483**
Facial and Body Treatments										
1601 Astringents	110	14,785	5,449	95	15,563	5,736	100	5,736	463	3,442
1602 Creams, scrubs, cleaners	336	23,673	286	95	24,919	301	10	30	2	18
1603 Rouges and blushes	70	1,144	10	95	1,204	11	100	11	1	7
1604 Foundations & fixatives	182	3,973	122	95	4,182	128	100	128	10	77
1605 Lipsticks	194	905	3	95	953	3	100	3	0	2
1606 Moisturizers	356	13,679	90	95	14,399	95	100	95	8	57
1607 Skin lighteners	8	255	17	95	268	18	100	18	1	11

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
1608 Facial masques	82	1,477	8	95	1,555	8	100	8	1	5
1610 Mascara	65	907	122	95	955	128	100	128	10	77
1611 Eyeliner	34	129	11	95	136	12	100	12	1	7
1612 Eye shadow	44	399	6	95	420	6	100	6	0	4
1613 Eye makeup remover	32	484	0	95	509	0	100	0	0	0
1614 Eyebrow pencil	17	55	0	95	58	0	100	0	0	0
1615 Hand and body lotions	192	55,068	311	95	57,966	327	100	327	26	196
1616 Skin protectants	47	11,710	136	95	12,326	143	100	143	12	86
1617 Depilatories	12	1,488	6	95	1,566	6	10	1	0	1
1618 Self-tanning preparations	20	841	28	95	885	29	100	29	2	17
1619 Suntan oils and lotions	51	1,500	47	95	1,579	49	100	49	4	29
1620 Sunscreens	81	4,126	123	95	4,343	129	100	129	10	77
1699 Other facial/body treatments	111	2,943	235	95	3,098	247	100	247	20	148
All Facial/Body Treatments	**2,044**	**139,541**	**7,010**		**146,884**	**7,376**		**7,100**	**573**	**4,261**
Oral Care Products										
1701 Mouthwashes	60	123,082	23,932	77	159,847	31,081	5	1,554	125	932
1702 Breath fresheners	10	588	386	95	619	406	5	20	2	12
1703 Toothpastes, etc.	42	85,055	1,083	95	89,532	1,140	5	57	5	34

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
1704 Plaque removal solutions	11	31,279	2,111	95	32,925	2,222	5	111	9	67
1705 Fluoride rinses	10	8,744	562	95	9,204	592	5	30	2	18
1706 Dental care products	19	3,675	33	95	3,868	35	5	2	0	1
1799 Other oral care products	21	1,031	25	95	1,085	26	5	1	0	1
All Oral Care Products	**173**	**253,454**	**28,132**		**297,080**	**35,502**		**1,775**	**143**	**1,065**
Health Use Products (External Only)										
1801 Over-the-counter drugs	302	41,205	3,989	95	43,374	4,199	100	4,199	339	2,519
1802 Prescription pharmaceuticals	96	2,397	412	95	2,523	434	100	434	35	260
1899 Other health use products	150	9,960	1,538	95	10,484	1,619	100	1,619	131	971
All Health Use Products	**548**	**53,562**	**5,939**		**56,381**	**6,252**		**6,252**	**504**	**3,750**
Miscellaneous Personal Care Products										
1901 Hand cleaners and soaps	497	458,559	13,115	75	611,412	17,487	5	874	70	524
1902 Rubbing alcohol	30	35,230	23,027	95	37,084	24,239	100	24,239	1,955	14,543
1903 Shaving creams, gels, etc.	95	46,550	1,842	97	47,990	1,899	5	95	8	57
1999 Other misc. personal care	167	113,425	3,862	95	119,395	4,065	100	4,065	328	2,439
All Misc Pers Care Prod	**789**	**653,764**	**41,846**		**815,881**	**47,690**		**29,273**	**2,361**	**17,563**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
HOUSEHOLD PRODUCTS										
Hard Surface Cleaners										
2101 General purpose cleaners	1,176	476,656	25,425	90	529,618	28,250	5	1,413	114	848
2102 Glass cleaners	455	206,322	14,688	95	217,181	15,461	100	15,461	1,247	9,277
2103 Oven cleaners	127	27,177	1,734	95	28,607	1,825	100	1,825	147	1,095
2104 Tub, tile, and sink cleaners	226	54,161	2,576	95	57,012	2,712	50	1,356	109	814
2105 Mildew removers	21	18,805	15	100	18,805	15	100	15	1	9
2106 Toilet bowl cleaners	202	55,364	189	100	55,364	189	5	9	1	5
2107 Rust stain removers	34	3,337	1	100	3,337	1	100	1	0	1
2108 Metal cleansers	316	20,303	1,458	100	20,303	1,458	100	1,458	118	875
2109 Soap scouring pads	11	12,233	93	100	12,233	93	100	93	8	56
2199 Other hard surface cleaners	945	226,340	5,874	100	226,340	5,874	5	294	24	176
All Hard Surface Cleaners	**3,513**	**1,100,698**	**52,053**		**1,168,800**	**55,878**		**21,925**	**1,768**	**13,156**
Laundry Products										
2201 Detergents	274	2,289,441	41,027	81	2,826,470	50,651	1	507	41	304
2202 Soaps	13	20,535	1	73	28,130	1	1	0	0	0
2203 Presoaks	14	3,263	17	73	4,470	23	1	0	0	0

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
2204 Prewash spot removers	68	63,484	2,527	73	86,964	3,462	25	866	70	520
2205 Bleaches	79	809,638	714	58	1,395,928	1,231	1	12	1	7
2206 Whiteners/brighteners	17	16,229	16	73	22,232	22	1	0	0	0
2207 Bluing	2	161	0	73	221	0	1	0	0	0
2208 Fabric softeners	111	436,397	6,022	75	581,863	8,029	1	80	6	48
2209 Water conditioners	20	39,658	10	73	54,326	14	1	0	0	0
2210 Starches, sizings, etc.	36	92,813	4,404	73	127,141	6,033	100	6,033	487	3,620
2299 Other laundry products	53	22,837	1,284	73	31,284	1,759	1	18	1	11
All Laundry Products	**687**	**3,794,456**	**56,022**		**5,159,029**	**71,225**		**7,516**	**606**	**4,510**
Fabric and Carpet Care Products										
2301 Carpet cleaners	314	42,843	1,529	100	42,843	1,529	50	765	62	459
2302 Carpet deodorizers	64	21,458	222	100	21,458	222	100	222	18	133
2303 Upholstery cleaners	30	2,065	197	100	2,065	197	100	197	16	118
2304 Spot removers	192	5,103	984	100	5,103	984	100	984	79	590
2305 Fabric stain repellants	66	4,886	1,042	95	5,143	1,097	100	1,097	88	658
2306 Water repellants	7	205	3	50	410	6	100	6	0	4
2307 Fabric dyes	4	33	0	100	33	0	5	0	0	0
2308 Antistatic sprays	35	106	22	50	212	44	100	44	4	26

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

	Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
2309	Dry cleaning fluids	12	1,690	1,630	100	1,690	1,630	100	1,630	131	978
2399	Other fabric/carpet care	82	2,999	154	100	2,999	154	100	154	12	92
	All Fabric/Carpet Care	**806**	**81,388**	**5,783**		**81,956**	**5,863**		**5,099**	**411**	**3,058**
Dishwashing Products											
2401	Dish detergents (manual)	226	497,400	22,708	78	637,692	29,113	5	1,456	117	874
2402	Dish detergents (machine)	120	303,994	3,370	79	384,803	4,266	2	85	7	51
2403	Rinse aids	71	6,554	88	73	8,978	121	1	1	0	1
2404	Film and spot removers	16	361	1	73	495	1	1	0	0	0
2499	Other dishwashing products	42	1,790	4	73	2,452	5	1	0	0	0
	All Dishwashing Products	**475**	**810,099**	**26,171**		**1,034,420**	**33,506**		**1,542**	**124**	**926**
Waxes and Polishes											
2501	Furniture waxes and polishes	186	30,314	3,406	95	31,909	3,585	100	3,585	289	2,151
2502	Floor waxes and polishes	631	154,969	3,667	95	163,125	3,860	100	3,860	311	2,316
2503	Dusting aids	110	3,627	559	90	4,030	621	100	621	50	373
2599	Other waxes and polishes	74	19,391	501	90	21,546	557	100	557	45	334
	All Waxes and Polishes	**1,001**	**208,301**	**8,133**		**220,610**	**8,623**		**8,623**	**695**	**5,174**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category		Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Air Fresheners											
2601	Room air fresheners	376	114,686	25,410	95	120,722	26,747	100	26,747	2,157	16,048
2602	Toilet deodorant blocks	56	7,246	6,648	75	9,661	8,864	50	4,432	357	2,659
2699	Other air fresheners	146	9,824	1,916	90	10,916	2,129	100	2,129	172	1,277
	All Air Fresheners	**578**	**131,756**	**33,974**		**141,299**	**37,740**		**33,308**	**2,686**	**19,984**
Shoe and Leather Care Products											
2701	Leather treatments	21	287	101	100	287	101	100	101	8	61
2703	Shoe polishes	7	243	43	50	486	86	100	86	7	52
2799	Other leather care products	14	235	85	75	313	113	100	113	9	68
	All Shoe & Leather Care	**42**	**765**	**229**		**1,086**	**300**		**300**	**24**	**181**
Miscellaneous Household Products											
2801	Lubricants	253	6,500	1,641	50	13,000	3,282	100	3,282	265	1,969
2802	Drain openers	80	18,278	386	100	18,278	386	1	4	0	2
2803	Charcoal lighters	16	86,340	35,653	90	95,933	39,614	10	3,961	319	2,377
2804	Wick lamp fuels	21	7,716	5,963	90	8,573	6,626	10	663	53	398

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
2805 Plant leaf cleaners and waxes	7	53	6	100	53	6	100	6	0	4
2806 Driveway cleaners	17	216	3	90	240	3	100	3	0	2
2899 Other misc. HH products	195	21,299	5,031	90	23,666	5,590	100	5,590	451	3,354
All Misc Household Prod	**589**	**140,402**	**48,683**		**159,743**	**55,507**		**13,509**	**1,089**	**8,106**
AUTOMOTIVE AFTERMARKET PRODUCTS										
Detailing Products										
3101 Waxes, polishes, sealers	271	15,954	3,924	95	16,794	4,131	100	4,131	333	2,479
3102 Vinyl and leather cleaners	43	1,163	157	95	1,224	165	100	165	13	99
3103 Upholstery fabric cleaners	34	2,707	226	95	2,849	238	100	238	19	143
3104 Tire cleaners	66	5,089	383	90	5,654	426	100	426	34	256
3105 Wheel cleaners	41	2,703	142	90	3,003	158	100	158	13	95
3106 Bug and tar removers	44	1,327	858	95	1,397	903	100	903	73	542
3107 Chrome cleaners, polishes	16	528	103	95	556	108	100	108	9	65
3108 Rubber and vinyl protectants	65	2,851	1,101	95	3,001	1,159	100	1,159	93	695
3199 Other detailing products	226	16,846	1,622	90	18,718	1,802	100	1,802	145	1,081
All Auto Detailing Products	**806**	**49,168**	**8,516**		**53,196**	**9,090**		**9,090**	**733**	**5,455**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Maintenance and Repair Products										
3201 Engine degreasers	175	17,518	10,506	98	17,876	10,720	25	2,680	216	1,608
3202 Carburetor, choke cleaners	140	12,704	11,159	95	13,373	11,746	50	5,873	474	3,524
3203 Brake cleaners	93	15,219	3,772	95	16,020	3,971	100	3,971	320	2,383
3204 Brake anti-squeal compounds	19	281	18	95	296	19	100	19	2	11
3205 Tire sealants and inflators	20	10,956	3,260	100	10,956	3,260	100	3,260	263	1,956
3206 Belt dressings	34	337	54	100	337	54	100	54	4	32
3207 Engine starting fluids	32	4,592	4,099	90	5,102	4,554	50	2,277	184	1,366
3208 Lubricants (exc engine oil)	482	70,325	17,342	100	70,325	17,342	100	17,342	1,399	10,405
3209 Antifreezes	49	217,527	0	90	241,697	0	100	0	0	0
3210 Brake fluids	28	27,033	5,468	90	30,037	6,076	100	6,076	490	3,646
3211 Body repair (exc coatings)	99	11,171	472	90	12,412	524	100	524	42	314
3212 Windshield deicers	46	3,944	2,031	100	3,944	2,031	100	2,031	164	1,219
3213 Windshield washer fluids	84	128,913	48,313	60	214,855	80,522	100	80,522	6,494	48,313
3299 Other repair products	599	58,863	39,356	90	65,403	43,729	100	43,729	3,527	26,237
All Auto Maint/Rep Prod	**1,900**	**579,383**	**145,850**		**702,633**	**184,548**		**168,358**	**13,577**	**101,014**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
ADHESIVES AND SEALANTS										
Consumer Adhesives										
4101 Household glues and pastes	41	12,312	287	90	13,680	319	100	319	26	191
4102 Arts and crafts adhesives	37	2,780	481	90	3,089	534	100	534	43	320
4103 Carpet and tile adhesives	95	72,345	4,365	90	80,383	4,850	100	4,850	391	2,910
4104 Wallpaper adhesives	6	2,103	3	90	2,337	3	100	3	0	2
4105 Woodworking glues	42	21,745	571	90	24,161	634	100	634	51	380
4106 Pipe cements and primers	29	5,896	5,049	90	6,551	5,610	100	5,610	452	3,366
4107 Thread locking compounds	14	2,493	7	90	2,770	8	100	8	1	5
4108 Automotive adhesives	121	52,060	1,937	90	57,844	2,152	100	2,152	174	1,291
4109 Construction adhesives	166	138,965	28,367	90	154,406	31,519	100	31,519	2,542	18,911
4199 Other adhesives	540	102,249	19,781	90	113,610	21,979	100	21,979	1,773	13,187
All Consumer Adhesives	**1,091**	**412,948**	**60,848**		**458,831**	**67,608**		**67,608**	**5,452**	**40,563**
Sealants										
4201 Spackling compounds	19	20,551	9	90	22,834	10	100	10	1	6
4202 Caulking compounds	132	75,689	2,340	90	84,099	2,600	100	2,600	210	1,560
4203 Window glazing compounds	33	16,275	237	90	18,083	263	100	263	21	158

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
4204 Pipe thread sealants	18	1,238	16	90	1,376	18	100	18	1	11
4205 Plumbers putties	1	443	0	90	492	0	100	0	0	0
4206 Painters putties	1	2	0	90	2	0	100	0	0	0
4207 Wood fillers	24	2,395	635	90	2,661	706	100	706	57	424
4208 Insulating and sealing foams	14	5,176	8	90	5,751	9	100	9	1	5
4209 Driveway patch compounds	48	3,108	137	90	3,453	152	100	152	12	91
4210 Cold process roof cements	38	3,633	1,220	90	4,037	1,356	100	1,356	109	814
4299 Other sealants	343	51,459	2,753	90	57,177	3,059	100	3,059	247	1,835
All Sealants	**671**	**179,969**	**7,355**		**199,965**	**8,173**		**8,173**	**659**	**4,904**
FIFRA-REGULATED PRODUCTS										
Insecticides										
5101 Lawn and garden insecticides	276	57,946	6,599	75	77,261	8,799	100	8,799	710	5,279
5102 Space insecticides, foggers	167	23,283	3,480	95	24,508	3,663	100	3,663	295	2,198
5103 Flying insect sprays	151	15,920	5,465	95	16,758	5,753	100	5,753	464	3,452
5104 Residual insecticides	256	43,950	16,320	95	46,263	17,179	100	17,179	1,385	10,307
5105 Hornet and wasp sprays	69	4,385	1,206	95	4,616	1,269	100	1,269	102	761
5106 Flea and tick products	117	11,306	2,602	95	11,901	2,739	100	2,739	221	1,643
5199 Other insecticides	339	94,480	16,039	90	104,978	17,821	100	17,821	1,437	10,693

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
All Insecticides	**1,375**	**251,270**	**51,711**		**286,285**	**57,223**		**57,223**	**4,615**	**34,333**
Fungicides & Nematicides										
5201 Lawn and garden treatments	62	3,833	381	90	4,259	423	100	423	34	254
5202 Wood preserv. (AIM)	0	0	0	100	0	0	100	0	0	0
5203 Mold and mildew retardants	7	440	23	100	440	23	100	23	2	14
5299 Other fungicides/nematicides	101	64,597	23,312	90	71,774	25,902	100	25,902	2,089	15,541
All Fungicides/Nematicides	**170**	**68,870**	**23,716**		**76,473**	**26,348**		**26,348**	**2,125**	**15,809**
Herbicides										
5301 Aquatic herbicides	16	13,814	15	90	15,349	17	5	1	0	1
5302 Swimming pool algicides	42	9,352	183	90	10,391	203	5	10	1	6
5303 Herbicides, defoliants	400	328,636	43,143	100	328,636	43,143	100	43,143	3,479	25,886
5399 Other herbicides	63	86,289	20,164	100	86,289	20,164	100	20,164	1,626	12,098
All Herbicides	**521**	**438,091**	**63,505**		**440,665**	**63,527**		**63,318**	**5,106**	**37,991**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category		Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Antimicrobial Agents											
5401	Sanitizers	161	65,585	1,559	100	65,585	1,559	50	780	63	468
5402	Disinfectants	644	364,103	28,651	99	367,781	28,940	50	14,470	1,167	8,682
5403	Sterilants	20	13,597	2,373	90	15,108	2,637	75	1,978	160	1,187
5499	Other antimicrobial agents	96	8,876	344	100	8,876	344	75	258	21	155
	All Antimicrobial Agents	**921**	**452,161**	**32,927**		**457,350**	**33,480**		**17,486**	**1,410**	**10,492**
Other FIFRA-Regulated Products											
5501	Insect repellants	69	10,183	7,951	99	10,286	8,031	100	8,031	648	4,819
5502	Cat and dog repellants	20	1,323	168	100	1,323	168	100	168	14	101
5503	Rodent poisons and baits	31	3,148	12	100	3,148	12	100	12	1	7
5599	Misc other FIFRA products	116	43,054	29,853	100	43,054	29,853	100	29,853	2,408	17,912
	All Other FIFRA Products	**236**	**57,708**	**37,984**		**57,811**	**38,064**		**38,064**	**3,070**	**22,839**
COATINGS AND RELATED PRODUCTS (Except Architectural and Industrial Maintenance Coatings)											
Aerosol Spray Paints											
6101	Nonflat enamels	168	54,694	40,414	100	54,694	40,414	100	40,414	3,259	24,248

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
6102 Flat enamels	67	15,432	8,514	100	15,432	8,514	100	8,514	687	5,108
6103 Nonflat lacquers	85	9,919	8,054	100	9,919	8,054	100	8,054	650	4,832
6104 Flat lacquers	45	2,092	1,651	100	2,092	1,651	100	1,651	133	991
6105 Metallic pigmented coatings	90	6,039	5,065	100	6,039	5,065	100	5,065	408	3,039
6106 Clear coatings	111	4,251	3,643	100	4,251	3,643	100	3,643	294	2,186
6107 Traffic marking coatings	47	5,348	3,323	100	5,348	3,323	100	3,323	268	1,994
6108 Exact match auto paints	29	1,956	1,487	100	1,956	1,487	100	1,487	120	892
6109 Vinyl/fabric coatings	5	255	214	100	255	214	100	214	17	128
6110 Glass coatings	5	681	14	100	681	14	100	14	1	8
6111 Automotive sanding primers	50	3,587	2,840	100	3,587	2,840	100	2,840	229	1,704
6112 Rust-inhibitive primers	107	5,075	3,706	100	5,075	3,706	100	3,706	299	2,224
6113 Spatter finishes	7	1,014	628	100	1,014	628	100	628	51	377
6114 Wood stains	11	1,659	222	100	1,659	222	100	222	18	133
6115 Engine enamels	44	3,619	2,967	100	3,619	2,967	100	2,967	239	1,780
6116 High temperature coatings	38	2,273	1,900	100	2,273	1,900	100	1,900	153	1,140
6199 Other aerosol spray paints	255	13,447	3,702	100	13,447	3,702	100	3,702	299	2,221
All Aerosol Spray Paints	**1,164**	**131,341**	**88,344**		**131,341**	**88,344**		**88,344**	**7,125**	**53,005**

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
Coating-Related Products										
6201 Paint thinners (non-auto)	52	14,093	14,061	90	15,659	15,623	100	15,623	1,260	9,374
6202 Paint removers	214	14,335	5,333	90	15,928	5,926	100	5,926	478	3,556
6203 Brush cleaners	14	434	370	90	482	411	100	411	33	247
6204 Packaged solvents	346	41,705	31,115	90	46,339	34,572	100	34,572	2,788▲	20,743
6299 Other related products	157	22,107	3,721	90	24,563	4,134	100	4,134	333	2,480
All Coating Related Prod	**1,083**	**92,674**	**54,600**		**102,971**	**60,666**		**60,666**	**4,892**	**36,400**
MISCELLANEOUS PRODUCTS (Not Otherwise Covered)										
Arts and Crafts Supplies										
7101 Artists paints, thinners	16	1,017	577	90	1,130	641	100	641	52	385
7102 Fixative sprays	6	143	87	90	159	97	100	97	8	58
7103 Specialty cleaning products	43	1,182	643	90	1,313	714	100	714	58	428
7104 Ceramic finishing products	15	393	19	90	437	21	100	21	2	13
7199 Other arts and crafts supplies	36	2,209	526	90	2,454	584	100	584	47	350
All Arts & Crafts Supplies	**116**	**4,944**	**1,852**		**5,493**	**2,057**		**2,057**	**166**	**1,234**
Non-Pesticidal Veterinary and Pet Products										

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
7201 Animal drugs (external only)	67	15,399	256	100	15,399	256	100	256	21	154
7202 Animal grooming products	49	1,621	126	100	1,621	126	100	126	10	76
7203 Cat litters	9	191,761	262	60	319,602	437	100	437	35	262
7299 Other vet and pet products	95	5,810	37	100	5,810	37	100	37	3	22
All Pet/Vet Products	**220**	**214,591**	**681**		**342,432**	**856**		**856**	**69**	**514**
Pressurized Food Products										
7302 Pan sprays	35	9,408	2,584	95	9,903	2,720	100	2,720	219	1,632
7303 Whipped dessert toppings	9	6,837	107	90	7,597	119	100	119	10	71
7399 Other pressurized products	2	142	0	90	158	0	100	0	0	0
All Pressurized Food Prod	**46**	**16,387**	**2,691**		**17,658**	**2,839**		**2,839**	**229**	**1,703**
Office Supplies										
7401 Pens	26	5,931	16	25	23,724	64	100	64	5	38
7402 Ink	7	32	2	25	128	8	100	8	1	5
7403 Permanent markers	17	603	14	25	2,412	56	100	56	5	34
7404 Dry erasable markers	4	76	0	25	304	0	100	0	0	0
7405 Highlighters	7	478	2	25	1,912	8	100	8	1	5
7406 Correction fluids	1	0	0	25	0	0	100	0	0	0

TABLE 5-1 RESULTS OF THE CONSUMER PRODUCTS SURVEY (Continued)

Product Category	Products Reported (Number)	Product Sales Reported (Tons)	RVOC Content Reported (Tons)	Estimated Market Coverage (Percent)	Adjusted Product Sales (Tons)	Adjusted RVOC Content (Tons)	RVOC Content Emitted (Pct)	RVOC Emitted in U.S. (Tons)	Emissions per 10,000 Persons (Pounds)	Emissions Nonattain Areas (Tons)
7408 Inked ribbons	1	307	0	25	1,228	0	100	0	0	0
7499 Other office supplies	13	1,426	692	25	5,704	2,768	100	2,768	223	1,661
All Office Supplies	**76**	**8,853**	**726**		**35,412**	**2,904**		**2,904**	**234**	**1,743**
ALL SURVEYED CATEGORIES	**24,005**	**11,249,164**	**1,133,431**		**13,621,483**	**1,262,014**		**995,352**	**80,270**	**597,209**

Notes on Results of the Consumer Products Survey

1. Reportable volatile organic compounds (RVOC) are a subset of VOC (EPA's definition of VOC can be found in 57 FR 3941, February 3, 1992). RVOC are those VOC which have a vapor pressure greater than 0.1 mm Hg at 20°C or which, if the vapor pressure is unknown, contain 12 or less carbon atoms. Those VOC which exist as solids at 20°C and readily sublime or become vapors at the temperature at which they are used are also RVOC.

