POLLUTION PREVENTION RESEARCH FOR ORGANIC AIR EMISSIONS

by

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The Organics Control Branch (OCB) of the U.S. Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (AEERL) is charged with developing and assessing pollution prevention (P2) techniques and add-on control technologies for reducing emissions of organic compounds to air; *i.e.*, volatile organic compounds (VOCs) and air toxics. This presentation provides a brief overview of OCB's P2 research in three areas: 1) Surface Coating; 2) Solvent Cleaning; and 3) Consumer/Commercial Products, including traditional consumer products and non-process solvent use in commercial operations.

1. INTRODUCTION

"For more than two decades, the U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory (AEERL), located in Research Triangle Park, North Carolina, has been exploring control approaches for the pollutants and sources that contribute to air quality problems. AEERL has successfully developed and demonstrated cost-effective sulfur dioxide, nitrogen oxides (NO_x), and particulate control technologies for fossil fuel combustion sources. More recently, it has expanded its interest to areas that include indoor air quality, radon, organics control, stratospheric ozone depletion, and global warming. The AEERL also develops inventories of many types of air emissions. Over the past several years, AEERL has made a substantial effort to expand pollution prevention as the preferred choice to reduce air emissions. Its goal is to conduct research that will result in the greatest possible reduction of air pollution for the lowest cost[1]."

The OCB of AEERL is charged with developing and assessing P2 techniques and control technologies for reducing emissions of organic compounds; *i.e.*, air toxics (hazardous air pollutants [HAPs]) and VOCs. OCB's program is driven by both the Clean Air Act Amendments of 1990 (CAAA) and the Pollution Prevention Act of 1990. Title I of the CAAA, among other things, focuses on reducing ground-level ozone to achieve the National Ambient Air Quality Standard of 120 ppb (1-hour maximum). Ambient ozone is an oxidant and source of respiratory illness. Ground-level ozone is formed by complex atmospheric reactions between VOCs and

NO_x in the presence of sunlight[2]. Thus, the control of VOCs and NO_x, the precursors of ozone, is essential in order to meet the ozone standard. OCB's program will reduce VOC emissions in order to reduce ambient ozone. Title III requirements of the CAAA will reduce air toxic emissions. Standards are to be set by the year 2000 for 174 source (industry) categories which emit 189 listed toxic compounds. EPA's air regulatory office, the Office of Air Quality Planning and Standards, will develop Maximum Achievable Control Technology (MACT) standards for each of these categories. OCB will provide technical input on methods to reduce emissions of toxic organic compounds in support of key MACT standards.

The Pollution Prevention Act of 1990 [§6602(b)] established a national policy that:

- pollution should be prevented or reduced at the source whenever feasible;
- pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible;
- pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and
- disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner[3].

EPA's definition of pollution prevention states: "Pollution prevention means 'source reduction'... The Pollution Prevention Act defines source reduction to mean any practice which:

"• reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and

"• reduces the hazards to public health and the environment associated with the release of such substances, pollutants or contaminants.

"The term includes: equipment or technology modifications; process or procedure modifications; reformulation or redesign of product; substitution of raw materials; and improvements in housekeeping, maintenance, training or inventory control.[4]" OCB seeks to implement this philosophy of preventing pollution throughout its research program.

This paper will discuss OCB's P2 research in each of three technical areas:

(1) Surface Coating, such as paints and surface finishes (*e.g.*, wood furniture finishing), inks, and the use of adhesives and radiation-cured coatings;

(2) Solvent Cleaning, such as vapor degreasing, process equipment cleaning, and in-process precision cleaning; and

(3) Consumer/Commercial Products, including traditional consumer products (*e.g.*, hair spray and household cleaners) and non-process solvent use in commercial operations such as textile manufacturing, roofing, and furniture refinishing.

Each of the industries with which OCB is working has concerns about emissions from these areas. Most of these industries use surface coatings, solvents (to prepare surfaces for coating or to clean equipment), and a wide variety of prepackaged commercial products in their facilities.

Generally, projects in each of the technical areas can be divided into four categories or types:

(1) Scoping Studies which characterize an industry or process and its emissions and identify P2 opportunities to reduce those emissions. Scoping projects are ongoing for furniture restoration and repair, paper and other webs coating, printing, roofing, and consumer/commercial adhesives.

(2) Technology Assessment and Development Projects which evaluate the technical and economic feasibility of specific coating technologies or P2 techniques. Research and Development (R&D) projects are included in this category. Technology assessment and development projects are ongoing to evaluate very low-VOC coatings for wood furniture manufacturing and automobile body refinishing, to identify technical barriers to the use of radiation-cured and waterborne coatings, and to assess innovative ink-feed systems for printing, improved degreasing systems, cleanliness criteria for parts cleaning, and methods for determining the VOC content of consumer products.

(3) Demonstration Projects which investigate methods of reducing emissions in cooperation with industrial partners. Demonstration projects are planned for coated and laminated substrate manufacturing, for the design of recirculating spray booths incorporating VOC concentration gradient phenomena, and for precision and non-precision cleaning.

(4) Technology Transfer is an important project activity in OCB. Through technology transfer, the results of OCB's research are provided to the people who can use them, hopefully in a format that they can easily use. Technology transfer also provides OCB an opportunity to interact with its potential clients (*i.e.*, through workshops and conferences) to better understand their needs and the status of technology in many industries.

Projects in each of the technical areas are summarized below.

2. SURFACE COATING

2.1. Scoping

2.1.1. Status and Future Developments in Very Low