2. Figures for ***Products Reported, Product Sales Reported,*** and ***RVOC Content Reported*** were obtained directly from the survey responses.

3. ***Estimated Market Coverage*** information was obtained from CSMA, CTFA, and SDA.

4. ***Adjusted Product Sales*** and ***Adjusted RVOC Content*** were obtained by dividing ***Product Sales Reported*** and ***RVOC Content Reported*** by ***Estimated Market Coverage***.

5. ***Percent RVOC Content Emitted*** is based on information submitted by CSMA, CTFA, and SDA. This factor accounts for biodegradation or other fates (other than being emitted to the air) of consumer product RVOC which enter the wastewater stream.

6. ***RVOC Emitted in U.S.*** was obtained by multiplying ***Adjusted RVOC Content*** by ***Percent RVOC Content Emitted*** and reflects actual RVOC emissions to the air.

7. ***Emissions per 10,000 Persons*** was obtained by dividing ***RVOC Emitted in U.S.*** by the U.S. population (248 million) and multiplying by 10,000.

8. ***Emissions in Ozone Nonattainment Areas*** was obtained by multiplying ***RVOC Emitted in U.S.*** by 0.60, which is the fraction of U.S. population living in ozone nonattainment areas
   (148 million / 248 million ≈ 0.5968 = 0.60).

5.4 INDUSTRIAL PRODUCTS AFFECTED BY EXISTING FEDERAL PROGRAMS

This segment of the consumer and commercial products inventory includes those products which are used industrially and are affected by existing or ongoing regulations developed by the EPA and/or by the States. These products include a wide range of surface coatings, metal cleaning solvents, adhesives, inks, agricultural pesticides, asphalt paving materials, and a host of others. Estimates of VOC emissions from these products were obtained from background documentation developed for the respective regulations or guidance documents. Emission estimates for previously regulated categories are based on "residual" emissions (i.e., emissions which continue after controls have been applied). Estimates for categories associated with ongoing standards development are 1990 "baseline" emission estimates from those categories (i.e, emissions before any controls have been applied).

5.4.1 Emission Estimates

The purpose of this inventory study was to develop estimates of VOC emissions in ozone nonattainment areas. Accordingly, the estimates presented in this report reflect nonattainment area emissions. For many of the industrial products discussed in this section, estimates were developed based on actual locations of emission sources, and include only those emissions in nonattainment areas. For categories for which specific locations of sources are unknown, the scaling method discussed in Section 5.2 was used to apportion emissions based on population distribution.

Table 5-2 presents a summary of VOC emissions in nonattainment areas attributable to industrial products and activities subject to §183(e) for which federal regulatory programs are existing or under development. Section 5.4.2 contains descriptions of the products and processes listed in Table 5-2.

TABLE 5-2

VOC EMISSIONS IN NONATTAINMENT AREAS FOR PRODUCTS AFFECTED BY EXISTING FEDERAL REGULATORY PROGRAMS

Category	Nonattainment Emissions (tons/yr)	Year of Estim	Ref	Federal Control Measure
Architect & indust maint coatings	315,000 [a]	1990	7	B[b]
Automobile refinishing products	55,000 [a]	1990	8	A, B[b]
Aerospace paints and coatings	107,500	1990	9	M[b], C[b]
Wood furniture coatings	60,000	1990	10	M[b], C[b]
Ship and boat coatings	15,100	1990	11	A, M[b], C[b]
Metal furniture coatings	63,000 [a]	1985	12	C, N
Flat wood paneling coatings	20,000 [a]	1985	12	C
Large appliance coatings	15,600 [a]	1985	12	C, N
Magnet wire coatings	4,800 [a]	1985	12	C
Metal can coatings	45,000 [a]	1985	12	C, N
Metal coil coatings	21,600 [a]	1985	12	C, N
Other metal product coatings	218,400 [a]	1985	12	C
Auto and light truck assy coatings	75,000	1990	12	C, N
Paper, film, and foil coatings	65,000	1985	12	C
Magnetic tape coatings	5,500	1990	12	C, N, M
Business mach plastic part coating	5,500	1990	12	C[b], N
Automotive plastic part coatings	16,500	1990	12	C[b]
Flexible packaging printing	150,000	1990	12	C, M[b]
Rotogravure publication printing	20,000	1990	12	C, N, M[b]
Lithographic printing	600,000	1990	12	A
Letterpress printing	28,200 [a]	1985	12	
Tire manufacturing cements	26,400 [a]	1985	12	C, N
Miscellaneous industrial adhesives	201,600 [a]	1985	12	

TABLE 5-2 (Continued)

VOC EMISSIONS IN NONATTAINMENT AREAS FOR PRODUCTS AFFECTED BY EXISTING FEDERAL REGULATORY PROGRAMS

Category	Nonattainment Emissions (tons/yr)	Year of Estim	Ref	Federal Control Measure
Metal cleaning (degreasing)	36,000	1990	12	C, N, M
Industrial cleaning solvents	150,000 [a]	1990	13	A
Petroleum drycleaning solvents	54,600 [a]	1985	12	C, N
Agricultural pesticides	15,000 [a]	1987	14	A
Cutback asphalt paving materials	128,400 [a]	1985	12	C
Synthetic fiber spinning solvents	46,200 [a]	1985	12	N
Fabric coating	21,000 [a]	1985	12	C, N
Fabric printing	25,200 [a]	1985	12	
TOTAL FOR THIS TABLE	2,611,100			

a Nonattainment area emission estimates were obtained by adjusting nationwide estimates according to the distribution of nationwide population in nonattainment areas in 1990. Estimates for categories without this footnote were developed for nonattainment areas and needed no adjustment.

$$\frac{\text{148 million (nonattainment areas)}}{\text{248 million (nationwide)}} = 59.68\% \approx 60\%$$

b Document or regulation currently being developed

A Alternative Control Techniques Document (ACT)

B Regulation requiring Best Available Controls under §183(e)

C Control Techniques Guidelines Document (CTG)

M Maximum Achievable Control Technology (MACT) Standard

N New Source Performance Standards (NSPS)

5.4.1 Architectural and Industrial Maintenance Coatings [7]

The U.S. architectural and industrial maintenance (AIM) coating industry is composed of roughly 500 manufacturers. This wide array of AIM coatings are used by do-it-yourself, professional, and industrial painters. These coatings include house paints, wood finishes, cement coatings, roof coatings, traffic paints, and industrial maintenance coatings. For purposes of regulation, AIM coatings have been further classified into numerous coating categories. These categories include:

Alkali Resistant Primers
Antenna Coatings
Anti-fouling Coatings
Anti-Graffiti Coatings
Bituminous Coatings & Mastics
Bond Breakers
Chalkboard Resurfacers
Concrete Curing Compounds
Concrete Protective Coatings
Dry Fog Coatings
Extreme High Durability Coatings
Fire-Retardant/Resistive Coatings
Flat Coatings
Floor Coatings
Flow Coatings
Form Release Compounds
Graphic Arts Coatings
Heat Reactive Coatings
High Temperature Coatings
Impacted Immersion Coatings
Industrial Maintenance (I/M) Coatings
Lacquers
Lacquer Stains
Magnesite Cement Coatings
Mastic Texture Coatings
Metallic Pigmented Coatings
Multi-Color Coatings
Non-Flat Coatings
Nuclear Power Plant Coatings
Ornamental Metal Lacquers
Pre-Treatment Wash Primers
Primers and Undercoaters
Quick Dry Coatings
Repair/Maint Thermoplastic Coatings
Roof Coatings
Rust Preventative Coatings
Sanding Sealers
Sealers
Shellacs
Stains
Swimming Pool Coatings
Thermoplastic Rubber Coatings
Traffic Marking Paints
Varnishes
Waterproofing Sealers
Wood Preservatives

5.4.2 Automobile Refinishing Products [8]

The steps involved in automobile refinishing include surface preparation, coating application, and spray equipment cleaning. Each of these steps can be a source of VOC emissions. Emissions can be reduced by using waterborne surface preparation products, and by using coatings that are inherently low in VOC, such as urethanes. Emissions could also be reduced by reformulating conventional coatings to lower their VOC content. Improved transfer efficiency reduces VOC emissions by decreasing the amount of coating overspray. Gun cleaning equipment that controls evaporative losses also recirculates solvent for several cleanings to reduce solvent use.

Gun cleaning is a source of solvent emissions. Spray equipment can be cleaned manually with little to no control of evaporative emissions or with gun cleaning equipment designed to reduce solvent consumption, evaporation, and worker exposure. Solvent may be emitted from gun cleaning equipment both during actual cleaning operation (active losses) and during standby (passive losses). An estimated 60 percent reduction in VOC emissions is achieved by shops that switch from cleaning guns manually to a gun cleaner.

5.4.3 Aerospace Coatings [9]

The most common coatings used are the broad categories of non-specialized primers and topcoats. There are also numerous specialty coatings ranging from temporary protective coatings to radiation effect coatings designed to shield aircraft from radar detection. Coatings are applied to aerospace vehicles and components using several methods of application. The methods most commonly used are spraying, brushing, rolling, flow coating, and dipping. Spray application systems include conventional air spray, airless spray, air-assisted airless, electrostatic, and high volume low pressure spray. Emissions from coating applications occur from the evaporation of the solvents during mixing, application, drying, and overspray.

5.4.4 Wood Furniture Coatings [10]

Wood furniture coatings are used in the manufacture of furniture. Adhesives are used in assembling furniture components, in laminating veneers, and in installing upholstery. Solvents are used to thin coatings, to remove coatings from furniture that did not meet specifications, and to clean equipment.

Formaldehyde may be emitted from conversion varnishes, a type of coating used to finish kitchen cabinets and some office furniture. Styrene may be emitted from some ultraviolet light cured coatings and polyester coatings.

5.4.5 Ship and Boat Coatings [11]

Emissions from shipyard operations are primarily VOC emissions that result from painting operations. Emissions of VOC from painting operations result in three components: (1) organic solvent in the paint "as supplied" by the paint manufacturer, (2) organic solvent in the thinner, which is added to the paint prior to application and becomes part of the paint "as applied", and (3) any additional volatile organic released during the cure. The organic solvents from both components are emitted as the applied paint dries/cures. This organic solvent portion of a paint is composed of a mixture of different solvents that perform either of two equally important functions: (1) reduce viscosity so the paint can be atomized as it leaves the spray gun, or (2) provide essential surface characteristics of the paint once it is applied. Solvents used for atomization typically have low boiling points and flash to a vapor upon leaving the spray gun. These solvents evaporate relatively quickly during initial drying to prevent excessive flow. Solvents responsible for imparting the desired surface characteristics must have higher boiling points and subsequently evaporate more slowly than atomizing solvents to allow sufficient leveling and adhesion. Of the solvents used in marine paints, most are VOC.

5.4.6 Metal Furniture Coatings [12]

Metal furniture coating consists of the application of prime and top coatings to any piece of metal furniture or metal part included in the categories of household furniture, office furniture, public building and related furniture, and partitions and fixtures. Typically, the metal substrate is first cleaned, rinsed in a phosphate bath, and oven-dried to improve coating adhesion. If a prime coat is necessary, the part may be dipped, sprayed, or flow coated and then dried in a curing oven. Subsequent topcoats, or in the event no prime is required, the single topcoat is usually by spray. The freshly coated parts are conveyed to the oven through a flash-off tunnel during which the coating "flows out" to a uniform thickness and some of the solvent evaporates. The parts are baked in single or multi-pass ovens at 150-230°C.

Specific emission sources on the coating line are the coating application, the flash-off area, and the bake oven. On the average conveyorized spray coating line, it is estimates that about 40 percent of the total VOC emissions come from the application station, 30 percent from the flash-off area, and 30 percent from the bake oven. In addition, fugitive emissions also occur during mixing and transfer of coatings.

5.4.7 Flat Wood Paneling Coatings [6]

A typical flat wood coating facility applies stains and varnishes to natural plywood panels used for wall coverings. Other plants print wood grain patterns on particle board panels that were first undercoated with an opaque coating to mask the original surface. Coatings applied to flat wood paneling include fillers, sealers, "groove" coats, primers, stains, basecoats, inks, and topcoats. Most coatings are applied by direct roll coating. Filler is usually applied by reverse roll coating. The offset rotogravure process is used where the coating and printing operation requires precision printing techniques. Other coating methods include spray techniques, brush coating, and curtain coating. A typical flat wood paneling coating line includes a succession of coating operations. Each individual operation consists of the application of one or more coatings followed by a heated oven to cure the coatings.

Emission of VOC from a flat wood coating occurs primarily at the coating line, although some emissions also occur at pain mixing and storage areas. All solvent that is not recovered can be considered a potential emission.

5.4.8 Large Appliance Coatings [12]

Large appliance products include kitchen ranges, ovens, microwave ovens, refrigerators, freezers, washers, dryers, dishwashers, water heaters, and trash compactors. A "large appliance surface-coating line" consists of the coating operations for a single assembly line within an appliance assembly plant. Typically, the metal substrate is first cleaned, rinsed in a phosphate bath, and oven dried to improve coating adhesion. If a prime coat is necessary, the part may be dipped, sprayed, or flow-coated and dried in a curing oven. Subsequently, the topcoat is applied, usually by spray. The fresh coated parts are conveyed through a flash-off tunnel to evaporate solvent and cause the coating to flow our properly. After coating and flash-off, the parts are baked in single or multipass ovens at 150-230°C. Major emissions occur at the application (spray booth) area, flash-off area, and the curing oven. Fugitive emissions occur during mixing of coatings.

5.4.9 Magnet Wire Coatings [12]

Magnet wire coating is the process of applying a coating of electrically insulating varnish or enamel to aluminum or copper wire for use in electrical machinery. The uncoated wire is unwound from spools and passed through an annealing furnace to make the wire more pliable and to burn off oil and dirt left from previous operations. The wire passes from the furnace to the coating applicator. At a typical applicator, the wire acquires a thick coating by passage through a coating bath. The wire is then drawn vertically through an orifice or coating die which scrapes off excess coating and leaves a film of the desired thickness. The wire is routed from the coating die into an oven where the coating is dried and cured. A typical oven has two zones. The wire enters the drying zone, held at 200°C, and exits through the curing zone, held at 430°C. A wire may pass repeatedly through the coating applicator and oven to build a multilayered coating. After the final pass through the oven, the wire is rewound on a spool for shipment. There are approximately 30 plants nationwide which coat magnet wire.

The oven exhaust is the most important emission source in the wire coating process. Solvent emissions from the applicator are low due to the dip coating technique.

5.4.10 Metal Can Coatings [12]

The coatings used depend on the type of can and the type of product to be packed in the can. A "three-piece" can is made from a cylindrical body and two end pieces. A large metal sheet is first roll coated with both an exterior and an interior coatings, then cut to size, rolled into a cylinder (body) and sealed at the side seam. A bottom end piece formed from coated metal is then attached to the body. The can interior may then be spray coated before the can is filled with a product and sealed with the top end piece. A "two-piece can body and bottom is drawn and wall ironed from a single shallow cup. After the can is formed, exterior and interior coatings are applied by roll coating and spraying techniques, respectively. The can is then filled with product and the top end piece is attached.

Solvent emissions from can coating operations occur from the application area, flash-off area, and the curing/drying oven. Emissions vary with production rate, VOC content of coatings used, and other factors.

5.4.11 Metal Coil Coatings [12]

The metal coil coating industry applies coatings to metal sheets or strips that come in rolls or coils. The metal strip is uncoiled at the beginning of the coating line, cleaned, and then pretreated to promote adhesion of the coating to the metal surface. When the coil reaches the coating application station, a coating is applied, usually by rollers, to one or both sides of the metal strip. Some coil coatings are applied by electrodeposition. The strip then passes through an oven to cure the coating and is then water or air quenched.

Approximately 90 percent of the total VOC content of the coating evaporates in the curing ovens. Of the remaining 10 percent, about 8 percent evaporates at the applicator station and 2 percent at the quench station. The rate at which VOC emissions occur is determined by the operating parameters of the line, including: (1) the width of the metal strip, (2) the VOC and solids content of the coating, (3) the speed at which the strip is processed, (4) the thickness at which the coating is applied, and (5) whether emission abatement equipment has been installed.

5.4.12 Other Metal Product Coatings[12]

The original equipment manufacturers discussed here have been referred to by a variety of names, including coaters of miscellaneous metal parts. The category includes hundreds of small- and medium-sized industries and their companies which coat metal parts for which more specific regulatory guidance was not published as part of the guideline series (i.e., can, coil, wire, automobile and light-duty truck, metal furniture, and large appliances).

Organic emissions from coating miscellaneous metal parts and products are emitted from the application, flash-off area, and the bake oven (if used). The bulk of VOC emitted by lines which spray or flow coat, evaporates from the application and flash-off areas. For dip-coating operations, the bulk of the VOC is emitted from the flash-off area and bake oven. Fugitive emissions also occur during mixing and transfer of coatings.

5.4.13 Auto and Light Truck Assembly Coatings[12]

The automobile and light-duty (less than 8,500 pounds gross vehicle weight) truck assembly industry receives parts from a variety of sources and produces finished vehicles ready for sale to vehicle dealers. The automobile and light-duty truck coating process is a multistep operation performed on an assembly line producing up to 90 units per hour. There were about 65 automobile or light-duty truck assembly plants in the United States in 1984.

Body surfaces to be coated are cleaned with various materials which may include solvents to remove oil and grease. Then a phosphating process prepares the surface for the prime coat. The primer is applied to protect metal surfaces from corrosion and to ensure good adhesion of the topcoat. Primer may be solvent-based or waterborne. Solvent-based primer is applied by a combination of manual and automatic spraying, flow coat or dip processes. Waterborne primer is most common now and is most often applied in an electrodeposition (EDP) bath. The prime coat is oven cured before further coating. When EDP is used to apply primer, the resulting film may be too thin and rough to compensate for all surface defects, so a guide coat (primer-surfacer) is usually applied and oven-cured before the topcoat application. Recent developments in EDP technology produce a thicker dry film which in some cases eliminates the need for the guide coat. On some vehicles an additional coating called a chip guard or anti-chip primer is applied along the bottom of the doors and fenders. These flexible urethane or plastisol coatings help protect susceptible parts of the coated vehicle from damage by stones or gravel.

The topcoat (color) is then applied by a combination of manual and automatic spraying. The topcoat requires multiple applications to ensure adequate appearance and durability. An oven bake may follow each topcoat application, or the individual coats may be applied wet-on-wet with a final oven back.

Solvent emissions occur in the application and curing stages of the surface coating operations. The application and curing of the prime coat, guide coat, and topcoat accounted for a majority of the VOC emitted from most assembly plants in the past. Conversions to lower VOC content coatings and more efficient application equipment has reduced the contribution of these operations to total plant-wide VOC emissions at many assembly plants. Final topcoat repair, cleanup, adhesives, sound deadeners, and miscellaneous coating sources account for the remaining emissions. Approximately 70 to 90 percent of the VOC emitted during the application and curing process is emitted from the spray booth and flash-off areas, and 10 to 30 percent from the bake oven.

5.4.14 Paper, Film, and Foil Coatings [12]

Paper is coated for a variety of decorative and functional purposes with a variety of coatings which may be waterborne, organic solvent-borne, or solventless extrusion type materials.

The coating of pressure sensitive tapes and labels (PSTL) is an operation in which a backing material such as paper, cloth, or cellophane is coated one or more times to create a tape or label that sticks on contact. Adhesives and release agents are the two primary types of coatings applied in this industry. Essentially all of the VOC emissions from the PSTL industry come from solvent-based coatings which are used to produce 80 to 85 percent of all PSTL products.

In the solvent-based coating process, a roll of backing material is unrolled, coated, dried, and rolled up. The coating may be applied to the web by knife coater, blade coater, metering rod coater, gravure coater, reverse roll coater, or a dip and squeeze coater. After the coating has been applied, the web moves into a drying oven where the web coating is dried by solvent evaporation and/or cured to a final finish. Direct-fired ovens are the most common type used. Drying ovens are typically multizoned with a separate hot air supply and exhaust for each zone. The temperature increases from zone to zone in the direction in which the web is moving, thus the zone maintained at the highest temperature is the final zone that the web traverses before exiting the oven. A large drying/curing oven may have up to six zones ranging in temperature from 43°C to 204°C.

The main emission points from paper-coating lines are the coating applicator and the oven. In a typical paper-coating plant, about 70 percent of all emissions are from the coating lines. The other 30 percent are emitted from solvent transfer, storage, and mixing operations. Most of the VOC emitted by the line are from the first zone of the oven. Fugitive emissions from solvent transfer, storage, and mixing operations can be reduced through good housekeeping practices, such as maintaining lids on mixing vessels, and good maintenance, such as repairing leaks promptly.

By definition, all PSTL products have an adhesive coating. It is generally the thickest coating applied and the source of 85 to 95 percent of the total emissions from a line. In an uncontrolled facility, essentially all of the solvent used in the coating formulation is emitted to the atmosphere. Of these uncontrolled emissions, 80 to 95 percent are emitted from the drying oven. A small fraction of the coating solvent may remain in the web after drying. The remaining 5 to 20 percent of applied solvent is lost as fugitive emissions by evaporation from a number of small sources such as the applicator system and the coated web upstream of the drying oven. Some fugitive losses also occur from storage and handling of solvent, spills, and mixing tanks, and during cleaning of equipment, such as a gravure roll.

5.4.15 Magnetic Tape Coatings [12]

Organic solvent, metal-oxide particles, and suitable resins are combined to form the coatings used by magnetic tape coating operations. The coating equipment consists of an unwind roll for the plastic film substrate, a coating applicator, a drying oven, and a windup roll for the coated tape. The coating mixture is supplied to the plastic film substrate by the coating applicator (often via some sort of roll or rotogravure coater). The plastic film is carried through the drying oven where organic solvent evaporates. The plastic substrate with the dried magnetic coating is then rewound at the end of the line. Slitting operations to produce the consumer product are almost always performed later as an off-line operation.

Roughly 10 percent of the solvent used by a plant evaporates from mix and storage tanks. Another 10 percent evaporates from the coating applicator and the flash-off area between the coater and the oven. The remainder evaporates in the drying oven and is exhausted through the oven exhaust stack.

5.4.16 Business Machine Plastic Parts Coatings [12]

Plastic parts for business machines are coated for several reasons. Exterior coatings are applied to improve appearance, color match, and provide chemical resistance. Emissions from plastic parts coating occur in the spray booth flash-off area and back oven. Up to 90 percent of all VOC emissions come off in the spray booth.

5.4.17 Automotive Plastic Parts Coating [12]

These coatings are used to finish interior and exterior plastic parts used in automotive and other transportation equipment. Examples include bumpers, bumper covers, body panels, dashboards, and other interior and exterior parts. Emission sources are similar to other coating operations.

5.4.18 Flexible Packaging Printing [12]

The image areas on the image cylinder of a flexographic press are raised above the nonimage areas. A distinguishing feature is that the image carrier is made of rubber which is attached to the cylinder. A feed cylinder which rotates in an ink fountain delivers ink to a distribution roll, which in turn transfers ink to the image cylinder. following transfer from the image cylinder to substrate, the ink dries by evaporation in a high velocity, low temperature ($<120°F$) air dryer. Some solvent is absorbed into the web. Typical ink solvents are alcohols, glycols, esters, hydrocarbons, and ethers. An estimates 21,400 flexographic presses were in operation in the United States in 1984.

The major emission points from a flexographic press are the ink fountains, feed cylinder, distribution roll, image cylinder, printed web, and dryer exhaust. The potential amount of VOC emissions is equal to the total amount of solvent consumed by the printing plant if none of the ink reacts to form an organic by-product. This includes the solvent in the raw inks, solvent in any extenders used, the solvent added at the press, and clean-up solvent.

5.4.19 Rotogravure Publication Printing [12]

In the rotogravure printing process, image areas are recessed relative to nonimage areas. The rotating cylinder picks up ink from an ink trough or fountain. Excess ink is scraped from the blank area by a steel doctor blade. The ink is then transferred directly as the roll contacts the web. The web is then dried in a low temperature dryer. Typical ink solvents include alcohols, aliphatic naphthas, aromatic hydrocarbons, esters, glycol ethers, ketones, and nitroparaffins. It is estimated that there were approximately 1,600 rotogravure presses in the United States in 1984.

The major emission points from a rotogravure press are the ink fountains, wet printing cylinders, wet printer web, and drier exhaust. The total amount of organic solvent consumed by the printing plant is the maximum potential VOC emission (if no reaction by-products are formed during the drying operation). This consists of solvent in the raw ink, solvent contained in any extenders used, solvent added at the press, and solvent used for cleanup.

5.4.20 Lithographic Printing [12]

Lithography is a printing process characterized by a planographic image carrier (i.e., the image and nonimage areas are on the same plane) which is mounted on a plate cylinder. The image area is made water repellant while the nonimage area is water receptive. Rotation of the place cylinder causes the image plate to first contact an aqueous fountain solution which typically contains up to 25 weight percent isopropyl alcohol. This solution wets only the nonimage area of the plate. The image plate then contacts the ink which adhered only to the image area. In offset lithographic printing, the ink is transferred from the image plate to a rubber-covered blanket cylinder. The blanket cylinder then transfers the image to the web. Lithographic heatset inks, containing approximately 40 volume percent solvent, require a heated dryer to solidify the printed ink. Other lithographic inks, containing about 5 volume percent solvent, dry by oxidation or by absorption into the substrate.

Emission points on a web-offset lithographic printing line include the ink fountains and associated inking rollers, the water fountains and associated dampening rollers, the plate and blanket cylinders, the dryer, and the final printed product. Alcohol is emitted from the dampening system and the plate and blanket cylinders at a rate of about 0.5 kilograms per kilogram of ink consumed. Wash-up solvents are a small source of emissions from the inking system and the plate and blanket cylinders. When heat-set inks are printed, the drying oven is the major source of VOC emissions with 40 to 60 percent of the ink solvent evaporating from the oven.

5.4.21 Letterpress Printing [12]

Letterpress is the oldest form of moveable type printing, with the image areas raised relative to the blank or nonimage areas. The image carrier may be made of metal or plastic. Viscous ink is applied to the image carrier and transferred directly to paper or other substrate. Letterpress is the dominant printing process for periodical and newspaper publishing. Newspaper ink is composed of petroleum oils and carbon black, but no volatile solvent. The ink "dries" by adsorption into the substrate. Web presses printing on nonporous substrates employ solvent-borne inks which dry by evaporation. Sheet-fed presses employ solventless inks which dry by air oxidation. There are over 10,000 commercial letterpress printing plants in the United States.

The major VOC emission points on web letterpress printing lines are the image carrier and inking mechanism of the press, the dryer, the chill rolls, and the printed product. About 60 percent of the solvent in the ink is lost in the drying process. Use of washup solvents contribute to overall VOC emissions.

5.4.22 Tire Manufacturing Cements [12]

The tire manufacturing process generally consists of four main steps: (1) compounding of raw materials, (2) transforming the raw materials into tire components and preparing the components for assembly, (3) assembling the components (tire building), and (4) molding, curing, and finishing of the assembled components into the final product. Each of these steps is a potential source of VOC emissions.

Tire components are made in several parallel operations. Rubber stock and other raw materials, including wire and fabric, are used to make tire tread, sidewalls, cords, belts, and beads. The major source of VOC emissions during this step is the evaporation of VOC from solvent-based cements. Tire building is the assembly of the various tire components to form an uncured or "green" tire. The assembly takes place on a collapsible, rotating drum. Organic solvents may be applied to some tire components in this step to further "tackify" (make sticky) the rubber. Green tires are then sprayed on the inside with lubricants and on the outside with mold release agents before molding and curing in automatic presses.

Each of the four production steps may include one or more sources of VOC emissions. Organic solvent-based green tire spraying, undertread cementing, sidewall cementing, tire building, tread end cementing, and bead cementing contribute 97 percent of the total VOC emitted from tire production.

5.4.23 Miscellaneous Industrial Adhesives [12]

Adhesives are used for joining surfaces in assembly and construction of a large variety of products. Adhesives allow faster assembly speeds, less labor input, and more ability for joining dissimilar materials than other fastening methods. By far the largest use of adhesives is for the manufacture of pressure sensitive tapes and labels. Other large industrial users are automobile manufacturing (including especially attachment of vinyl roofs), packaging laminating, and construction of shoes. Adhesives may be waterborne, organic solvent-borne, or hot-melt. Only organic solvent-borne adhesives have the potential for significant VOC emissions.

The VOC emissions from solvent-based adhesives are a result of the evaporation of the solvents in the adhesive. Emissions arise mainly at the point of application and in many cases are swept from the area with local ventilation systems. Essentially all of the organic solvent in an adhesive is emitted to the atmosphere as the adhesive dries. Adhesives vary widely in composition but a typical solvent-borne adhesive might contain 80 weight percent solvent so that approximately 0.8 kg of VOC evaporates for every kg of adhesive used.

5.4.24 Metal Cleaning (Degreasing) Solvents [12]

Solvent metal cleaning (degreasing) uses organic solvents to remove soluble impurities from metal surfaces. Organic solvents include petroleum distillates, chlorinated hydrocarbons, ketones, and alcohols. Industrial uses include solvent metals cleaning include automobiles, electronics, appliances, furniture, jewelry, plumbing, aircraft, refrigeration, business machinery, and fasteners.

Methods of solvent metal cleaning include cold cleaning, open top vapor degreasing, and conveyorized degreasing. Cold cleaning uses all types of solvents with the solvent maintained below its boiling point. Open top vapor degreasers use halogenated solvents heated to their boiling points. Both cold cleaners and open top vapor degreasers are batch operations. Conveyorized degreasers are loaded continuously and may operate as vapor degreasers or as cold cleaners.

For cold cleaners, emission sources are as follows: (1) bath evaporation, (2) solvent carry-out, (3) agitation, (4) waste solvent evaporation, and (5) spray evaporation. Unlike cold cleaners, open top vapor degreasers lose a relatively small proportion of their solvent in the waste material and as liquid carry-out. Most of the emissions are vapors that diffuse out of the degreaser into the work place. These fugitive emissions escape to the atmosphere through doors, windows, and exhausts. Emission sources for conveyorized degreasers include bath evaporation, carry-out emissions, exhaust emissions, and waste solvent emissions. Carry-out emissions are the largest single source.

5.4.25 Industrial Cleaning Solvents [7]

A variety of cleaning solvents are used by industry to remove contaminants such as adhesives, inks, paint, dirt, soil, oil, and grease. Parts, products, tools, machinery, equipment, vessels, floors, walls, and other work areas are cleaned for a variety of reasons including housekeeping, safety, operability, and to avoid product contamination. Solvents are used in enormous volumes and a portion evaporates during use, making cleaning fluids a major source of emissions of VOC.

The EPA conducted a study which focused on the cleaning practices employed in six industries (automotive, electrical equipment, metal furniture, photographic supplies, packaging, and magnetic tape). On average, 25 percent or more of the solvent that was used for cleaning purposes by the six industries was lost by spillage or evaporation. This value varied significantly among industries depending on the type of cleaning performed.

All use of solvent for cleaning can be evaluated on the basis of one of only nine general types: cleaning of spray guns, spray booths, equipment, large manufactured components, small manufactured components, floors, tanks, lines, and parts. Within each group, however, there is considerable variation, including differences in cleaning techniques, soils removed, solvency, and a likely host of others.

5.4.26 Petroleum Drycleaning Solvents [12]

Dry cleaning is a service industry, involved in the cleaning of apparel or renting apparel. Basically, the industry is segregated into three areas based on customers and types of services offered. These areas are: (1) coin-operated, (2) commercial, and (3) industrial. The industry is also subdivided according to the type of solvent used which are: petroleum solvents, perchloroethylene (perc), and trichlorotrifluorethane (Freon-113®). Freon-113 and perc will not be discussed further since they are considered negligibly reactive. Dry cleaning operations are similar to detergent and water wash operations. There are approximately 6,000 facilities in the United States with petroleum dry cleaning equipment.

Emissions of VOC escape from dryers, washers, solvent filtration systems, settling tanks, stills, and piping and ductwork associated with the installation and operation of these devices. Because of the large number of variations in the types of equipment and operating practices, in dry cleaning plants there is a large variation in emission rates. For that reason, details on emission factors or typical plant emission rates will not be discussed here. The emission sources in dry cleaning plants can be characterized in two broad groups - vented and fugitive emissions. Solvent is vented from article dryers, solvent stills, and filter and article drying cabinets. The largest source of vented emissions is from article dryers. Fugitive emissions occur from all equipment in dry cleaning facilities, however, these emissions vary greatly since they are dependent on equipment operating and good housekeeping practices. The major fugitive emission sources are solvent or liquid leaks from pipes or ductwork, and wet or not completely dried articles, used-wet filters, and solvent and still waste which are all left in open containers in or outside dry cleaning facilities.

5.4.27 Agricultural Insecticides and Herbicides [8]

Insecticides are used in agriculture to destroy or control populations of harmful insects. Herbicides are chemical weed killers that are used extensively on farms and other areas. Herbicides are grouped using a multiple-classification system based on selectivity, mode of action (contact versus translocation), timing of application, and areas covered. Herbicides are classed as selective when they are used to kill weeds without harming the crop and as nonselective when the purpose is to kill all vegetation. Contact herbicides kill the plant parts to which the chemical is applied, whereas translocated (systematic) herbicides are absorbed by roots or above-ground parts of plants and then circulate within the plant system to distant tissues.

Pesticides may be applied as liquids, dry solids, or gases. Liquid pesticides are applied as a spray of water or oil droplets containing a solution or suspension of active ingredients.

Pesticides formulated as dusts or granules are normally applied dry. Pesticides that exist in a gaseous state at ambient temperature and pressure may be applied either as gases or pressurized liquids or as solids that vaporize upon release. This type of pesticide application is known as fumigation.

Emissions of VOC from pesticide applications are the result of volatilization of the active ingredient (AI), organic solvents, emulsifiers, and other organic compounds that may be used in the formulation.

5.4.28 Cutback Asphalt Paving Materials [12]

Liquefied asphalts are generally prepared by cutting back or blending asphalt cement with petroleum distillate or by emulsifying asphalt cement with water and an emulsifying agent. Heated asphalt cement is generally used to make asphalt pavements such as asphalt concrete. Cutback and emulsified asphalt are used in nearly all paving applications. In most applications, cutback and emulsified asphalt are sprayed directly on the road surface; the principal other mode is in cold mix applications normally used for wintertime patching.

Emissions from cutback asphalt occur as the petroleum distillate (diluent) evaporates; the average diluent content in the cutback is 35 percent by volume. The percentage of diluent to evaporate is dependent on the cure type. The emission factors are: slow cure (SC) - 20 to 30 percent of diluent content, average 25 percent; medium cure (MC) - 60 to 80 percent, average 70 percent; rapid cure (RC) - 70 to 90 percent, average 80 percent. These factors are independent of the percent of diluent in the mix within the normal range of diluent usage for cutback asphalts.

5.4.29 Synthetic Fiber Spinning Solvent [12]

Synthetic fibers are manufactured as continuous filaments (which may then be chopped into staple) of modified cellulose or manmade polymers. They are used to manufacture carpets, apparel, industrial textiles, rope, tires, cigarette filters, and composite materials. There are three broad manufacturing classifications: melt spinning, solvent spinning, and reaction spinning.

Typical polymers suitable for solvent spinning are acrylics, modacrylics, acetates, triacetates, rayon, and spandex. Solvent spinning can be subdivided into two types of processes, wet or dry. Both first require the polymer to be dissolved in a suitable solvent at a ratio of about three parts solvent to one part polymer. In wet spinning, the polymer solution is extruded through a spinneret that is submerged in a liquid that extracts the solvent, thereby precipitating the polymer filament. In dry spinning the polymer solution is extruded into a zone of heated gas that evaporates the solvent leaving the polymer filament behind.

5.4.30 Fabric Coating [12]

Fabric coating involves the application of decorative or protective coatings to a textile substrate. A large segment of this industry is application of rubber coatings to fabrics. More specifically, for purposes of the regulatory program, fabric coating is the uniform application of (1) an elastomeric or thermoplastic polymer solution, or (2) a vinyl plastisol or organisol,

across all of one (or both) side of a supporting fabric surface or substrate. The coating imparts to the fabric substrate such properties as elasticity, strength, stability, appearance, and resistance to abrasion, water, chemicals, heat, fire, or oil. Coatings are usually applied by blade, roll coater, reverse roll coater, rotogravure coater, or dip coater.
The basic fabric coating process includes preparation of the coating, the application of the coating to the substrate, and the drying/curing the applied coating. The web substrate is unwound from a continuous roll, passed through a coating applicator and drying/curing oven, and then rewound.

The major sources of VOC emissions in a fabric coating plant are the mixer and coating storage vessels, the coating applicator, and the drying oven. The relative contribution of these three areas are estimated at 10 to 25 percent, 20 to 30 percent, and 45 to 70 percent, respectively. The potential VOC emissions from a fabric coating plant are equal to the total solvent used at the plant.

5.4.31 Fabric Printing [12]

Fabric printing is application of a decorative design to a fabric by intaglio (etched) roller (another name for rotogravure), rotary screen, or flat screen printing operation. The fabric web passes through the print machine where a print paste is applied to the substrate. After leaving the print machine, the web passes over steam cans or through a drying oven to remove water and organic solvent from the printed product.

The most significant source of VOC emissions in a fabric printing plant is the drying process, either the steam cans or the ovens. Other emissions occur as fugitive VOC. These are as evaporation from wastewater streams, open print paste barrels, printing troughs, the printing rollers and screens, "strikethrough" onto the backing material, and from the printed fabric before it reaches the drying process.

5.5 PRODUCTS ADDRESSED BY SPECIAL STUDIES

Several categories of products fall beyond the scope of Sections 5.3 and 5.4. These categories were the subjects of special studies carried out by the EPA to develop 1990 emission estimates based primarily on information in the literature. For those products for which data on emissions was not available, any useful information (e.g., VOC content, function of the product, etc.) was summarized and included in the inventory report. Specific methodology is discussed for each category included. The estimates presented in Table 5-3 have been scaled down based on population in ozone nonattainment areas using the adjustment factor discussed in Section 5.2.

5.5.1 Construction Materials

5.5.1.1 *Building Materials and Indoor Air Sources* [15]

Since the mid-1970's, a growing number of complaints have surfaced regarding the indoor environment to which occupants of modern buildings are exposed. Energy efficiency also became increasingly important during this time. Consequently, new buildings were being built

TABLE 5-3

VOC EMISSIONS IN NONATTAINMENT AREAS FOR PRODUCTS COVERED BY SPECIAL STUDIES

Category	Nonattain Area Emissions (tons/year) [a]	Year	Ref
CONSTRUCTION MATERIALS			
Particle board	*		15
Plywood	*		15
Wallpaper	*		15
Carpeting	*		15
Roofing - built-up	7,126	1989	16
Roofing - elastomeric	9,123	1989	16
Roofing - modified bitumen	2,276	1989	16
Asphalt concrete paving materials	360	1991	17
SMALL COMBUSTION SOURCES			
Kerosene space heaters	39	1990	15
Camp stoves, lanterns, heaters	6	1990	15
Commercial explosives	2,422	1990	15
Artificial fire logs	154	1990	15
TEXTILE INDUSTRY			
Platen Adhesives	2,092	1990	18
Equipment cleaning solvents	68	1990	18
Spot Cleaners - Screen Printers	848	1990	18
Spot Cleaners - Woven Goods	0 [b]	1990	18
Spot Cleaners - Knit Goods	0 [b]	1990	18

TABLE 5-3 (Continued)

VOC EMISSIONS IN NONATTAINMENT AREAS FOR PRODUCTS COVERED BY SPECIAL STUDIES

Category	Nonattain Area Emissions (tons/year) a	Year	Ref
MISCELLANEOUS PRODUCTS			
Mold Release Agents	75,400	1989	16
Automotive Repair - Parts Washers	2,607	1987	17
Fiberglass Boat Manufacturing Products	12,100	1990	19
TOTAL FOR ALL SPECIAL STUDIES	114,621		

* This category was investigated and is discussed in the inventory report, but an emission estimate could not be developed based on the available information.

a Nonattainment area emission estimates were obtained by adjusting nationwide estimates according to the distribution of nationwide population in nonattainment areas in 1990. Estimates for categories without this footnote were determined specifically for nonattainment areas and needed no further adjustment.

$$\frac{\text{148 million (nonattainment areas)}}{\text{248 million (nationwide)}} = 59.68\% \approx 60\%$$

b These activities resulted in no VOC emissions. However, cleaning is performed using exempt (non-VOC) organic solvents (e.g., 1,1,1 trichloroethane, etc.)

with less outside air infiltration, thus confining more indoor air pollutants. Since the early 1980's, much work has been done by the EPA and other groups to identify and measure VOC emission rates from building materials and consumer products in small test chambers and laboratories.

The building materials source category contains a number of different product lines, each with a variety of manufacturers and manufacturing methods. For the purposes of this report, the term building materials refers to carpet, plywood, particle board, chipboard, fiberboard, treated lumber, gypsum board, laminated plastics, insulation, linoleum, and wallpaper. Each of these materials has been found to have the potential of emitting various types of VOC during their expected lifetime. These materials are present in many kinds of structures including apartments, automobiles, commercial buildings, hospitals, mobile homes, nursing homes, office buildings, residences, and schools. Previous studies of building materials have shown emissions to be very dependent upon test variables such as air exchange rate, temperature, humidity, product loading (area of product/volume of test chamber), and age of material. To date, much research has been conducted to determine the concentrations of speciated VOC in the ambient air surrounding building materials. This research has been performed in chamber tests, laboratory experiments, and on-site tests of various types of buildings. However, only a limited number of these studies have developed emission rates for these materials. Several short term tests (*i.e.*, days and weeks) have specified emission rates calculated as an average for the duration of the experiment. However, based on the current available literature, no long term tests (*i.e.*, one year) have been conducted to determine an annual average speciated VOC emission rate from any one specific type of building material. Therefore, no annualized total or speciated VOC emission estimates from building materials can be developed at this time.

5.5.1.2 *Roofing Materials* [16]

A modern roof design normally includes a structure to carry loads, insulation to control heat flow, a barrier to control air and vapor flow, and vapor retarders to prevent water retention. Several different types of roofs have been developed to accomplish these objectives. The main types of roofs used today are sloped roofing materials (e.g., asphalt shingles, wood shakes and shingles, slate roofs, thatched roofs, etc.), built-up roofing (BUR), elastomeric (primarily ethylene-propylene-diene monomer, or EPDM), thermoplastic, modified bitumen (MBR), and liquid-applied roofing.

The total amount of commercial/industrial roofing performed in 1989 was approximately 3.3 billion square feet, with 1.3 billion square feet as BUR, 1 billion square feet as EPDM, and 0.7 billion square feet as MBR. These three roofing types make up over 90 percent of the commercial roofing market.

In 1970, BUR was 90 percent of the roofing market; in 1989 it was less than 40 percent. In the BUR application process, several layers of felts, insulations, and other materials are applied using hot asphalt, asphalt emulsions, or asphalt mastics. Coal tar may be used in place of asphalt.

A typical BUR reroofing job begins with surface preparation of the roof by removing the old roof and surfacing material (e.g., gravel). After the surface is prepared, an asphalt primer is applied if the deck is constructed of concrete. Next, a base ply or insulation layer is applied using hot asphalt or cold process asphalt. Several layers of felts are then attached to the roof with an intermediary layer of asphalt between each layer. A cap sheet layer is then applied, followed by a flood coating of asphalt to seal the roof. Flashing, vents, and other areas of the roof receive a layering of flashing cement to provide extra sealing capabilities in these areas. Solvent cleaners are used to remove asphaltic materials from tools and may also be used by workers to clean their hands. Emissions points for BUR are the application of roofing materials using asphaltic compounds, flashing cements, asphalt primers, and cleaning operations.

Elastomeric roofing consists of natural and synthetic rubbers and rubberlike materials. The most common elastomeric roofing material is ethylene-propylene-diene monomer (EPDM). Three methods have been identified for the application of EPDM roofing systems: loose-laid and ballasted, comprising 70 percent of the total; fully-adhered, comprising 20 percent of the total; and mechanically-fastened, comprising 10 percent of the industry. A typical fully-adhered EPDM roofing process involves removing the old roofing system, surfacing materials, and debris, leaving a clean substrate. EPDM sheets are laid side-by-side with a three inch overlap and are bonded to the roof using bonding cement. The seams are cleaned and primed in preparation for taping. Tape is applied to each seam leaving a waterproof surface. General cleaning operations are carried out daily to remove roofing materials from skin, tools, clothing, etc. Emissions result from the use of primers, cements, and cleaners.

The MBR process is very similar to the BUR category. Modified bitumen sheets are constructed using asphaltic materials like BUR felts and plies, but are augmented by adding thermoplastic materials like styrene-butadiene-styrene (SBS) or atactic polypropylene (APP). These plasticizers lend greater elongation and roof movement tolerance. The modified bitumen sheets are typically built-up in the factory. Fewer layers of modified bitumen sheets are applied in a typical roofing job than in a BUR job since the MBR sheets are already built up.

Modified bitumen can be applied in several ways, including hot asphalt, propane torch-activated adhesive and self-adhering sheets; squeegee-applied cold adhesives; and spray-applied cold adhesives. The most common means of attaching MBR are hot asphalt, torch activation, and self-adhering sheets, representing 99 percent of the market.

5.5.1.3 *Asphalt Concrete Paving Materials* [17]

Generally, paved roads are constructed of either bituminous asphalt concrete or portland cement concrete. Asphalt concrete is blended at a facility that may be located several hours from the job site. The hot asphalt concrete mixture (hot mix) is blended and maintained at approximately 300°F until being laid and compacted. The major constituent of asphalt concrete is aggregate, a mixture of sand and gravel. Asphalt, a derivative of the bottom cut in the distillation of crude oil, serves as the binder for the aggregate.

An estimated 460 to 500 million tons of hot mix was prepared in 1991. This estimate does not include cutback asphalt. Approximately 5 percent of the hot mix is asphalt. Asphalt concrete contains low concentrations of VOC when properly prepared. A common test to determine the suitability of asphalt concrete is the "loss on heating" test. When heated, if more than 0.5 percent volatilizes, the material is rejected. In practice, asphalt concrete typically contains about 0.0025 percent VOC.

Based on 500 million tons of asphalt concrete used annually, the usage of asphalt cement in this material (5%) is estimated to be 25 million tons nationwide. At a typical VOC content of 0.0025 percent, the asphalt cement contains approximately 600 tons of VOC. It is assumed that all the VOC contained in the concrete are emitted.

In the asphalt paving industry, regular equipment cleaning currently is performed using high pressure water sprays rather than solvents, although this has not always been the practice. However, many construction crews coat the truck and hopper beds with diesel fuel to prevent sticking. The asphalt concrete absorbs any excess liquid, which ultimately evaporates. Diesel fuel is also used to clean shovels and rakes. There is insufficient data to develop an estimate of these additional emissions.

5.5.2 Small Combustion Sources

5.5.2.1 *Kerosene Space Heaters* [15]

Kerosene heaters are typically used as a supplemental heat source in areas in which: 1) residential central heating systems are not installed, 2) inadequate heat is available and/or 3) temperatures are extremely cold. Kerosene heaters usually supplement other heating sources such as electric, fuel oil and gas furnaces. Portable kerosene heaters are limited to supplemental heating because the kerosene tank on each heater is too small to provide continuous heating without constant refilling.

Kerosene heaters can be divided into three main categories: (1) convective (white flame), (2) radiant (blue flame) and (3) hybrid (two-stage). The most popular type of portable kerosene heater among consumers is the convective heater. These three types of heaters are described below.

1) The convective (white flame) heater operates at relatively high combustion temperatures. It uses a relatively simple unobstructed wick.

2) The radiant (blue flame) heater operates at lower temperatures than does the convective heater. It uses a cylindrical wick. Flames extend up from the wick into a perforated metal baffle, consisting of two concentric cylinders inside a glass plenum. After the warm up period the metal baffle glows red hot, causing a portion of heat to be output as radiative heat.

3) The hybrid (two-stage) heater is similar to the radiant heater, except a second chamber is located above the radiant element where more combustion air is introduced. In this region the flame temperature is allowed to rise, the color becomes white, and secondary combustion of unburned hydrocarbons with an increase in carbon monoxide production occurs before the combustion product leaves the burner. This type of heater incorporates features from both radiant and convective heaters; thus it is appropriately named "hybrid."

Although kerosene heaters are a logical choice for supplementing a central heating source, their lack of exhaust ventilation has prompted a considerable amount of research on the effects of emissions from kerosene heaters on indoor air quality. These studies have quantified emissions rates and provide the basis for a general methodology to estimate emissions from portable kerosene heaters.

The major VOC pollutant from portable, unvented kerosene heaters is the unburnt combustible formaldehyde (HCHO). Significant quantities of formaldehyde are produced and emitted to an indoor atmosphere under the conditions which portable heaters are normally operated.

5.5.2.2 *Camp Stoves and Lanterns* [15]

Camp stoves, camp lanterns and portable heaters are used in the U.S. for various outdoor activities including backpacking and camping, or work in open areas. Two primary kinds of camp stoves sold in the U.S. are backpack type single burner stoves and family type two or three burner stoves. These stoves are designed to burn Coleman® fuel (C_7H_{16}), regular unleaded gasoline, kerosene, or propane gas. Other fuels used less frequently include aviation gas, starter fluid (ethyl ether), butane and isobutane. Many camping supply stores sell propane and butanes as liquefied gases in pressurized containers.

Camping lanterns used include single or dual mantle lanterns which burn propane gas, Coleman® fuel, unleaded gasoline or kerosene. Portable heaters, used for outdoor heating jobs, include the standard single-head or double-head bulk mount types which are usually designed to operate on propane gas.

Given the limited time and the difficulty in obtaining all the relevant information, it was not possible to accurately calculate the total annual VOC emissions from this product category during this study. Based on the information provided by Coleman® from the use of Coleman® stoves and lanterns, a first approximate estimate of total VOC emissions per year was calculated to be less than 10 tons of unburnt Coleman® fuel. Emissions calculation data are not provided due to the lack of more accurate emissions concentrations which should include fugitive emissions.

5.5.2.3 *Artificial Fireplace Logs and Other Fire Starting Materials* [15]

Fire starting materials are products used to aid or initiate the combustion process of various consumer products. Fire starting materials include solid and gel starters, and alternative combustion materials such as self-starting charcoal and artificial fire logs. These products may be used for household fireplaces and for outdoor cooking purposes as in grills and camp stoves. These materials may be used throughout the year. However it is not likely to expect as much camping or outdoor activities in the winter as in the summer.

Solid starters usually consist of wood shavings held together with paraffin wax. The actual percentages by volume/weight of these components could not be found at this time although the material was found to be similar to manufactured fire logs. The Department of Ecology, State of Washington stated that products of combustion due to the burning of one type of solid starter are not found to be any more polluting than the burning of artificial fire logs. Gel starters are usually alcohol-based products. Alco Brite® manufactures a gelled alcohol fuel called Cook 'n' Heat Fuel® which contains 1000 ppm ethanol and 200 ppm methanol. Other similar gel products include the Snap-On-Stove® and Alco Brite® Fire Starter. It was not possible during this study to find out whether Alco Brite has performed any emissions testing of its products. Another manufacturer makes a product known as Mautz Fire Ribbons which consists of a standard petroleum-based solvent, usually p-naphtha, mixed with clay. This product consists of 95 percent solvent and is often used to start fires in bar-b-que grills and torches. No other product types or consumption data from solid or gel starters were located during the time period of this study.

Artificial household fire logs are made by compressing sawdust and petroleum wax. Canadian Firelog Ltd. makes a product that contains cedar sawdust (38 percent), paraffin wax (61 percent), calcium carbonate (0.75 percent) and copper sulfate (0.5 percent). One source indicated that the product composition of fire logs does not vary drastically from manufacturer to manufacturer. A representative from Duraflame Firelogs estimated that approximately 40 to 60 percent of households in the U.S. use artificial fire logs and of these 15 percent are regular users and up to 30 percent are occasional users. He projected that between 10 to 12 million log cases, each weighing 30 to 36 pounds are sold each year in the U.S.

In 1987, Canadian Firelog Ltd. had research conducted to test atmospheric emissions from the burning of their product. The test was conducted by measuring stack emissions from a wood burning stove. This testing measured emissions for various products of combustion including polynuclear aromatic hydrocarbons (PAHs). The results of the study indicated that the total PAHs were at minimal concentrations of no greater than 0.02 mg/m^3. Using the information from their study it is possible to estimate emissions from similar products. The assumption made here is that the composition of artificial fire logs does not greatly vary from manufacturer to manufacturer and therefore emissions will be similar.

5.5.3 Products Used in the Textile Industry [18]

The textile industry includes facilities involved in the following activities:

- fiber preparation followed by manufacturing of yarn and thread;
- manufacturing of woven fabrics, knit fabrics, carpets, and rugs from yarn;
- dyeing and finishing of fiber, yarn, fabric, knit, and woven apparel;
- manufacturing of apparel and other articles from yarn; and
- manufacturing of nonwoven fabrics and other miscellaneous textiles.

Both man-made and natural fibers are processed. Examples of the latter group include cotton, wool, silk, flax, and jute while the former include such fibers as rayon, polyester, acetate, and nylon. Blends of these fibers may also be processed.

Estimates of VOC emissions can be made for certain solvent-containing products that are used in the textile industry. In this study, estimates were calculated for emissions from:

- parts washer solvents used by garment screen printers;
- platen adhesives; and
- spot cleaners.

Garment screen printers primarily use parts washer solvents to clean ink from press parts. Most garment screen printers also use platen adhesives. Spot cleaners may be used in any textile facility that produces a finished product (e.g., thread, yarn, fabric, garments, etc.).

In some instances, it is difficult or impossible to estimate emissions from a specific product. For example, estimates of emissions from winder cleaners are complicated by the fact that facilities may use products that contain very different amounts of solvent. Estimates of emissions from cot adhesives pose a similar problem since some facilities use fiber-, metal-, or plastic-lined cots that do not require adhesive. The same difficulty is encountered when attempting to determine emissions from the screen cleaners used in garment screen printing facilities. Some facilities use products containing 100 percent petroleum distillates while others use water-based products containing d-limonene. Similarly, the screen reclaimers that are used may or may not contain solvent. Although data were collected during the site visits on each of these specific products, this information may not represent the true distribution of their use within the industry and, therefore, cannot be extrapolated on a national basis for emission estimates.

5.5.3.1 *Parts Washer Solvent*

Two factors may affect the emission of solvent from parts washers: evaporation from the sink and evaporation from depleted solvent that is splattered or carried out of the washer on wet parts. In general, newer models of parts washers are designed so that the solvent returns by gravity to the reservoir, where it is less likely to evaporate. Therefore, for the purposes of this estimate, emissions due to evaporation from the sink will be ignored. In some instances, these emissions may be significant (e.g., at a facility where an older parts washer with an open reservoir is used). Exact measurements of solvent depletion through carryout are not available.

Therefore, an assumption that 10 percent of the solvent is lost during the interval of usage was used for this calculation.

The emission estimates are also based on usage data collected from site visits to three garment screen printing facilities. The amount of parts washer solvent used by a printer will depend not only on the number of press pieces cleaned but also, to some extent, on the number of garments printed. Therefore, an estimate of the amount of parts cleaning solvent used per garment was calculated and used to determine emissions.

5.5.3.2 *Platen Adhesives*

The emissions estimates for platen adhesives were determined from two sources of data: (1) platen adhesive usage data; and (2) the total number of garment screen printing facilities. The outcome of the estimate shows that 4,935.9 tons of platen adhesives are used by garment screen printers each year. Water-based platen adhesives account for 2.6 percent, or 126.6 tons, of the usage. Yearly VOC emissions are 3,486.4 tons, of which 37.6 percent is from VOC propellants. Non-VOC organic chemicals emissions are 797.1 tons; 1,1,1-TCA and $MeCl_2$ account for 44.0 and 56.0 percent, respectively, of this amount.

5.5.3.3 *Spot Cleaners*

Only emissions from garment screen printers and finishers of woven or knit goods were determined in this section. Garment screen printers use 3,256.3 tons of VOC-based spot cleaners each year. Finishers of woven and knit goods use spot cleaners which contain no VOC but which contain 1,1,1 trichloroethane. Therefore, no VOC emissions can be attributed to the use of spot cleaners in these two segments of the industry.

5.5.4 Miscellaneous Consumer and Commercial Products

5.5.4.1 *Mold Release Agents* [16]

A mold release agent (MRA) can be generically described as any substance used to control or eliminate the adhesion of a material to itself or to another material. The MRA prevents the molded product from sticking to the mold so that the product can easily be removed in one piece. Factors such as penetration, chemical reaction and compatibility, low surface tension, surface configuration, and differences in polarity between the two materials influence adhesion between materials. MRA's may also be known as abherents, anti-blocking agents, external or surface lubricants, parting agents, and slip aids. The MRA consists of the active ingredient (the ingredient that actually causes the abhesion) and a carrier or additive that is used to apply the MRA. The active ingredient is most often inert, that is, it contains no VOC. The carriers and additives often contain VOC, although non-VOC carriers and additives may be used. Major industrial applications for MRA's include casting, molding, forming, and materials transfer operations in a wide variety of industries, including plastic (or polymer) processing, rubber, metal processing, glass, food processing, textiles, printing, and others.

The category is divided into two major types of agents: topical coatings and semi-permanents. Topical coatings, which currently dominate the MRA market, are further divided into external MRA's and internal MRA's. External MRA's operate much in the same manner as oil, lard, and nonstick sprays operate on cookware. Abherents can be applied to a surface by standard coating methods such as spraying, brushing, dusting, dipping, electrostatic powder coating, and plasma arc coating. The product (e.g., resin, metal, rubber, glass, etc.) is injected, laid, rolled, sprayed, etc., in the mold where the product is cured. The part is then released from the mold and the MRA is reapplied to the mold.

Internal MRA's, typically metallic stearates, are agents that are added to the resin itself. While there is no consensus as to how such agents work, one hypothesis is that the MRA migrates to the surface of the resin, that is, to the part/mold interface, during the interval between the injection and the ejection. The agent then acts as an external release agent, essentially lubricating the boundary. A number of factors influence the performance of internal MRA's, including solubility in the resin, rate of migration, lubricity, melting point of the additive, and extent of electrostatic inhibition.

Semipermanents, or multiple release products, are a relatively new concept in release agents. Semipermanents allow a large number of processing cycles to occur before re-application of the MRA is needed. They are usually water- or solvent-based with the latter predominantly used in heat-cured systems. They can be used to coat the mold or can be applied to become an integral part of the mold. Advantages include low buildup, promotion of excellent part surface and finish, minimal transfer to the part, high release efficiencies, low or non-toxicity of some products and high temperature stability (up to 375°C).[1]

Emissions from MRA use can occur at several points in the application process and depend primarily on the mode of application. With external MRA's, VOC emissions will occur from the application of sprays and liquids. Emissions points are the applicator, the mold and the product. With internal MRA's, emissions may occur from the surface of the mold and the surface of the product. However, most internal mold release agents are not mixed with additives and carriers, and therefore, there would be no VOC emissions. Emissions points for application and use of semipermanents are similar to those of external MRA's. However, since these MRA's are not applied as frequently as externals, their relative emissions (assuming the same VOC content as a comparable external MRA) will be lower.

Another source of emissions from the MRA application process involves clean up activities. Mold surfaces are cleaned at regular intervals to increase the efficiency of the MRA. Many of the products used in clean up are solvents with high VOC contents (e.g., mineral spirits, trichloroethylene).

5.5.4.2 *Products Used in the Manufacture of Fiberglass Boats* [19]

The fiberglass boat manufacturing and repair industry consists of about 1,800 facilities. These facilities employ about 47,000 people and are located in 34 of the 48 continental United States. About 88 percent of these establishments are small operations, employing less than 50 people. States that have a large number of boat manufacturing facilities include California, Florida, Illinois, Indiana, Michigan, North Carolina, South Carolina, Tennessee, Texas, and Washington.

The most common fiberglass boat production method is open contact molding. This method consists of laying up plies of fiberglass reinforcement impregnated with resin on an open male (convex) or female (concave) mold. For manufacturing boats, a female mold is generally preferred since it yields a smooth outer surface which is more desirable for hulls and decks. The layers are built up to the desired thickness and allowed to cure.

The initial layer of resin is formed without any reinforcing material by spraying gel coat (unsaturated polyester resin, catalyst, and pigments) into the empty mold to a precise thickness. After allowing the gel coat to cure fully, laminates of resin and fiberglass are applied by machine lay-up, hand lay-up, or spray lay-up. Machine lay-up involves the simultaneous mechanical application of fiberglass reinforcement material and is generally reserved for large hull boats; e.g., sailboats with deep keels. In hand lay-up, resin is brushed or sprayed on the tacky surface of the gel coat, the fiberglass reinforcement material is placed into the mold, then the laminate is completely wet out with resin and rolled by hand to remove air pockets and other imperfections. The spray lay-up method uses a chopper gun which simultaneously deposits chopped strand fiberglass and catalyzed resin on the mold, after which rollers are used, as in hand lay-up, to remove entrapped air.

Two alternative closed molding methods which have been experimented with in the fiberglass boat manufacturing industry are bag molding and resin transfer molding (RTM). Bag molding uses a bag or flexible membrane to apply vacuum or pressure during the molding operation. Vacuum bag molding applies pressure against the laminate by drawing a vacuum under a cellophane, vinyl, or nylon bag which covers the laminate. Pressure bag holding forces the bag against the laminate using compressed air or steam. In the RTM process, fiberglass reinforcement consisting of continuous or chopped strand glass fiber mats is placed between halves of a mold. After the mold is closed, catalyzed resin is injected into the mold and allowed to cure. The mold is then opened and the finished part removed. The major technical difficulty in using this process for boat manufacturing is that resin void spaces may occur, rendering the part unusable. Also, highly skilled labor is required for RTM to be successful.

VOC emissions from fiberglass boat manufacturing consist mainly of acetone and styrene. There are four areas in the fiberglass boat production process where VOC may be emitted to the atmosphere: resin storage, production, assembly, and waste disposal. The major emissions sources are exhausts from gel coat spray booths, room exhausts from the lamination area, and evaporation of acetone or other solvents during cleanup. Emission factors for resin application in open contact molding range from 5 to 13 lb styrene per 100 lb of styrene used. Emissions from gel coat application and curing are 26 to 35 lb per lb of styrene monomer used. Cleaning solvent emissions, primarily acetone, can account for 36 percent of the total VOC emissions and are about equal to 56 percent of the styrene emissions.

5.5.4.3 *Automotive Repair Parts Washers*[17]

A large variety of services may be offered by an automotive repair facility. In addition to engine maintenance, these facilities may repair and service brakes, transmissions, and cooling, air conditioning, and electrical systems. Parts cleaning is common to most facilities and often involves the use of a parts washer.

These washers, which may be maintained and serviced by the facility itself or by an outside company, usually consist of a sink which covers a drum containing solvent and a pump with a filtered intake. The pump circulates solvent from the drum to the sink through a flexible hose. A brush, sometimes mounted to the nozzle of the hose, is used to aid cleaning. Many newer models have a lid that closes to reduce solvent loss through evaporation. Some older parts washers consist of a grate over an open reservoir of solvent. Self-contained systems for immersing parts in solvent for several hours are widely used.

The solvents used in parts washers can vary, but most are based on petroleum distillates. One commonly used solvent contains 85 percent petroleum distillates. Carburetors are usually cleaned by immersion in cleaners that may contain other solvents. One such solvent system used for carburetors is 2-butoxy-1-ethanol and n-methyl-pyrolidine. Other solvents may include methlyene chloride.

Emissions can be attributed to evaporation from the sink and solvent loss through splattering, spillage, or incomplete drainage of cleaned parts. For older washers, evaporation occurs even when the cleaner is not in use. In newer models, the solvent is returned to the drum, and the sink is equipped with a cover to reduce emissions when the cleaner is not in use. Typical parts washers have a storage capacity of 20 gallons. The washers are usually serviced every 30 days, when the dirty solvent is collected and clean solvent installed in the machine.

Estimates of VOC emissions from these cleaners were made based on the assumption that 10 percent (2 gallons) of the solvent is lost during the typical service interval of 1 month. The annual losses are estimated to be 157 pounds per machine. In 1990, there were approximately 55,000 repair facilities nationwide. Assuming one machine per shop, nationwide emissions were estimated to be 4317 tons per year.

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CHAPTER 6

FATE OF CONSUMER PRODUCT VOC IN LANDFILLS AND WASTEWATER

The two studies summarized in this chapter were undertaken in order to determine whether adjustments to VOC inventory data should be made to account for the VOC in consumer products which enter landfills or wastewater and, due to physical or chemical mechanisms, do not enter the ambient air. It is important to keep in mind that the purpose of the studies is to establish the ultimate fate of consumer product VOC other than emissions to the ambient air. The purpose was not to determine the impact of consumer products on landfills and/or wastewater treatment systems.

6.1 FATE OF CONSUMER PRODUCT VOC IN LANDFILLS

This study was initiated by EPA with the specific objective of investigating the fate of VOC in consumer products disposed of in municipal landfills. This effort was undertaken in order to determine whether the VOC remaining in spent consumer product containers is ultimately emitted to the air, and whether the EPA's emission estimates should be adjusted to account for fates other than emission to the air. Key factors in this determination are landfill operating practices, characteristics of the packaging, and chemical/physical properties of the VOC.

6.1.1 Landfill Design

The two major approaches to landfilling are the trench method and the area method. Results of the 1987 EPA survey of MSW landfills indicate that about 70 percent of the landfills in the United States use the trench method and 28 percent use the area method, while 6 percent use another method (some landfills use a combination of methods).

The trench method is based on excavating trenches that are designed to hold the amount of waste expected to be received during a single day. Trenches are typically 100 to 400 feet long, 3 to 6 feet deep, and 15 to 25 feet wide. The waste is spread in layers 1.5 to 2 feet thick and then compacted before the next layer is applied. The trench method is most suitable on flat or gently rolling land with a low groundwater table.

The area method involves spreading waste over the natural ground surface or landfill liner. Waste is deposited in layers of less than 2 feet in depth, which are then compacted before successive layers are applied. The area method is often used in areas such as California, where natural depressions (e.g., canyons) are abundant. If the landfill site has a high water table, the trench method may not be feasible and the area method must be used. The number of layers is restricted by safety considerations and limitations placed on the landfill by the community or by permit.

The basic landfill cell is common to various landfilling methods. A cell is an area of the landfill that is designated to be filled within a day and closed at the end of the day. Waste is spread in the designated area and compacted, and more waste is applied and compacted until waste operations are concluded for that cell. A daily cover is then applied and compacted, resulting in a completed cell, of usually less than 8 feet in height. Series of cells at the same height constitute a lift. Intermediate cover is generally placed between lifts. The working face of a cell can extend to the facility boundaries and may be designed to accommodate a specific number of vehicles unloading at the same time. It is kept as small as possible in order to reduce the problem of litter control. Waste is compacted into the cell at compaction densities ranging from 500 to 1,500 lb/yd^3. Most landfills achieve waste densities on the higher side of this range.

6.1.2 Factors Affecting VOC Release to the Atmosphere

The fate-determining mechanisms for the VOC in landfills can be divided into two groups: (1) VOC-release mechanisms primarily associated with landfill operating practices, and (2) potential chemical and physical mechanisms that take place within the landfill system. Superimposed on these two groups are the physical and chemical characteristics [i.e., physical state (solid, liquid, vapor), vapor pressure, boiling point, molecular weight, solubility, adsorption properties, and reaction potential] of the individual VOC.

Volatile organic compounds in consumer product residuals placed in landfills may be in one of three physical states: gas, liquid, or solid. The following factors determine how and when the residual VOC will be released following placement in the landfill:

- Landfill operating practices,
- Characteristics of product packaging,
- Physical and chemical properties of the VOC, and
- Existence of emission controls at the landfill.

These factors are interrelated in terms of how they affect the fate of the VOC. Whether a consumer product is in the process of being placed in a landfill or has already been buried will determine which factor predominates.

Figure 6-1 presents a flowchart identifying potential pathways for VOC in consumer product residuals once they are placed in a landfill. A detailed discussion of factors that affect each step in a given pathway are presented below, followed by a discussion focused on the potential physical and chemical pathways for the VOC of interest in this study.

6.1.2.1 *Landfill Operating Practices*

Waste handling prior to disposal and the use of landfill equipment to crush and compact waste will cause most product containers to be ruptured or broken almost immediately upon entering the landfill. Once garbage is compressed in trucks (which exert a pressure of up to 50 lb/in^2) and crushed and compacted by landfill machinery, it is highly likely that most plastic and glass containers will be crushed or ruptured. Although metal containers are more durable than plastic or glass, they will probably be affected in a similar manner. These theories are supported by a study of residential refuse delivered to a landfill that found 95 percent of household product containers empty.

Newly received waste at a landfill is likely to remain in contact with the ambient air for several hours while the waste is covered and possibly compacted. Landfill operators crush and compact the received waste and use an earth cover at the end of the day. Therefore, consumer product residuals will probably be exposed to the air for a period of time after initial placement. The physical and chemical characteristics of a VOC will determine whether it enters the air immediately or is actually buried in the landfill and follows a different pathway (e.g., absorption, chemical reaction, biodegradation). The various pathways that VOC may take in a landfill are discussed in more detail later in this section.

6.1.2.2 *Product Packaging*

Some landfills do not extensively process (i.e., compact, spread, or excavate) waste once it is placed in the landfill. This allows product containers to remain intact and VOC are released over a period of time. One of the factors affecting the rate of VOC release when product residuals remain in the container is the type of product packaging. For example, in aerosol products, VOC may leak from the container through failed gaskets or o-rings. With nonaerosol products, VOC may escape through seals in the caps and covers of product containers. Over time, the product packaging and seal materials will degrade and VOC will be released more readily.

With containers made from plastic (e.g., polyethylene, polypropylene, polyethylene terephthalate), release of VOC may occur through permeation, as all plastics can be permeated. This phenomenon is generally a function of the type of material stored, wall thickness of the container, surface area of the container, and temperature. For example, in the case of polyethylene, high permeation rates are observed for propane and isobutane because of the chemical similarity to polyethylene and the low molecular weight of these gases.

Because of the large amount of time required for plastics to degrade, it is unlikely that degradability affects the fate of VOC in plastic containers. The VOC in plastic containers still intact once buried in a landfill will likely be released by permeation through the container wall or leakage through failed seals.

Decomposition (e.g., corrosion) of metal containers as well as degradation of sealant materials and subsequent leakage is likely play a role in the release of VOC. Chloride, which is often present in municipal waste, is a strong promoter of corrosion in acidic media and will attack steel and aluminum. Although aluminum is resistant to acids in general, it will deteriorate rapidly in strong basic media. Presence of water in the landfill resulting from moisture in the waste, precipitation, and/or leachate recirculation is expected to hasten corrosion of metal containers. Although corrosion of the entire container is expected to occur over a long period of time, VOC in the container will escape sooner through cracks and corroded seams.

Approximate decomposition times for tin-plated steel and aluminum cans exposed to the air have been estimated at 100 years, and 100 to 500 years, respectively, depending on the availability of sunlight and rainwater. In one study where metal cans were subjected to varying environmental conditions (pH, temperature, and corrosivity), the shelf-life estimated for tin-plated steel and aluminum containers ranged from 1 year to greater than 50 years.

	VOC RELEASE MECHANISMS ASSOCIATED WITH LANDFILL OPERATING PRACTICES		POTENTIAL CHEMICAL AND PHYSICAL MECHANISMS WITHIN A LANDFILL	POTENTIAL FOR VOC EMISSION TO AIR
		Instantaneous VOC release when container crushed during waste placement		
	Compacting/crushing/spreading	VOC release over a period of time due to: - corrosion - leaking - failed o-rings - permeation - container decomposition/degradation - VOC degradation		
Consumer Product Placed in Landfill			Volatilization	High
			Absorption	Low
			Adsorption	Low
			Chemical reaction	Moderate
			Biodegradation	None
	No compaction/crushing/spreading	VOC release over a period of time due to: - corrosion - leaking - failed o-rings - permeation - container decomposition/degradation - VOC degradation		

Figure 6-1. Potential Pathways for VOC in Consumer Product Residuals Placed in Municipal Landfills.

Most glass containers will be broken either in the compactor truck before the container is placed in a landfill or as it is being placed or subsequently compacted and crushed. It is possible, however, that some consumer product glass containers will remain intact once placed in a landfill. Under such circumstances, release of VOC from glass containers depends on factors similar to those for metal and plastic containers, as most glass containers use either a metal or plastic top to contain and seal the product. Although glass containers are practically non-degradable, the top may degrade or corrode and eventually allow VOC to be released.

6.1.2.3 *Physical and Chemical Properties of VOC*

In addition to landfill operating practices and product packaging characteristics, the fate of a VOC in consumer products discarded in landfills is dependent on the specific physical and chemical properties of the VOC. Volatile organic compounds with high vapor pressures (i.e., high volatility) will be released more readily than those with low vapor pressures. Also, VOC with high permeabilities will escape from plastic containers more readily than those with low permeabilities. Volatile organic compounds with high solubilities will tend to dissolve in the landfill leachate and be released to the air more slowly than nonsoluble VOC with similar rates of volatilization. Also, prior to release from a product container, some VOC in a specific formulation may degrade to other VOC or non-VOC. This will occur over a period of time, as most formulations are characterized by shelf-life or date of expiration.

Once residual VOC are released from product containers as a result of crushing and compacting, leakage, corrosion, or permeation, there are five major mechanisms that can take place within the landfill:

- Volatilization,
- Absorption,
- Adsorption,
- Chemical reaction, and
- Biodegradation.

Mass transfer processes, including convection, diffusion, and displacement, facilitate these mechanisms by moving of VOC within the landfill. For municipal landfills, landfill gas convection is by far the predominant transport mechanism. As it flows through the refuse, landfill gas sweeps vapors present in the landfill to the surface. In addition to these transport processes, other activities may also result in transport of VOC to the landfill surface. Examples include methane gas explosions and excavation of inactive or closed landfills.

The potential for each of the mechanisms listed above is dependent on the physical and chemical properties of the VOC (e.g., physical state, vapor pressure, molecular weight, solubility, adsorption characteristics, reaction potential) and the prevailing environmental conditions within the landfill (e.g., moisture content, pH, temperature, soil characteristics, age of refuse, and presence of bacterial).

Major factors affecting volatilization of VOC in consumer product residuals following release from product containers include:

- Concentration of the individual compound in the landfill,
- Properties of the individual compound (e.g., physical state, vapor pressure), and
- Landfill conditions (e.g., temperature, moisture content).

Volatilization of a compound is controlled by the equilibrium between the vapor and liquid phases within the landfill system. Organic compounds in a landfill will evaporate until vapor concentration equilibrium is reached at the landfill temperature and pressure. Higher temperatures and lower pressures in the landfill will yield higher volatilization rates. Also, higher vapor pressures of consumer product ingredients will yield higher volatilization rates.

An alternative pathway for VOC in a landfill following release from product containers is absorption in the water in the surrounding medium. Potential sources of water are groundwater or leachate recirculation. The primary factor that determines the potential for absorption is the solubility of a VOC in water. For example, VOC with a high vapor pressure (e.g., low molecular weight paraffins) are insoluble in water and will remain in vapor form, whereas aromatic hydrocarbons are much more soluble in water. Other factors that affect the absorption rate include relative concentrations in vapor/liquid phases and temperature. Also, the presence of slightly soluble compounds (e.g., chloroform, benzene, alcohols) will enhance the solubility of other VOC.

The VOC volatilization rates following absorption in water will be determined by the vapor pressure and solubility of the compound and temperature of the medium. Compounds with higher vapor pressure-to-solubility ratios will volatilize more rapidly. Also, higher temperatures and lower pressures in the landfill will enhance vaporization rates.

Adsorption onto solids within the landfill is another pathway for VOC released from product containers. The potential for this pathway is dependent on the adsorptive characteristics of the VOC with respect to different types of solids and soils present in the landfill. For example, high-molecular-weight and low-vapor-pressure VOC are likely to be adsorbed on soils, as has been observed for halogenated hydrocarbons and some paraffins. As in the case of volatilization following absorption in water, the potential for desorption or evaporation of VOC from the soil or solid surface will depend on temperature and pressure in the landfill.

Chemical reaction between VOC released from different product containers is a possible mechanism for production and/or destruction of VOC. These reactions may occur as a result of contact between reactive wastes placed in the landfill or reactive gases generated in the landfill. Reactions with other wastes can speed, slow, or end the volatilization process. The primary factor affecting the rate of chemical reaction is the composition of the refuse in the landfill. For example, 1,1,1-trichloroethane (not defined as a VOC) will degrade into 1,1-dichloroethene and possibly further into vinyl chloride in the presence of bare aluminum. Possible chemical reactions are also affected by the landfill temperature and pH, but only if the reactive compounds are present. Higher temperature can result in either increased or decreased reaction rates.

Higher-molecular-weight organic constituents in landfill wastes may be decomposed by naturally occurring bacteria. The product of this decomposition can be a lower-molecular-weight constituent with a higher vapor pressure or volatility. For example, it has been shown that microbial involvement causes trichloroethylene to degrade to 1,2-dichloroethylene.

Biological decomposition of one organic compound into another is affected by the composition of the landfill refuse and the landfill conditions (i.e., temperature, pH) supporting biological activity. The best overall indicator of biological activity is the rate of landfill gas generation. Landfill gas, consisting primarily of methane and CO_2 (approximately 50/50 split) with small amounts of VOC, is produced by microorganisms in the landfill under anaerobic (without oxygen) conditions.

Factors that affect biodegradation rate include:

- Refuse composition,
- Refuse moisture content,
- Refuse age,
- Landfill temperature, and
- Landfill pH.

Biological degradation is a potential pathway for a majority of the VOC of interest in this study, with the exception of certain chlorinated VOC that are toxic to the bacteria in the landfill.[11] Biodegradation of consumer product residual VOC may be expected to be significant for approximately the first 6 years, as biological activity in a typical landfill peaks within 6 years of initial waste placement and declines steadily afterwards.

6.1.2.4 *Emission Controls and the Fate of Consumer Product VOC in Landfills*

Whether a landfill has a gas emission collection and treatment system (e.g., flares, turbines, internal combustion engines) in-place will have an impact on the extent to which VOC's from consumer products in landfills will be emitted to the air. The collection efficiency of a collection system as well as the VOC reduction effectiveness of the treatment system will affect the extent to which VOC emissions are reduced. Landfills with well designed gas collection and treatment systems can eliminate about 50 to 60 percent of the VOC emissions to the air.

The two basic options for controlling and treating landfill gas are combustion and purification. Combustion control can be applied with or without energy recovery. Controls that do not involve energy recovery include flares and afterburners. Options that involve energy recovery include gas turbines, internal combustion engines, and boiler-to-steam turbine systems, all of which generate electricity from combustion of landfill gas.

Purification techniques (adsorption, absorption, and membranes) process raw landfill gas into pipeline-quality natural gas. All purification techniques involve removal of water before removing carbon dioxide (CO_2). The water is removed by either absorption with glycols or adsorption with silica gel, alumina, or molecular sieve. The nonmethane hydrocarbons removal method depends on the CO_2 removal technique chosen and the composition of the landfill gas.

Usually the same techniques used for CO_2 removal are also used to remove nonmethane hydrocarbons by simply adding an extra absorption, adsorption, or condensation step. Standard natural gas pipelines generally do not accept halogenated compounds and sulfur derivatives. Consequently, the removal of these compounds from landfill gases is a significant part of process design.

The proposed new source performance standards (NSPS) for landfills (scheduled for promulgation in August 1995) will require certain new landfills to install gas collection systems and combust the captured gas. It is estimated that these regulations will reduce VOC emissions from new landfills by approximately 70 percent. This, in turn, will have an effect on the amount of VOC's ultimately emitted from consumer products that enter landfills.

Although an increasing number of landfills employ collection systems, the EPA was unable to determine what portion of discarded consumer products are disposed of in landfills with controls in place. Consequently, no adjustment to emission estimates could be made to account for the fate of consumer product VOC in landfills.

6.1.3 Conclusions of the Landfill Fate Study

The major findings of this study are summarized below. In reviewing these conclusions, it is important to consider the limitations and the scarcity of the information available for use in this study.

- There is limited information available on the potential fate mechanisms for VOC in consumer product residuals placed in municipal landfills. A large portion of the information identified is qualitative in nature and derived from studies conducted in environments other than those representative of subsurface or municipal landfill environments.

- Landfill operating practices (e.g., landfilling methods, the use of liners, the use of covers), product packaging characteristics (e.g., metal, glass, plastic), and physical and chemical properties (e.g., volatility, solubility, adsorptivity) of the VOC determine how and when the residual VOC in a consumer product container will be released following placement in the landfill.

- Once the VOC in consumer product residuals are released, their ultimate fate is dependent on the specific physical and chemical properties of the VOC and the environmental conditions (e.g., temperature, moisture content, pH) within the landfill.

- Based on the review of available information, the majority of the VOC/VOC groups included in this study are likely to be affected by three mechanisms in the landfill: volatilization, absorption, and biodegradation. Adsorption and chemical reaction are likely to be less significant fate mechanisms.

TABLE 6-1 ULTIMATE FATE OF VOC AND VOC GROUPS

	Emitted to Air as VOC[a]	Emitted to Air as non-VOC[b]	Absorbed in Water	Adsorbed on Solids
Paraffins and Isoparaffins				
Aliphatic Hydrocarbons	✓	--	--	✓
Butane	✓	--	✓	--
Isobutane	✓	--	✓	--
Petroleum Distillates	✓	--	--	✓
Propane	✓	--	✓	--
VM&P naphtha	✓	--	--	✓
Aromatic Hydrocarbons				
Toluene	✓	✓	✓	--
Xylene	✓	✓	✓	--
Chlorinated Hydrocarbons	✓	✓	✓	✓
Alcohols				
Ethanol	✓	✓	✓	--
Isopropanol	✓	✓	✓	--
Ethylene Glycol	--	✓	✓	--
Propylene Glycol	--	✓	✓	--
Ketones				--
Acetone	✓	--	✓	--

[a] Via volatilization, evaporation, and desorption.

[b] Via chemical reaction and/or biodegradation.

6.2 FATE OF CONSUMER PRODUCT VOC IN WASTEWATER

Many emissions inventories assume that all VOC in consumer products will eventually volatilize to the air. However, the VOC in some products, such as soaps, laundry detergents and household cleaners, may be combined with water before being completely or even partially volatilized. This study summarizes the fate of VOC associated with consumer products once they are introduced into the wastewater treated by publicly-owned treatment works (POTW's). It should be noted that no quantitative data have been developed that estimate the portion of a given product that actually gets washed down the drain.

6.2.1 Consumer Products Most Likely to Enter Wastewater

Recent EPA studies aimed at expanding the available information describing formulation data and VOC emissions potential from consumer products have yielded formulation data for nearly 50 product categories. These categories include both aerosol and nonaerosol products and vary greatly in their VOC content. In addition, the typical use and disposal of these consumer products play a critical role in determining the contribution of a specific product category to domestic wastewater.

The typical use and disposal practices associated with each of these consumer product categories were studied to determine which of the categories may have a significant impact on domestic wastewater. The categories were rated as follows, based upon the probability of discharging VOC into wastewater:

Rating	Rationale
Low	Any product category not typically used or disposed of by means of a sanitary drain or any product category with formulation data void of VOC.
Moderate	Any product category that requires clean-up in water or any product used in a manner that residual components would be removed by washing or bathing.
High	Any product category that requires use or disposal in a sanitary drain.

A list of the consumer product categories evaluated during this study and their potential for entering the wastewater stream is provided in Table 6-2.

TABLE 6-2
POTENTIAL FOR CONSUMER PRODUCTS TO ENTER WASTEWATER

Product Type	Product Form[a]	Potential for VOC Entering Wastewater
Adhesives (Consumer)	A/N	Low
Air Fresheners	A/N	Low
Anti-static Sprays	A/N	Low
Auto Antifreeze	N	Low
Auto Cleaners	A/N	Low
Brake Cleaners	A	Low
Carburetor & Choke Cleaners	A	Low
Carpet Deodorizers	N	Low
Car Polishes & Waxes	N	Low
Caulking & Sealing Compounds	A/N	Low
Engine Degreasers	A	Low
Engine Starting Fluids	A	Low
Hair Care Products (hair sprays)	A/N	Low
Herbicides & Fungicides	A/N	Low
Insect Sprays	A/N	Low
Lubricants & Silicones	A/N	Low
Moth Control Products	A/N	Low
Paints, Primers & Varnishes	A	Low
Prewash Stain Removers	A/N	Low
Shoe Polishes	A/N	Low
Starch & Fabric Finish	A	Low
Undercoatings	A/N	Low
Waxes & Polishes	A/N	Low
Window & Glass Cleaners	A/N	Low
Windshield Deicer	A/N	Low
Animal Insecticides	A/N	Moderate
Colognes, Perfumes & Aftershaves	A/N	Moderate
Floor Waxes & Polishes	N	Moderate
Hair Removers	A	Moderate
Hair Spray	A/N	Moderate
Insect Repellents	A/N	Moderate
Metal Cleaners & Polishes	N	Moderate
Oven Cleaners	A/N	Moderate
Personal Deodorants	A/N	Moderate
Pharmaceuticals	A	Moderate
Rug & Upholstery Cleaners	A/N	Moderate
Spot Removers	A/N	Moderate
Styling Mousse	A	Moderate
Suntan Lotions	A	Moderate
All Purpose Cleaners	A/N	High
Disinfectants	A/N	High
Drain Openers	N	High
Liquid Detergents	N	High
Shaving Lathers	A	High
Tile & Bathroom Cleaners	A/N	High

[a] A = aerosol, N = nonaerosol and A/N = both aerosol and nonaerosol products.

6.2.2 Principal Product Ingredients Entering Wastewater

Formulation data for each of the consumer product categories established as "High" or "Moderate" in their potential to reach domestic wastewater were reviewed. Whenever multiple formulation data within a specific product category were available, a "typical" product formula was developed by assuming equal market share for each of the formulations and averaging the specific constituents across each formula. If formulation data were only provided in ranges, the upper extremes of all reported ranges were used to identify potential VOC constituents.

A list of target VOC constituents contributing to the composition of domestic wastewater through the use or disposal of consumer products was developed by compiling the VOC constituent data from the "typical" product formulation for each category. Detailed quantitative determinations about the amount of these materials discharged into the wastewater were not attempted since national consumption data and market share information were not available for specific product formulations in all product categories.

Analyzing a product's potential to enter wastewater and reviewing either actual product formulation data or generic formulations identified five compounds that could enter wastewater from consumer products at potentially significant levels. These five compounds are ethanol, isopropanol, α-terpineol (pine oil), propylene glycol and Stoddard solvents. The VOC grouping called Stoddard solvents is defined as a mixture of 85 percent n-nonane and 15 percent trimethyl benzene isomers and is representative of solvents that are actually a complex mixture of various compounds (e.g., mineral spirits). Table 6-3 lists each compound, the consumer product categories in which it is found, the potential for entering wastewater and the average weight percent of the compounds in the formulation of each product.

The Stoddard solvents group and isopropanol are the only compounds listed in Table 6-3 which have the potential to volatilize rapidly from wastewater. A standard measure of the potential for a compound to volatilize from water is the Henry's law constant (H). H is equal to the vapor pressure of a compound in atmospheres (atm) divided by a compound's solubility in water in moles per cubic meter (mol/m^3) and is expressed in units of atm-m^3/mol. The potential for a compound to be volatile in water is characterized as follows:

- Low if H is less than 1×10^{-7} atm-m^3/mol, the substance is less volatile than water and its concentration will increase as water evaporates.

- Moderate in the range of $10^{-7} < H < 10^{-5}$ atm-m^3/mol, the substance volatilizes slowly at a rate dependent on H with the gas-phase resistance dominating the liquid-phase resistance by a factor of ten. Therefore, the rate is controlled by slow molecular diffusion through air.

- High when H is greater than 10^{-5} atm-m^3/mol, volatilization from water is rapid.[8]

Henry's law constants for ethanol, isopropanol, ∝-terpineol, propylene glycol and Stoddard solvents and the potential for each to volatilize from water are listed in Table 6-3.

As these data show, two compounds have both the potential to enter wastewater from commercial/consumer products and the potential for significant volatilization: Stoddard solvents and isopropanol. Ethanol and propylene glycol are moderately volatile, while ∝-terpineol is essentially non-volatile.

Analyzing a product's potential to enter wastewater and reviewing either actual product formulation data or generic formulations identified five compounds that could enter wastewater from consumer products at potentially significant levels. These five compounds are ethanol, isopropanol, alpha-terpineol (pine oil), propylene glycol, and Stoddard solvents.

TABLE 6-3
VOLATILITY OF CONSUMER PRODUCT VOC IN WATER

Compound	Henry's Law Constant ($atm\text{-}m^3/mol$)	Potential for Volatility in Water
Ethanol	3.03×10^{-5}	Moderate
Isopropanol	1.50×10^{-4}	High
∝-Terpineol	3.55×10^{-7}	Moderate
Propylene Glycol	1.50×10^{-6}	Moderate
Stoddard Solvents	8.49[a]	High

[a] The value for Stoddard Solvents was estimated from a mixture 85 percent n-nonane and 15 percent trimethyl benzene.

The categories of consumer products that are most likely to be disposed of into a municipal or community sewer system were analyzed. The analysis included:

- Determining the potential for products from each category to enter the sewer
- Estimating the national annual consumption of each product type
- Determining the percent by weight of each VOC species in each product type
- Calculating the annual consumption of each VOC species for each product type
- Estimating the daily per capita usage of each VOC species by product type
- Calculating the daily per capita releases of each VOC species down-the-drain

The product categories *Liquid Dish Detergent, Liquid Laundry Detergent, All-Purpose Cleaners, Tile and Bathroom Cleaners*, and *Shaving Lather* were all assumed to be disposed of down-the-drain through use with water and were designated as having a high potential for entering a POTW. The product category *Disinfectants* was assumed to be used in a manner likely for down-the-drain disposal for liquid formulations, but with only moderate potential for aerosol formulations (e.g., aerosol disinfectants used as room deodorizers and/or as surface sanitation). The remaining product categories included in the analysis for this effort (*Hair Sprays, Styling Mousse, Insect Repellents, Aftershaves, Oven Cleaners, Perfumes and Colognes, Suntan Lotions* and *Animal Insecticides*) were assumed to have a moderate potential for entry into the wastewater stream.

6.2.3 Pathways for VOC Release from Municipal Wastewater Systems

Components of the municipal wastewater system include a sewer collection network, treatment facilities and an outfall and/or disposal facility, depending on the ultimate fate of various wastes. A typical system has at least one POTW; the expression "POTW" specifically identifies the treatment operations. However, the term POTW has often been used to encompass all functions of the municipal wastewater system. To avoid confusion, this discussion presents each major functional component of the system (i.e., collection, treatment and disposal).

Location, size and configuration of the wastewater system are determined by the location of sources and the nature and magnitude of waste constituents. No single system uses all of the processes presented here: some combination of the devices and processes discussed in the following pages is employed to meet the particular treatment needs and capital limitations.

Wastewater is collected or received from several sources including homes, institutions, industries, stormwater, and infiltration. The collection and conveyance system encompasses collection from the point of waste generation to entrance into the wastewater treatment works, including the various drains, sewers and pumps necessary to deliver the water to the treatment system. However, municipalities maintain and operate only the conveyance network from the street sewer to the treatment plant.

The wastewater collection process actually starts where the wastewater is generated, most often in buildings. Plumbing fixtures empty into batteries of horizontal drains and vertical stacks which discharge into the **building drain**. Approximately five feet from the building, this drain becomes the **building sewer** which empties into the **street sewer**.

Other necessary building drainage features include traps and vents. **Traps** hold a water seal that obstructs and prevents foul odors and noxious gases, insects and vermin from passing through the drainage pipes and sewers into the building. **Vents** to the atmosphere are used to equalize the difference in air pressure and prevent failure of the water seal caused by the entrainment of air in the plumbing fixtures.

Gravity sewers are designed as open channels flowing partly full, or at most, just filled, using free or gravity flow. Sewer grades are constructed steeply enough to maintain the wastewater flow at self-cleaning velocities of 2 to 2.5 feet per second. Except in large sewers, **manholes** are built at all junctions with other sewers, at all changes in direction or grade, and between 300 and 500 feet apart at a minimum. Construction materials for gravity sewers include vitrified-clay, asbestos-cement pipes and fiberglass reinforced plastic.

Where conditions are not suitable for gravity flow, a **pumping** or **lift station** can lift flows through a **force main** into a higher-lying gravity sewer. The lift station is an arrangement of pumps, electric motors, sets, piping, valves, strainers, controls and alarms with a ventilation fan, sump pump, dehumidifier, lights and space heater assembled in an enclosed structure. Other optional equipment includes **pressurized sewers and vacuum sewers**. (Pressurized sewer force mains full flow and are laid parallel to the ground surface.) Some system designs have provisions for comminuters or grinders and pumps to discharge nonclogging wastewater from individual systems through pressurized pipes.

The potential for VOC to be emitted from a conveyance system has been discussed in the literature. Mathematical models based on fluid mechanics, air exchange rates, drag at the air-wastewater interface, barometric pressure gradient, temperature differences, "breathing losses" due to changes in liquid level and forced ventilation have been proposed. The consensus in the literature is that releases from conveyance systems are rather limited.

The potential for releasing VOC is expected to be greatest in the first physical treatment processes in a POTW for two reasons: the amount of VOC in the wastewater is greatest as the waste stream first enters the plant and the increase in surface area and turbulence associated with primary treatment will allow greater volatilization than would be expected in the conveyance system. However, physical treatment processes occurring after biological treatment are expected to play a less important role since most VOC would be greatly reduced by the time wastewater reaches these processes.

The potential for removal of VOC without creating emissions is greatest with biological treatment. This potential is due to microbial organisms that rapidly consume organic compounds, turning them into cellular material, and adsorption of organics to the highly organic sludge. However, the greater surface area found in the bubbles in aerated activated sludge basins and on the surfaces of trickling filters creates a high potential for volatilization. Therefore, the potential for the VOC to be consumed by the microbial flora of the biological treatment process is tempered by the potential for greater volatility due to increased air-water interface area.

The potential for VOC emissions from treated wastewater in outfall and disposal processes is determined by the process type and the efficiency of the biological treatment used to remove the VOC. Emissions would be expected to be greater in aeration processes than in a process such as landfilling of sludges and slurries.

6.2.4 Computer Models for Estimation of Fate of VOC in Model POTWs

This section reviews the methods available to estimate the fate of VOC in POTW's. The VOC of interest in this study include ethanol, isopropanol, α-terpineol (pine oil), propylene glycol and Stoddard solvents. The configurations of three model POTW's are also considered in this section of the report.

There are three basic approaches for estimating the fate of individual and total VOC associated with consumer products within POTW's:

- Field measurement of VOC emissions in the different units of the POTW plants
- Performing of an overall mass balance in the plant by calculating the difference between the VOC mass present in the influent and effluent streams
- Utilization of mathematical models with algorithms for estimating VOC removal rates due to volatilization, biodegradation, and/or adsorption to solids

The first approach is impractical due to limitations in ambient VOC monitoring techniques for some processes. Additionally, day-to-day differences in wastestreams and conditions make any measurements difficult to use. The second approach is certain to overestimate ambient VOC emissions, since it does not account for other competing VOC removal mechanisms such as biodegradation and adsorption to solids and biomass. The third approach is less expensive and faster than actual field measurements and allows for a better estimate of the fate of VOC than the overall mass balance approach. The third approach, using computerized mathematical models, was adopted for this study.

Documentation on existing models for waste treatment facilities and conveyance systems (sewer lines) was collected and reviewed to determine the applicability of each model to this project. When documentation of the model was not available, as in the case of the conveyance system, the model was evaluated based on information taken from published studies using the model.[1,2] Three comprehensive models were identified for the waste treatment facilities, one model was identified for the conveyance system and two alternative models for some POTW treatment units were identified. Table 6-5 shows a summary of the models identified and the corresponding offices responsible for the model's availability and/or development.

The following criteria were used to evaluate the models:

- Removal mechanisms and treatment units modeled
- Input requirements and the availability of input data
- Output provided by the model and the degree of conservatism exhibited
- Model testing and validation
- Model advantages and limitations
- Applicability to the POTW project

Three comprehensive models applicable to VOC emissions from POTW's were evaluated in this study: BASTE, SIMS, and CHEMDAT7. Each has certain limitations with respect to its ability to calculate VOC emissions from POTW's.

TABLE 6-4
SUMMARY OF THE MODELS IDENTIFIED

Model	Party Responsible for Model Availability and/or Development
Surface Impoundment Modeling System (SIMS) version 2.0	EPA/Control Technology Center Radian Corporation
CHEMDAT7	EPA/Office of Air Quality Planning and Standards
Bay Area Sewage Toxics Emission (BASTE) Model	Civil Eng. Dept., Univ. of California, Davis, CH2M-Hill/Bay Area Air Toxics Group
Corsi Model[a]	Civil Eng. Dept., Univ. of California, Davis
Pincince Model	Camp Dresser & McKee, Boston, MA
Reaeration Model	Tsivoglou and Neal (1976) WPCF 48(12):2669

[a] This model was developed by Dr. Richard Corsi using an adaptation of the Parkhurst-Pomeroy model to predict oxygen absorption in sewers. This model is not documented.

The SIMS and CHEMDAT7 models use many of the same algorithms. Neither model allows changes in temperature or changes in the compound's chemical and physical properties. The effect of these changes on the emission rates of compounds with low Henry's law coefficients, such as alcohols, can be significant. The models also perform steady-state mass balances, not allowing fluctuations on pollutant inlet concentration and flow rate, and assume that the wastewater in the impoundments is well mixed, which is not the case with sedimentation tanks and aeration basins. Finally, they do not include algorithms to calculate the adsorption of VOC on solids and the emissions from units comprising the headworks.

The BASTE model does allow for temperature changes and will model all aspects of a POTW, including split flows and multiple processes. However, BASTE is limited in the chemicals it will allow to be input into the model, and the VOC analyzed in this study could not be used with BASTE.

Despite their limitations in estimating VOC emissions from a POTW, either SIMS or CHEMDAT7 could have been used in this effort. However, the SIMS model presented certain advantages over CHEMDAT7 (discussed below) and was considered more appropriate for this study. Since the SIMS model was easier to use and manipulate, had a shorter execution time, and included algorithms to calculate emissions from weirs and other wastewater collection devices, it was utilized for this study.

6.2.4 Results of Modeling of VOC Fate in Wastewater Processes

The fate of each of the five selected VOC was evaluated using computerized mathematical models. The approach selected for this analysis was based on a review of currently available modeling techniques for VOC removal from POTW's. The estimated emissions of VOC from the conveyance system (sewer lines) leading to the model POTW's were based on Corsi's studies of VOC emissions in hypothetical sewer reaches. The results from modeling the conveyance system were used to provide the inputs for the model POTW's. The estimations for VOC removal from the treatment units of model POTW's relied on a combination of three models: SIMS, the Tsivoglou and Neal reaeration model, and the Pincince model for clarifier weir loss. The modeling of both the sewer system and the POTW's was performed for a steady influent flow and VOC concentration.

The steps involved in estimating VOC removal from a POTW included:

- Acquisition and preparation of input data
- Estimation of VOC losses in the sewer lines using the results of the Corsi studies
- Estimation of VOC losses at individual units in the POTW using a combination of three models: SIMS, the Pincince algorithms for clarifier weirs, and the Tsivoglou and Neal reaeration model for headworks processes
- Analysis of the results obtained from the modeling

The loss rates for each selected VOC were calculated for three POTW size configurations, each with a different flow rate. Additionally, three cases were applied to each POTW configuration:

- Case 1: default SIMS algorithms for clarifier weirs used with influent VOC concentrations at values calculated from Section 2
- Case 2: SIMS algorithms used with influent VOC concentrations at two times the calculated values
- Case 3: Pincince algorithms for clarifier weirs were used in place of the SIMS algorithms with influent VOC concentrations at calculated values[4]

Nine permutations among the three sizes and three cases were used with the model POTW's for each of the five compounds. A summary of the modeling results is presented in Table 6-5.

The greatest variability in removal rates between the selected VOC was driven by emissions to air. This variation in removal rates was found in the model conveyance systems and with several processes within the model POTW's. Within the conveyance systems the compounds with low Henry's law coefficients (i.e., alcohols) were stripped at a much lower rate than Stoddard solvents, which have a very high tendency to volatilize. The percentage of total VOC removal for the small sewer line was approximately twice the percentage removal for the medium and large sewer lines. This could be explained by the larger gas volume above the wastewater surface, which dominates the transfer process, associated with shallow flows and longer residence time in the system.

Within the model POTW's, the less volatile compounds (ethanol, propylene glycol, and α-terpineol) showed greatest potential for air emissions at the primary clarifier weir when the SIMS algorithms were used (Cases 1 and 2). Isopropanol had the potential for emissions at both the primary clarifier weir and the aeration basins. However, the overall removal of alcohols, when compared between model POTW's, was similar within each case, since biodegradation was the main removal mechanism for this chemical group.

Substitution of the Pincince clarifier weir algorithms for the default SIMS weir algorithms (Case 3) resulted in changes in emissions to air which differed from the other two cases and were dependent upon the nature of the compound being modeled. There were practically no changes in the air emissions of Stoddard solvent. This model compound is highly volatile and was stripped in the aeration basins for the small POTW and in the grit chambers for the medium and large POTW's (i.e., before the clarifier weirs were reached). However, there were noticeable reductions in the emissions of the less volatile compounds, such as the alcohols. The reduction in emissions calculated using the Pincince algorithms seemed to be related to the Henry's law coefficient for the compound being modeled. The greatest reduction in air emissions at clarifier weirs between Case 3 and Case 1 results was seen for α-terpineol (94 percent difference) and the lowest was seen for isopropanol (47 percent difference). These differences are most related to the Henry's law coefficient for these compounds.

The results from the Pincince algorithms (Case 3) for VOC emissions from clarifier weirs were found to be closer to the results reported in other studies than those predicted by the default SIMS algorithms. Therefore, Case 3 results have been used in the remainder of this discussion of results.

Results of the VOC air emissions estimates and corresponding percent mass removal by biodegradation and emissions to air for each case studied are presented in the report. The effect of doubling the initial VOC concentration was to increase the air emissions by the same factor in each of the model POTW's. This could be explained by the fact that most of the equations used in the modeling process are directly proportional to the initial VOC concentration.

The overall percent removal, however, remained virtually the same. The overall VOC air emissions from the use and disposal of consumer products were calculated using the results obtained when the Pincince clarifier weir models were used in the POTW's. The total VOC air emissions for the small sewer line and POTW were estimated at 0.1171 tons/yr: 31 percent emitted during the wastewater transportation to the POTW and 69 percent emitted at the POTW itself. For the medium and large sewers and POTW's, the total VOC air emissions were 1.386 tons/yr and 16.09 tons/yr, respectively. Approximately 14 percent of the VOC was emitted at the sewers and 86 percent at the POTW's.

Stoddard solvent was removed 100 percent in the three sewer-POTW systems, mainly through volatilization. The total removal for the alcohol compounds was approximately

99 percent for ethanol, 98 percent for alpha-terpineol, 91 percent for isopropanol, and 90 percent for propylene glycol. Biodegradation was the main removal mechanism for this group, accounting for over 96 percent of the total removal for ethanol and α-terpineol; 87 percent of the total removal for propylene glycol; and 76 percent of the total removal for isopropanol.

6.2.5 Conclusions of the Wastewater Fate Study

Consumer products were evaluated to determine which of the categories may likely enter domestic wastewater. All categories were rated as low, moderate, and high based upon the probability of discharging VOC into wastewater. The product categories found to have the highest potential to discharge to wastewater include liquid dish detergent, liquid laundry detergent, all-purpose cleaners, tile and bathroom cleaners, and shaving lather. They were all assumed to be disposed of down the drain through use with water and were designated as having a high potential for entering a POTW. Liquid formulation disinfectants were assumed to be used in a manner likely for down the drain disposal, but aerosol formulations have only a moderate potential. Hair sprays, styling mousse, insect repellents, aftershaves, oven cleaners, perfumes and colognes, suntan lotions, and animal insecticides were assumed to have a moderate potential for entry into the wastewater stream.

The VOC emissions can occur at any step in wastewater treatment where the wastewater comes in contact with air. The greatest potential is in processes where turbulence increases the water-air interface. The potential for releasing VOC is expected to be greatest in the physical treatment processes. These processes include screening, sedimentation, flotation and filtration to remove materials which can damage or foul subsequent treatment and process equipment. There are two reasons for this high potential: the amount of VOC in the wastewater is greatest as the waste stream first enters the plant and the increase in surface area and turbulence associated with primary treatment will allow greater volatilization than would be expected in the conveyance. The potential for removal of VOC without creating emissions is greatest with biological treatment. This potential is due to microbial organisms that rapidly consume organic compounds, turning them into cellular material, and adsorption of organics to the highly organic sludge. However, the greater surface area found in the bubbles in aerated activated sludge basins and on the surfaces of trickling filters creates a high potential for volatilization. Therefore, the potential for the VOC to be consumed by the microbial flora of the biological treatment process is tempered by the potential for greater volatility due to increased air-water interface area. There is also some potential for VOC emissions from treated wastewater in the wastewater outfall and sludge disposal process. Emissions would be expected to be greater in aeration processes than in processes such as landfilling of sludges and slurries.

Fate analyses were reported for specific classes of VOC in the consumer product categories addressed by this evaluation. For aliphatic alcohols, biodegradation represents the principal removal mechanism for simple alcohols in wastewater. Glycols are also primarily removed by biodegradation. Empirical rules for biodegradation also suggest that straight-chained alkanes are highly susceptible to microbial degradation and probably do not enter the domestic wastewater stream in significant quantities. In addition, these compounds are generally used as propellants and volatilize during product use. They would therefore, not be found in wastewater streams. Most chlorinated aliphatic hydrocarbons and aromatic compounds are removed by volatilization. Petroleum products are removed by biodegradation. In general, biodegradation is the principal removal mechanism for most of the selected VOC from consumer products in wastewater, with the exception of Stoddard solvents, which are mostly air-stripped in aeration basins.

The fate of each of the five selected VOC identified as having the potential to enter the wastewater stream in significant quantities was evaluated using computerized mathematical models. The approach selected for this analysis was based on a review of currently available modeling techniques for VOC removal from POTW's.

TABLE 6-5

FATE OF SELECTED CONSUMER PRODUCT VOC IN WASTEWATER

Compound	Percent Emitted	Percent Biodegraded	Percent Remaining in Effluent
Ethanol	3.7	95.4	0.9
Isopropanol	14.6	75.5	9.9
Stoddard Solvents	100.0	0.0	0.0
Propylene Glycol	3.0	86.7	10.3
α-Terpineol (pine oil)	0.7	97.1	2.2
Total (weighted)	12.2	86.3	1.5

1. Corsi, Richard L. *et al.* Assessment of the Effects of Ventilation Rate on VOC Emissions from Sewers. Presented at the 82nd Annual Meeting of the Air & Waste Management Association. Anaheim, CA. June 1989.

2. Corsi, Richard L. Prediction of Cross-Media VOC Mass Transfer Rates in Sewers Based Upon Oxygen Reaeration Rates. Presented at the 82nd Annual Meeting of the Air & Waste Management Association. Anaheim, CA. June 1989.

CHAPTER 7

ECONOMIC INCENTIVES TO REDUCE VOC EMISSIONS FROM CONSUMER AND COMMERCIAL PRODUCTS

This chapter presents a summary of the EPA's preliminary assessment of the feasibility and desirability of employing federal economic incentive programs to reduce VOC emissions from the use of consumer and commercial products. Section 183(e)(4) lists "..economic incentives (including marketable permits and auctions of emissions rights).." among the systems of regulation authorized to be used to achieve emission reductions from consumer and commercial products. This investigation of economic incentives was undertaken to evaluate the desirability of different regulatory strategies that may be appropriate under §183(e).

The principal tasks of the study are to examine alternative economic incentives and to compare them to a hypothetical command-and-control program. VOC content standards, which would consist of product-specific limitations on maximum VOC content (grams of VOC per unit of product). It is the basis of comparison because the ultimate purpose of this investigation is to search for the most desirable instrument in the set of potential instruments, which obviously would include instruments based on command-and-control.

The purposes of comparison are to determine how well the instruments accomplish certain policy objectives and to appraise their ability to cope with the complexities inherent in the task of environmental regulation. The specific bases of comparison are the following:

- program costs and initial information requirements when effects are uncertain.
- monitoring and enforcement.
- flexibility in distributing the economic impacts of regulation.
- adaptation to economic growth.
- incentives for technological innovation and diffusion, and
- unintended damages.

These criteria ensure a fairly comprehensive examination of the issues involved in designing environmental policy instruments. Further, a broad basis of comparison more fully reflects differences between economic incentives and command-and-control approaches.

This report does not serve as the final assessment of economic incentive strategies to reduce VOC from the many consumer and commercial products that may ultimately be regulated. Rather, it serves as a general assessment of the most prominent economic incentives for reducing air pollution, and it serves to set the stage for the future development of more detailed and industry-specific economic incentives.

Economic incentives may be particularly appropriate for the control of VOC from consumer and commercial products. The emissions source of concern is the use of the product but not the manufacture. This aspect of the pollutant leads to the existence of a great many small sources for which "end-of-pipe" control is practically infeasible. The products are very diverse. The types of consumer and commercial products and product forms number in the thousands. Product diversity reflects the adaptation of products to consumer demands, which vary from region to region and change from one year to the next. The core of the dynamics of consumer and commercial product industries is product innovation--each year, manufacturers and importers introduce hundreds of new products. In these circumstances, economic incentives may have great advantages over command-and-control strategies, such as VOC content standards, because (1) the Agency may need to accumulate less information on product technology and on performance; and (2) manufacturers have more flexibility to find the best balance between reducing VOC emissions and satisfying consumer demands.

Many VOC have specific characteristics that influence the design of a regulatory program. VOC are assimilative and uniformly mixed implying that emissions do not accumulate in the atmosphere and the concentration of ozone is independent of the location of sources in the airshed. Therefore, economic incentive programs need only to target total emissions of the pollutant rather than ambient concentrations of ozone.

Emission fees and emissions trading are the economic incentive most commonly proposed for the purposes of air pollution control. A comparison of these designs makes explicit the requirement for the consideration of certain fundamental policy issues, including the tradeoffs between: (1) certainty over the cost of emission reductions versus certainty over the quantity of emissions reduced, (2) the cost of control emissions versus administrative, monitoring, and enforcement costs, and (3) distributional flexibility versus the provision of incentives to advance technology. This report examines these tradeoffs in some detail.

Emission fee programs can be used to obtain real and quantifiable reductions in the emissions of VOC from consumer and commercial products. The basic rationale for these programs (and economic incentive programs in general) is to bring the full "social cost" of using VOC into the price of the product. A fee on the emission of VOC would increase the cost of using the atmosphere as a waste sink. The fee would have the same effect as the prices for the goods and services exchanged in conventional markets: for example, manufacturers would economize on their use of VOC because the "price" of using VOC would be higher, just as they would economize on the use of labor if wage rates were to increase.

Designing a fee program to reduce VOC emissions from consumer and commercial products presents many choices. Many of these design options are summarized in Table 7-1.

TABLE 7-1
SUMMARY OF FEE PROGRAM DESIGN OPTIONS

DESIGN ELEMENT	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
Program Purpose	Achieve VOC reductions at lower cost	Provide greatest incentives for technological change	Affect distribution of impacts	Combination of options	
Activity Charged	Impose fee in input market	Impose fee in wholesale product market	Impose fee at intermediate node in distribution channel		
Payer of Fee	Input user	Product supplier	Product demander		
Sources Included	All sources	Sources above size cutoff			
Phasing-in Sources	None	By size			
Fee Variability	With respect to season	With respect to VOC content	With respect to nonattainment status	With respect to emissions reduction progress	Combination of options
Method for Setting Initial Fee Level	Economic model	Value of Federal/State marketable emission rights	Negotiation	Combination of methods	
Collection of Fees	Sources remit fees to a special U.S. Treasury fund	Sources purchase VOC stamps (proceeds to U.S. Treasury special fund)			
Monitoring	Sources self-report VOC content & sales	EPA verifies reports	EPA checks remitted fees against VOC in products	States will verify reports	Combination of options
Noncompliance Penalties	Violator pays avoided fees and late fee	Raise fee rate for violator	Improve criminal penalty	Combination of options	
Use of Revenues	Fund R&D for VOC-reducing technologies	Fund labeling and/or education programs	Rebate revenues	Pay for program administration	Combination of options

Quantity-based emissions trading programs are alternative ways to generate economic incentives to obtain real and quantifiable reductions in the emissions of VOC from the use of consumer and commercial products. The two types of trading programs studied in this report are marketable emission permit programs and emissions averaging programs. Particular emphasis is given to emission permit programs because of their unique advantages and other unique characteristics.

The distinguishing characteristics of marketable emission permit programs are inter-source trading of emissions and the cap on the aggregate, absolute quantity of emissions. Unlike emission fee programs, VOC content standards, and emissions averaging programs, the absolute quantity of emissions is fixed in marketable permit programs. The restriction ensures the achievement of the environmental goal regardless of changes in the economy including the expansion of existing and entry of new sources (e.g., companies) of emissions. Emission averaging programs also rely on emissions trading and are most cost-effective when trades occur between companies, but they characteristically place an upper limit on emission rates instead of total emissions. The nature of the environmental goal is an essential difference between marketable permit programs and emissions averaging programs.
Table 7-2 summarizes many of the design options for marketable emission permit programs.

In all emission trading programs that allow external trades, companies have the incentive to seek potential trading partners. Opportunities for trade exist when the incremental or marginal cost of emission reductions differ in the industry. The consumer and commercial products industry is diverse, and manufacturers very probably will reduce emissions through unique combinations of product reformulation, packaging redesign, and reducing production. Therefore the marginal cost of emission reductions is likely to vary from company to company, and the company for which a reduction is more expensive will pay another company (i.e., one with lower costs) to reduce emissions. The benefit to the former company is reduced costs, and the benefit to the latter, increased profits.

Table 7-3 compares the performance of economic incentives and hypothetical VOC content standards on the criteria listed above. Table 7-3 assumes that every program aims to achieve the same environmental goal, a predetermined reduction in VOC emissions. The table includes the most important variants of both types of economic incentives: emission fee programs with and without rebates, and permit programs in which the EPA allocates permits to existing sources through an ordinary auction, zero-revenue action, or grant. The ranking of each program on a given criterion indicates relative performance and is discussed next.

Abatement Costs. In theory, marketable permit programs and fee programs will lead to the least costly emission reductions. In practice, however, none of these strategies will likely achieve the truly least cost solution that might be obtainable in a world of zero transaction costs and perfect certainty. In marketable permit programs with freely granted permits, transaction costs may restrict trading and hence reduce potential abatement cost savings, though costs of obtaining the same level of emission reductions would never exceed those resulting from content standards. Permit auctions may reduce the need for trading, but periodic auctions may impose uncertainty costs. Similarly, fee programs with adjustable fee rates may impose planning uncertainty or transition costs. Nevertheless, economic incentive strategies will generally result in reduced abatement costs compared to content standards because economic incentives provide

TABLE 7-2 SUMMARY OF PERMIT PROGRAM DESIGN OPTIONS

DESIGN ELEMENT	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
Program Purpose	Achieve VOC reductions at lower cost	Provide greatest incentives for technological change	Minimize adverse distributional impacts	Combination of options	
Permit Differentiation	By season	By nonattainment status	Annual permit	By State or nonattainment area	
Sources Included	Based on type of business	Based on size (emissions)			
Phasing-in Sources	None	By size (emissions)			
Opt-ins and External Groups	"Small" sources	Other C&CP manufacturers and importers	Manufacturers and importers of other VOC-containing goods	Environmental interest groups	Combination of options
New Sources	Purchase permits from existing sources	Reserved permit auction	Fixed-price sale of reserved permits		
Retiring Sources	EPA detracts permits at shutdown	EPA allows transfer at shutdown			
Type of Entitlement	Sources possess property rights	Sources possess temporary permission to emit			
Type of Commodity	Emission allowance (1 ton in 1 year	Emission reduction credit			

the flexibility to obtain emission reductions from the least costly sources.

Monitoring and Enforcement. For the purpose of comparison, nothing is lost by assuming that the penalty for noncompliance and probability of detecting noncompliance ensure a reasonable level of deterrence. With equal levels of deterrence, the comparison of policy instruments is a matter of differences in the activities and hence costs of detecting noncompliance. The economic incentive programs all require the collection of companies' reports of VOC content in the regulated consumer and commercial products and report verification; verification involves product sampling and reviewing product sales information. Marketable permit programs also require the Agency to track permit holdings. VOC content standards are less demanding than economic incentives because the Agency does not absolutely need to obtain sales information and monitor compliance nor does it need to track permit holdings. Sales information, however, would be necessary to monitor program performance.

Distributive Flexibility. At issue is not whether one pattern of distributive effects is preferred to some other pattern but rather the dialogue over distributive considerations. The ranking of policy instruments indicates the degree of flexibility to incorporate distributive values into instrument design. Fee programs with rebates and marketable permit programs with freely distributed permits or permits distributed through a zero-revenue auction may serve to minimize adverse distributional impacts on industry.

Adaptation to Economic Growth. All instruments can adapt to the changes in the economy that may strain the ability of the instruments to achieve the environmental goal, but the quickness of the adaptation and the costs to the EPA and regulated companies differ substantially. All permit programs adapt without action by the Agency because of the cap on emissions and hence are ranked the highest.[1] All fee programs, even those with formulas for the automatic but potentially sluggish adjustment of the fee rate, are likely to require the EPA to take corrective action when economic growth leads to an undesired increase in VOC emissions in nonattainment areas. VOC content standards would require the EPA to tighten the standards and, if new consumer and commercial products have appeared, to issue new standards; adaptation is likely to be slowest and Agency expenditures greatest.

Incentives for Technological Change. The evaluations are sensitive to the incentives that companies have to innovate, sell, and adopt cost-reducing technologies for reducing VOC emissions from consumer and commercial products. All of the economic incentive strategies promote technological innovation to a similar degree, but some strategies promote technological diffusion more than others.

Unintended Damages. Narrowness in the design of traditional or economic incentive regulatory programs may cause problems during implementation: intermedia transfer of

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[1] Permit banking requires a qualification of that judgment because aggregate emissions will exceed the cap in a year when previously banked permits are withdrawn and used, everything else equal. Nonetheless, without action by the EPA, the annual average emissions equals the emissions cap.

TABLE 7-3
COMPARISON OF ECONOMIC INCENTIVES AND HYPOTHETICAL VOC CONTENT STANDARDS WHEN THE ENVIRONMENTAL GOAL IS A FIXED QUANTITY OF EMISSIONS

CRITERIA	FEES		PERMITS		VOC CONTENT STANDARDS
	WITHOUT REBATES	WITH REBATES	FEE PERMITS AND ZERO-AVENUE AUCTION	ORDINARY AUCTION	
Abatement Costs	Good	Good	Good	Good	Poor
Monitoring	VOC content and sales	VOC content and sales	VOC content and sales and permit holdings	VOC content and sales and permit holdings	VOC content
Distributive Flexibility	Limited	Great	Great	Limited	Limited
Adaptation to Economic Change	Possibly slow and expensive	Possibly slow and expensive	Automatic	Automatic	Slow and expensive
Incentives for Technological Change	Very Good	Good	Good	Excellent	Poor
Unintended Damages	Possible	Possible	Possible	Possible	Probable

pollutants, increased VOC emissions due to inferior product performance, increased health risks, and increased air pollution in some areas. These unintended consequences are possible with all the policy instruments under review. Some of these potential problems, such as those due to product performance, appear to be more probable and to have greater avoidance costs with standards because companies have reduced flexibility to modify their products under the restrictions imposed by standards.

Conclusion. Overall, economic incentive programs appear superior to VOC content standards as strategies to reduce VOC emissions from consumer and commercial products. However, content standards may still be preferable if monitoring and other implementation costs are excessive.

The choice between traditional and economic incentive regulatory strategies is not necessarily an all or nothing choice. Combination content limit/economic incentive approaches are possible and may provide significant advantages, though these advantages need to be weighed against the shortcomings they may create.

The optimal selection of a regulatory strategy will depend on the specific characteristics of the universe of sources being regulated. For example, potential abatement cost savings, administrative and monitoring costs, and distributional implications of employing economic incentive strategies to regulate different industries will vary substantially.

The optimal selection of a regulatory strategy will also depend upon the program's objectives. For example, if stimulating technology advancement is considered of most importance, a marketable permit program with an ordinary auction might be most preferable. Alternatively, if distributional considerations are considered more important, a permit program with freely granted or zero-revenue auctioned permits, or perhaps a fee program with rebates, might be most preferable. Similarly, marketable permit programs might be best if certainty of emission reductions is of most importance (especially if product performance problems exist), but might be the worst if protecting consumers from potential future product price increases is of most importance. Tradeoffs are intrinsic to policy design, and the best regulatory strategy will depend upon the particular universe of sources being regulated and the priority of objectives.

CHAPTER 8

AEROSOL PRODUCTS AND PACKAGING SYSTEMS

Aerosol consumer products have been the subject of much discussion since the mid-1970's. Because of the degree of confusion and misinformation surrounding these products and their effect on the environment, the EPA included them as one of the major topics to be addressed by the consumer and commercial products study. The purpose of the aerosol products and packaging systems study is to develop information on these products and their delivery systems in order to determine their environmental significance and communicate this information to the Congress and the general public.

The term "aerosol product" is defined by the Chemical Specialties Manufacturers Association (CSMA) as "a sealed container pressurized with liquified or compressed gases so that the product is self-dispensing." The Department of Transportation (DOT) defines an aerosol as "a sealed package containing base product ingredients, in which one or more propellants are dissolved or dispersed, and fitted with a dispensing valve." According to these definitions, products such as trigger sprays or pump action dispensers are not considered aerosol products.

The concept of the aerosol product as a system is emphasized throughout the report. There are 4 primary components of the aerosol system: the product, the propellant, the valve, and the container. The product and propellant collectively are referred to as the formulation. Ideally, the system is designed such that each component operates in concert with the others. Consequently, as in any system of interrelated components, modification of one or more system components must be carried out judiciously in order to preserve the functionality of the system. The individual components of the aerosol packaging system and their interactions are discussed in detail in Section 8.2.

8.1 AEROSOL CONSUMER PRODUCTS AS SOURCES OF VOC EMISSIONS

In today's aerosol industry, nearly all aerosol consumer products employ hydrocarbon (HC) propellants. These propellants (primarily propane, normal butane, and isobutane) are VOC. The HC propellants were substituted for chlorofluorocarbons (CFC's) which were determined to contribute to the depletion of stratospheric ozone. The conversion to HC propellants was initiated by the industry in 1975 and was virtually complete by 1978, when the EPA banned the use of CFC's in most aerosol products. A discussion of this shift in propellants and its effect on the aerosol industry is presented in Section 8.3.

The CSMA publishes an annual *Aerosol Pressurized Products Survey* that reports information on aerosol containers filled in the United States. The 1989 CSMA survey reports that approximately 2.9 billion units were filled in the United States in 1989.[1] Table 8-1 presents data from the 1989 survey for several categories and subcategories of products. As the table shows, personal care products comprise the largest category followed by household products, automotive/industrial products, paints and finishes, insect sprays, and others, respectively. Hair sprays alone account for almost 18 percent of the number of all aerosol products filled in the United States. The next highest volume category includes paints, primers, and varnishes.

8.2 AEROSOL SYSTEM COMPONENTS

The purpose of this section is to describe the components of the aerosol system, to discuss the issues that are considered critical when designing a product, and to explain how these issues can affect VOC emissions. There are 4 primary components that comprise the aerosol system: the product, the propellant, the valve, and the container. Each of these components must be designed so that the product will meet the needs of the consumer. The formulation (product and propellant) is the most important part in that it must perform as designed, while being chemically compatible with the can and valve materials. The propellant must provide enough pressure so that the entire contents of the can will be expelled, yet not so much pressure that the product becomes dangerous or the spray pattern deteriorates. The valve design must achieve the desired spray pattern and delivery rate. The container must be designed for safety, cost effectiveness, and attractiveness.

8.2.1 Formulation

Almost all products that are available as aerosols are also available in other packaging forms such as creams, gels, or liquids. A product is packaged as an aerosol because of benefits to the consumer. To benefit the consumer, the product must be efficacious, that is, it must perform the function for which it is designed. The product should be convenient, safe, and aesthetically pleasing (i.e., it should have little or no offensive odor, not be messy, and be attractively packaged). The success of the marketed product depends on how well the system meets each of these criteria.

An aerosol formulation is made up of 3 major components: the active ingredients, the solvent, and the propellant. The active ingredients are the materials essential for the specific application for which the aerosol was designed. For example, the active ingredient in a paint is the suspended solids, and the active ingredient in an insecticide is the toxin. Solvents are usually present to act as diluents or to bring the active ingredients into solution with the propellant. Typical solvents include ethanol, odorless mineral spirits, and in some cases, water. The propellant is the third part of an aerosol and is discussed in more detail in Section 8.2.2.

The active ingredients are designed for a specific purpose such as odorizing (perfumes or deodorizers) or killing insects (insecticides). The chemicals that make up the active ingredients are almost as diverse as the number of products that are available. Because of this diversity, it is difficult to make generalizations about formulations. Any detailed discussion on formulations must take into consideration specific applications.

While solvents perform a number of functions in aerosol products, their primary purpose is to mix the active ingredients with the propellant. Solvents are also added to control the particle size of the spray. For example, if the formulation consists of chemicals that rapidly evaporate after discharge, a solvent may be added to retard the rate of evaporation, resulting in

TABLE 8-1
U. S. AEROSOL PRODUCTS FILLED IN 1989 [3]

Major Category	Subcategory	Units Filled		
		Number	Category (%)	Total (%)
Personal Care Products	Hair Sprays	516,193,000	50.9	17.7
	Shaving Creams	232,476,000	22.9	8.0
	Antiperspirants/Deodorants	221,751,000	21.8	7.6
	Medicinals/Pharmaceuticals	30,845,000	3.0	1.1
	Other Hair Products	9,356,000	0.9	0.3
	Other Personal Products	3,050,000	0.3	0.1
	Colognes/Perfumes	1,338,000	0.1	0.0
	Subtotal	1,013,660,000	100.0	34.9
Household Products	Room Deodorants/Disinfectants	220,660,000	32.5	7.6
	Cleaners	173,838,000	25.6	6.0
	Laundry Products	144,850,000	21.3	5.0
	Waxes/Polishes	94,951,000	13.9	3.3
	Other Household Products	45,800,000	6.7	1.6
	Subtotal	680,000,000	100.0	23.4
Automotive/Industrial	Lubricants	114,932,000	24.2	3.9
	Refrigerants	101,141,000	21.3	3.5
	Carburetor/Choke Cleaner	49,603,000	10.4	1.7
	Engine Starting Fluid	42,726,000	9.0	1.5
	Tire Inflator/Sealant	35,728,000	7.5	1.2
	Cleaners	33,292,000	7.0	1.1
	Brake Cleaner	31,008,000	6.5	1.1
	Engine Degreaser	27,665,000	5.8	1.0
	Other Automotive/Industrial	23,622,000	5.0	0.8
	Spray Undercoating	9,446,000	2.0	0.3
	Windshield/Lock De-icer	5,828,000	1.2	0.2
	Subtotal	475,000,000	100.0	16.3
Paints and Finishes	Paints, Primers, Varnishes	331,436,000	94.7	11.4
	Other Related Products	18,564,000	5.3	0.6
	Subtotal	350,000,000	100.0	12.0
Insect Sprays	Space Insecticides	124,538,000	63.2	4.3
	Residual Insecticides and Repellants	72,462,000	36.8	2.5
	Subtotal	197,000,000	100.0	6.8
Food Products	All Types	175,000,000	100.0	6.0
Animal Products	Veterinarian and Pet Products	8,000,000	100.0	0.3
Miscellaneous	Other Products	12,000,000	100.0	0.4
TOTAL		2,910,660,000		100.0

a larger droplet size. In some cases, solvents are also added to reduce the vapor pressure of the propellant system so that the aerosol product will comply with Department of Transportation (DOT) regulations.

To successfully market a product, the manufacturer (marketer) must go through a series of steps. First, the product must be developed. The active ingredients, inactive ingredients, and the propellant system must be selected. The next step is to determine if the formulation is compatible with the packaging system and if it is chemically stable. It is important to ensure that the formulation will not corrode the can or dissolve the valve. It is equally important that the formulation remain stable throughout the lifetime of the product. Next, the marketer must test the product to ensure that it is safe. This entails flammability testing and toxicological studies. Once it is determined that the product is safe, the product must be tested for performance in the field to ensure that the product performs as expected in the hands of the consumer. The next step is consumer testing, in order to determine whether the product is likely to be accepted by the consumer. The marketer is then ready to initiate the purchase of equipment or the negotiation of contracts to produce the product, etc.

Concurrently with the last 3 phases, the marketer usually obtains the necessary governmental approval. For example, insecticides, insect repellents, disinfectants, disinfectant cleaners, fungicidal sprays, and herbicides are regulated by the EPA under the Federal Insecticide and Fungicide and Rodenticide Act (FIFRA). The regulations require all products subject to the Act to be registered with the EPA before interstate shipment can occur. The regulations also contain labeling requirements for the products that are affected.

The Food and Drug Administration (FDA) regulates foods, drugs, cosmetics, and medical devices. The FDA must approve all ingredients in food products. Food additives, including propellants, must be on the FDA's "Generally Recognized as Safe" list. The FDA must also approve all drugs. An extensive new drug approval (NDA) process is required of each new pharmaceutical product. Although "over-the-counter" (OTC), drugs do not require such pre-market approval, they must meet the criteria of an existing drug monograph. Any drug product that deviates from an existing drug monograph is subject to the more extensive NDA process. Personal care products that affect bodily functions (e.g., antiperspirants, sunscreens, eye drops, etc.) are regulated by the FDA as drugs. Although the FDA does not require pre-market approval of cosmetics, it has authority to regulate cosmetic products. It can ban or restrict ingredients for safety reasons, mandate warning labels, inspect manufacturing facilities, issue regulatory letters, seize illegal products, and engage in nationwide recalls.

In general, it takes 2 to 5 years to get an aerosol product to the market. This time frame depends on the degree of product development, the extent of the required testing, regulatory requirements, and production needs.

8.2.2 Propellant

An aerosol propellant is defined as "a fluid capable of exerting a pressure when held in a sealed container at room temperature."[2] There are 3 major classes of propellants: fluorocarbons, hydrocarbons (HC's), and compressed gases. The fluorocarbons can be further divided into chlorofluorocarbons (CFC's), hydrochlorofluorocarbons (HCFC's), and hydrofluorocarbons (HFC's). The VOC include HC's (propane, normal butane, and isobutane) and dimethyl ether. The non-VOC compressed gases that are typically used as aerosol propellants are carbon dioxide (CO_2), nitrous oxide (N_2O), nitrogen (N_2), and compressed air.

The first significant aerosol product was an insecticide produced in 1943 for use by U.S. combat troops. This product and subsequent aerosol products used CFC's as propellants primarily because they are nontoxic and nonflammable. The HC propellants did not enter the market until about 1954. Studies conducted in the 1970's implicated the CFC propellants as contributing to the depletion of stratospheric ozone. Therefore, in 1975, the aerosol industry began substituting HC's and compressed gases in those aerosol products being manufactured that used CFC's. In 1975, approximately 50 percent of all aerosols were filled with HC propellants. This conversion was costly to the aerosol industry because many existing plants were not designed to handle flammable propellants. By 1978, when CFC's were banned by the EPA for use in most aerosol products, the conversion from CFC's to HC's was virtually complete.

A propellant functions by exerting pressure inside the container and forcing the product through the dip tube and into the rest of the valve assembly. When the valve is opened, the product is forced out of the container by this pressure. Liquified gas propellants (e.g., fluorocarbons or HC's) are used because they will maintain a relatively constant pressure as the contents of the can are expended. A constant pressure is maintained because the liquid propellant is constantly vaporizing into the head space of the container. As the liquid level of the container drops, more liquid-phase propellant vaporizes until equilibrium is established. The liquid serves as a reservoir to maintain the total pressure as the product level drops. This mechanism is contrasted with the compressed gases that lose pressure as the head space inside the container increases. Consequently, when a compressed gas is used, the container must be initially "over-charged" so that there will be sufficient pressure to expel the entire contents.

The physical properties that affect how a propellant functions in a specific application are the propellant's vapor pressure, solubility, and viscosity. The vapor pressure determines how much pressure is exerted on the liquid inside the container which, in turn, will affect the spray characteristics of the product. The solubility affects the manner in which the product must be used by the consumer. If the propellant is not soluble in the formulation, it is a two-phase formulation, and the container must be shaken in order to mix the propellant and product. If the propellant is soluble in the product, then it is a single-phase formulation, and no agitation is necessary. This is important because some products, such as wall dispenser air fresheners, cannot be shaken. Therefore, they must be single-phase formulations. The solvent properties of the propellant in relation to the valve components, such as gaskets and dip tubes, can also be important. If the propellant dissolves the valve components, the container may leak or the valve may not function correctly. Furthermore, the propellants must be pure. Impurities can result in problems such as inoperable valves or container corrosion. The propellant must be chemically stable in the formulation so that the propellant and product or solvent do not react to form undesirable compounds. The spray characteristics are affected by the viscosity. A high viscosity formulation may be discharged as a stream and not a spray. The propellant also influences whether the product is discharged as a foam, stream, or spray.

In addition to the propellant's physical properties, the formulator must consider its flammability, toxicity, odor, and cost. If the propellant is flammable, precautions must be taken during storage and the filling process to minimize the possibility of explosion. If the propellant is toxic, specific procedures must be implemented to protect employees, and the propellant is unsuitable for some applications such as food or personal care products. If the propellant has an undesirable odor, the consumer is less likely to use the product. If the propellant is very expensive, the cost of the product may affect consumer acceptance. When selecting a propellant for a product, the marketer must be aware of the ramifications of each of these issues.

Propane, n-butane, and isobutane are the principal VOC propellants used in today's aerosols. An additional VOC propellant, dimethyl ether (DME), is gaining more acceptance in the aerosol consumer product market.

The HC propellants are used because they have several very attractive properties. They are nontoxic, noncarcinogenic, noncorrosive, abundant, and cost effective (currently $.19 per pound, plus freight). These liquified gas propellants provide a consistent pressure over the life of the product, and they can be blended to achieve a wide range of vapor pressures. They are easy to transport, store, and handle. The major disadvantages are that they are flammable and that they are photochemically reactive in the atmosphere (i.e, they contribute to the formation of tropospheric ozone).

To achieve desirable spray characteristics, the formulator may require a propellant that has a pressure different from the vapor pressures of any of the pure compounds. This can be achieved by blending two propellants. The most common mixture is a propane/isobutane blend. For example, a mixture of 41.9 percent (by weight) propane and 58.1 percent isobutane results in a propellant with a pressure of 70 psig at 70°F. A significant problem associated with a HC blend is that the more volatile component of the mixture vaporizes into the headspace more quickly than the lower volatility component. As the product is expelled (and the higher volatility component is expended more rapidly than the lower volatility component), the lower volatility component accounts for an increasing percentage of the liquid propellant mixture. Consequently, the total pressure of the mixture decreases with product usage. This problem is exacerbated with the use of vapor tap valves because the higher volatility component is lost not only to the headspace but through the valve as well.

Compressed gases (e.g., CO_2, N_2O, N_2, and air) are used as propellants for some aerosol products. One company is experimenting with using hydrogen as a compressed gas. These gases are not VOC and are not considered photochemically reactive. It may appear advantageous, with respect to air quality concerns, to replace HC propellants with non-VOC compressed gas propellants. However, in a typical direct replacement formula, the compressed gas is present in small amounts (2 to 4 percent), and the remainder of the formula must include additional VOC which may have a higher ozone formation potential than the original HC propellant. This is because the HC propellant is an integral part of the product formulation and generally functions both as a propellant and a solvent. Consequently, removal of the HC propellant must be accompanied by addition of a solvent.

Compressed gases are high-pressure propellants that must be injected into the aerosol container in gaseous form instead of as a liquid under pressure. A compressed gas differs from a liquid HC propellant in that the vapor pressure of the HC propellant remains constant (at a given temperature) as long as there is liquid propellant in the container. When a compressed gas is used, the can pressure decreases as the contents of the can are expelled. As the volume of head space in the can becomes larger, the pressure decreases. Since the pressure decreases as the product is used, the filler must "over-charge" the can to ensure that the system will provide sufficient pressure to expel the entire contents.

Fluorocarbons, specifically CFC's, have been used as aerosol propellants for many years. These chemicals are nontoxic and nonflammable, which makes them attractive for use in aerosol consumer products. However, the use of these compounds in most aerosol propellant applications was banned in the United States in 1978 because of their potential to deplete the stratospheric ozone layer. The "Montreal Protocol on Substances that Deplete the Ozone Layer," a protocol to the "Vienna Convention for the Protection of the Ozone Layer," has been ratified by 65 countries and calls for a reduction in the production and consumption of CFC's. The Clean Air Act Amendments of 1990 require a phaseout of most CFC production by the year 2000.

8.2.3 Valve Assembly

This section describes the various valve components and the general types of valves. Most aerosol valve assemblies consist of 7 components: actuator, mounting cup, stem, stem gasket, spring, body (or housing), and dip tube. Figures 2-2 and 2-3 are diagrams of a vertical action valve. In general, the valve opens when a downward force is applied to the actuator, and it closes when the force is released. There are several different kinds of valves: vertical valves, tilt valves, female valves, "total release" valve systems and other special application valves. Valves must be designed to perform specific functions. Many aerosol products must deliver a fine spray. For these products the valve must be designed to break the liquid up into small particles. Products that are to be sprayed on a surface, whether it be a hard surface (paint) or the body (underarm deodorant), must have a valve that optimizes transfer efficiency. Some other types of valves include metering valves (dose inhalants), inverted use valves (compressed gases) and total release valve systems (indoor foggers), female valves (paints), and tilt valves (starches). In addition to the different valve types, there are over 300 varieties of valve bodies, a wide variety of stem gasket materials, 6 different sizes of valve springs, 5 variations of dip tubes, 2 materials for valve cups, and several types of valve gaskets. Each combination is designed to fulfill a set of specific functions.

Many different variables must be considered when deciding which valve is best suited for a specific application. The formulation must be tested to determine if it is compatible with the stem gasket, dip tube, valve body, and mounting cup. The manufacturer must also know what specific spray characteristics are desired so that a choice of mechanical breakup system, orifice size, and dip tube diameter can be made. If the product is prone to clogging, a female valve may be the best choice for the product. There are hundreds of different permutations of valve components, and the marketer and manufacturer must select a combination that will ensure that the specific product performs optimally.

8.2.4 Containers

The container is a critical component of an aerosol consumer product because it must withstand the pressure of the product formulation and propellant without bursting or leaking. It is also the portion of the product that the consumer sees when making a decision to buy a particular product. Therefore, it must be attractive and cost effective. Aerosol product marketers must consider each of these aspects of can design in order to choose a can that will be best suited to a specific application.

The DOT is responsible for regulating the transportation of hazardous materials. Almost all aerosol products are classified as materials presenting a limited hazard during transport due to their form, quantity, or packaging. The Code of Federal Regulations, Title 49, Part 173.306 (49 CFR Part 173.306) governs the shipment of most aerosol products. These regulations dictate the type of packaging that can be used (transported) based on the pressure of the product.

8.3 INDUSTRY PROFILE

8.3.1 History and Development

Aerosol products existed as early as the 1860's, with the first known aerosols being milk products and other beverages which were dispensed in aerated form through the use of carbon dioxide as a propellant. About 1910, cans and glass tubes of ethyl chloride were sold as topical anesthetics that chilled the skin prior to minor surgery. The most significant early work in aerosol product development was done in 1922, when Eric Rotheim of Norway developed an aerosol package comprised of a heavy brass shell and a primitive, threaded valve. Propellants for these early systems included isobutane, vinyl chloride, carbon dioxide, methyl chloride, and dimethyl ether. No further development of the aerosol packaging concept occurred until 1943, when U. S. Department of Agriculture researchers (Lyle Goodhue and William Sullivan) developed an insecticide "bomb" for use by U. S. troops in the South Pacific islands. Over 30 million of these units were produced from 1943 to 1947. These products utilized CFC propellants which were developed during the 1930's by Thomas Midgley of DuPont. Hydrocarbon propellants came into limited use in 1954, when Phillips Chemical Company introduced essentially odorless "Pure Grade" propane and butanes, and Risdon Manufacturing Company developed the first reliable mechanical breakup valve.[2]

A significant activity of today's aerosol industry is consumer education. Many consumers continue to believe that most aerosol products are propelled by CFC's and, therefore, contribute to stratospheric ozone depletion. One industry organization, the Consumer Aerosol Products Council (CAPCO), has produced an educational video, "The Aerosol Adventure -- How Tech Makes It Tick," that explains aerosol technology to a target audience of sixth to ninth grade students.[4]

8.3.2 Structure of the Aerosol Industry

Aerosol fillers perform the task of injecting the product formulation (product and propellant) into the aerosol container and sealing the pressurized container. Aerosol containers are either filled in-house by the marketer of the product (captive filling), or the filling operation is contracted out to another company (contract filling). There are approximately 100 fillers in the United States. About half these fillers are contract fillers that fill exclusively for the trade, while the other half fill for themselves as well as for marketers. The product formulation is usually blended at the same facility as the filling. Therefore, most fillers are also formulation blenders.

Because some companies fill exclusively for the trade and others fill for themselves as well as for other companies, it is hard to define a clear relationship between the fillers and other members of the aerosol industry. It is known, however, that many contract fillers form *one-on-one* relationships with formulators and marketers. These relationships create a dependence on the formulator and marketer for business.

Aerosol formulations for individual products are specified by the marketer. Generally, the formulation is blended at the same facility where the can is filled (either a captive or contract filler). In a few cases, usually involving proprietary formulations, the formulation is blended at a separate facility and is shipped to the filler.[5]

Propellant suppliers are another segment of the industry. Currently, about 81 percent of U. S. aerosol products are pressurized with HC propellants. Another 7 percent use CO_2, and the remaining 12 percent use N_2O, CFC's, DME, N_2, HFC-152a, and HCFC's (listed in approximately descending order).

Seven companies in the United States supply aerosol-grade HC's. Currently, 3 companies (Aeropres Corporation, Diversified CPC International, and Phillips 66 Company) produce over 80 percent of the HC propellants used in the United States. For some of these companies, the production of aerosol propellants comprises virtually 100 percent of their business (i.e., aerosol products are the only use for the propellants they manufacture). For example, Aeropres Corporation is almost totally dependent on the aerosol industry, because their primary activity is the production of aerosol propellants. Although they market small quantities of highly purified gases for instrument calibration purposes and some unpurified fuel gases, these markets represent only a small fraction of Aeropres's overall business. For more diversified companies such as Phillips 66 Company, the production of aerosol propellants may represent a much smaller segment of their overall business.

Approximately 25 container manufacturers supply tinplate, aluminum, glass, and plastic cans for the aerosol industry. Although many of these companies also produce nonaerosol containers or other products, some depend on the aerosol industry for most of their business. When making a decision about what type of can to use for a specific product, the marketer must consider the size of the can, whether the formulation may react with the can, what the pressure rating of the can should be, the aesthetics of the can, and product safety.

The valve is an essential element of every aerosol dispenser. When actuated, it releases the product from the container and produces a spray pattern appropriate for the specific application. In the United States, 9 firms supply virtually all aerosol valves. Three companies (Precision Valve Corporation, Seaquist Valve Company, and Summit Packaging Systems) supply over 90 percent of the aerosol valves used in the United States. Each of these companies, while also involved to varying degrees in the production of pump spray valves, depends on the production of aerosol valves for pressurized containers as a major portion of their business.

Although some valve manufacturers list suggested specific valve combinations for various standard aerosol products, the companies usually manufacture valves to the marketers' specifications. One U. S. valve manufacturer reportedly has over 10,000 specific aerosol valve designs from which to choose. While many marketers have their own unique ideas concerning what constitutes an acceptable spray pattern, a large degree of supplier interchangeability can be obtained by maintaining the same orifices, gaskets, and other attributes during the development of alternative or secondary source valve specifications.

Aerosol cover caps are necessary to protect the spray head from damage, prevent the actuator from discharging the contents during storage, prevent accumulation of dust or dirt on the valve, and enhance the general appearance of the container. Two companies (Berry Plastics and Knight Plastics) produce over 90 percent of the aerosol caps used in the United States.

8.4 ALTERNATIVE DISPENSING TECHNOLOGIES

One option that has been suggested as a means of reducing VOC emissions from aerosol consumer products is to switch from conventional aerosol packaging systems to alternative technologies that reduce the amount of HC propellant required to expel the product. While this is a reasonable and effective approach for many applications, each individual conversion must be considered carefully with regard to the net environmental benefit that will be achieved. This section describes the advantages and limitations of several alternative packaging technologies that have been or may be used for consumer products.

8.4.1 Bag-in-Can System

One alternative dispensing system for aerosol products is the bag-in-can system. This container (aluminum or tinplate) houses an inner bag containing the product concentrate and the exo-space propellant. The bag can be made of one of several different materials to ensure that the product and the propellant are kept separate. Under normal use, the system is designed to permit gas-free dispensing; however, upon disposal, the propellant would likely be released to the environment. The top of the can is fitted with a valve and an actuator. As the actuator is depressed, the inner bag begins to collapse due to the pressure of the exo-space propellant, and the product is dispensed. The Sepro Can® was the first bag-in-can unit introduced for aerosol products.

There are limitations to this type of packaging system, some of which are listed below:

- Products with high viscosities - result in slow transport through valve
- Products that are highly lubricating - result in a loss of seal for rubber components
- Products that are acidic - tend to attack certain types of bag materials
- Products with long shelf lives before use - the propellant permeates the bag and enters the product
- Products containing strong solvents - result in bag degradation or dissolution
- Products that must be hot-filled - results in flammability hazard and/or bag distortion

Most bag-in-can systems use HC propellants such as n-butane, isobutane, propane, and their blends. The use of compressed gases is severely limited because there is no reserve against slow leakage, and the propellant may be unable to dispense the entire contents of the can.

8.4.2 Piston Cans

A second type of alternative aerosol dispensing system is the piston can. This unit consists of an aluminum or tinplate can and a free-floating polyethylene piston that separates the propellant from the formulation. The propellant is injected through the base of the can below the piston. Hydrocarbons are the most common propellant type for the piston cans. Compressed gases cannot be used because they do not maintain a constant pressure as the contents are expelled.

These systems can be used for creams, gels, pastes, lotions, and other low to medium viscosity products such as shave creams, chocolate syrups, margarine, air fresheners, cheeses, cake toppings, and silicone-based tub and tile sealants. Piston cans typically dispense 95 to 98 percent of their contents. Limitations of piston cans include:

- Products with low viscosity will distort the piston
- Piston bypass and permeation will result in propellant reduction and foam generation in the product
- Incompatibility of the product with the can or piston

Piston cans are similar to the bag-in-can systems in that only a small amount of propellant is needed to dispense the contents. Typically, the piston can requires about 0.5 percent propellant. This can be compared to 3 percent used with traditional viscous aerosol products.

8.4.3 Enviro-Spray® System

The Enviro-Spray® system is the opposite of the bag-in-can system in that the product occupies the exo-space, and the propellant is inside the bag. The propellant bag consists of a large pouch containing a 50-percent citric acid solution in water, and four smaller pouches containing sodium bicarbonate. The smaller pouches are ruptured as the contents are expelled and the bag expands, pressurizing the container. Mixing of the citric acid and sodium bicarbonate produces sodium citrate salts and CO_2 gas that maintains the pressure in the unit at the original level. The product can be dispensed as a coarse spray, gel, paste, or post-foaming gel. The citric acid pouches in this unit are laminates that have a core layer of aluminum or polyester. The reservoir of sodium bicarbonate for the first pressurization step is contained in a special water-soluble polyvinyl alcohol bag. This system does not require any VOC propellants.

Enviro-Spray® dispensers are used for various insecticides, leaf shines, shave creams, colognes, rubefacient creams, catsup, mustard, and plant nutrient sprays. Some limitations of this dispensing system include:

- Product incompatibility with the can
- Product incompatibility/permeation of the pouch
- Variations in delivery rate due to pressure fluctuations

8.4.4 Pump Sprays

There are two basic types of pump dispensers, the aspirator type and the standard mechanical type. The aspirator type consists of a jar containing a dip tube, which aspirates the product into an orifice and out of the dispenser as a spray. Aspirator pumps have been used primarily for space spray insecticides; however, smaller versions of this type have been used for perfumes and colognes. The primary limitation of these units is that the product must have low viscosity so that it can be dispensed as a spray.

The aspirator-type pump sprayer consists of a cylinder and piston arrangement connected to a reservoir from which the product is aspirated through the dip tube, through a jet orifice, and propelled by a stream of air. An example of this type dispenser is the old "FLIT" gun. These have been used mainly for insecticides and were sold by companies such as Exxon and Gulf. Today, only a very limited number of these units are sold. These units do not use any kind of propellant.

The standard-type pump sprayers commonly in use today exist in two forms, the finger-pump sprayer and the trigger-action sprayer. The operating principles of the two systems are the same. The actuator/valve assembly usually has a threaded connection that fits into a glass or plastic container. As the actuator is depressed, the valve stem is forced downward into the body chamber that is normally filled with product. The product forces the chamber to expand outward, allowing product to flow past the piston into the orifices of the stem. The liquid then moves up the stem, through the adapter and button, and out the actuator as a stream or spray. When the button is released a partial vacuum is created in the chamber allowing product to refill the body chamber. The principal differences between the finger- and trigger-pump sprayers are the amount of product dispensed per actuation and the mechanical advantage of the pinioned trigger that provides higher internal pressure in the chamber.

8.4.5 Dispensing Closures (Squeeze Bottles)

Another aerosol alternative is the screw-threaded closure or cap with a dispensing hole which is plugged shut by various cap features when the product is not in use. A metal can or flexible plastic container is inverted and squeezed to dispense the product. This type dispenser is very efficient, because only the amount of product that adheres to the inside walls of the container will not be dispensed. These units are used for liquids, thin gels, soft creams, and lotions. Some examples are charcoal lighters, cosmetics, toiletries, other personal care products, paint thinners and strippers, furniture polishes, margarine, catsup, mustard, lubricants, carburetor and choke cleaners, silicone shoe and boot dressings, etc. The primary limitation is that the product dispensed in these units must be able to flow freely. Consequently, many of these products may require addition of solvent in order to achieve acceptable performance.

8.4.6 Twist-N-Mist®

The Twist-N-Mist II® is a pressurized packaging system that dispenses the product using energy supplied by manually rotating the full-diameter screw cap and integral piston. This is a propellantless dispenser. Accordingly, the only VOC will be those associated with the product itself. By twisting the threaded cap several revolutions, the piston is raised, creating a vacuum in the reservoir below. This causes the product to rise through the dip tube, past the stainless steel ball check valve, and into the cavity. The cap is then twisted an equal number of turns in the opposite direction, moving the piston downward, pressurizing the reservoir, and forcing the product into a Buna-N rubber bladder. The "memory" of the elastomer causes the bladder to return to its original shape as the product is dispensed through an aerosol-type valve. This unit dispenses about 95 percent of the product.

Currently existing drawbacks and limitations of this system include:

- Persistent stress cracking problem
- Inconvenience in that it can require many turns to expel the product
- Products cannot include foams
- Products cannot contain solvents incompatible with the Buna-N bladder
- Product incompatibility with the bladder results in product discoloration or odors.

8.4.7 The Exxel® System

Another alternative dispenser is the Exxel® system by Exxel Company, which consists of a thick, elastomeric rubber sleeve whose open end is fitted with a valve and actuator. The product is compressed into an inner PET sleeve and, because of the elasticity of the outer sleeve, is under pressure. Products currently dispensed in the Exxel® unit include welding flux spray, sun oil spray, muscle relaxant, sterile food products, Betadine® topical antiseptic solution, fragrances, hair gel, shampoo and conditioner, and hand and body cream. Skin care, hair care, and pharmaceutical products of the post-foaming gel type are in the developmental stages. The limitations of the Exxel® system include the following product types and/or conditions:

- Solvents such as terpenes and ketones
- Products with pH values over 10.0
- Products containing more than 5 percent isopropanol
- Products containing more than 60 percent ethanol
- Prolonged exposures to temperatures over 113°F
- High surface tension products
- Resins capable of drying and clogging actuators
- Products that require in-package mixing

8.4.8 The Mistlon Eco-Logical® System

The Mistlon Eco-Logical® Spray Bottle is a propellantless system in which the product is poured into a bottle fitted with a screw-threaded closure with an aerosol valve and actuator and a polypropylene cap. The base section of the unit contains a hollow cylinder with a one-way compound valve, which functions as a piston within a cylinder protruding into the container, also ending in a one-way valve. To pressurize the air in the container, the base section is pumped a number of times. The maximum pressure achieved is about 100 psig. By pressing a soft diaphragm in the center of the base, excess air pressure within the hollow cylinder is removed. The spray is very coarse. However, the unit can be equipped with a MBU unit to produce a more acceptable spray.

8.4.9 Airspray® System

This propellantless system is similar to the Mistlon Eco-Logical® system in that it uses a pumping action to compress air into a pressure-resistant container. This unit is distributed with a refillable screw top or with a disposable crimp-on. The containers can be made of plastic, metal, or glass. When pressurized to the maximum pressure of 55 psig, this unit will dispense up to 100 ml of product before it requires repumping.

The limitations of the Airspray® system are similar to those of the Mistlon Eco-Logical® system. It is not compatible with highly flammable formulations and formulations that deform polypropylene or attack polyvinyl acetate. It should not be used for products that are highly viscous or are direct foams.

8.4.10 The Selvac® System

The Selvac® system is a self-pressurized dispensing system. It consists of an aerosol valve, an inner membrane made of butyl rubber to hold the product, and an outer energy storage structure. The outer structure expands when the unit is filled under pressure with the product. When the actuator is depressed, the outer energy structure exerts pressure on the inner membrane and causes the product to be dispensed through the actuator. This system can be used for liquids, pastes, gels, lotions, and creams. Typical products include bath gels, body lotions, deodorants, hair products, shampoo, toothpastes, air fresheners, disinfectants, insect sprays, plant sprays, stain removers, antiseptic sprays, nasal sprays, dental products, topical creams, and flea and tick sprays.

8.4.11 The Werding Nature Spray® System

The Werding system consists of various actuators and nozzles, depending on the product to be dispensed. The Werding 'R' Actuator can be designed to provide a constant delivery rate, regardless of the internal pressure of the unit, thereby making it most useful for products pressurized with compressed gases. The thrust regulator controls flow into the nozzle, where the multistaged, interconnected venturi system results in a higher mechanical breakup effect than conventional actuators. The system also includes two stainless steel accelerator discs, a plastic expansion chamber, and a regulation disc. The design of the regulation disc and the nozzle are responsible for the regulation of the product flow. Under high pressures, the metal disc compresses, and the orifice size increases. This causes an increase in turbulence and a resistance to product flow through the thrust regulator. This ability to accommodate pressure fluctuations results in a constant dispensing rate of the product.

8.4.12 Vaporizers

Vaporizers provide mists or condensation nuclei of the product in the air. Electrically operated vaporizers consist of a wafer containing the concentrate and a small heater that is connected to an electrical wall outlet. As the wafer is warmed, the product is vaporized and released into the air. These units are used primarily for insecticides and air fresheners and are limited to products with appreciable vapor pressures.

8.5 REFERENCES

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16. ABSTRACT

This Report to Congress presents the findings of the EPA's study of consumer and commercial products and addresses such topics as (1) scope of products covered by Section 183(e); (2) emission estimates for all categories of products subject to Section 183(e); (3) the role of consumer and commercial products in the ozone nonattainment problem; (4) control measures and systems of regulation available under Section 183(e); (5) the regulatory environment surrounding consumer products; and (6) opportunities for emission reductions from regulation of specific categories of consumer products. The Report also addresses the issue of relative photochemical reactivity as it relates to consumer and commercial products, including: (1) a description of the reactivity-related requirements of Section 183(e); (2) a discussion of the science of photochemical reactivity; (3) an explanation of the role of relative reactivity in developing ideal ozone control strategies; and (4) methodologies which could be used now, based on the current uncertainties and limitations associated with reactivity, to fulfill the requirements of Section 183(e). In addition, the Report presents a detailed discussion of the criteria developed by the EPA for regulating consumer and commercial products under Section 183(e), describes how the criteria are being used, and lists the considerations on which the EPA will base the selection of categories for regulation.

17. KEY WORDS AND DOCUMENT ANALYSIS

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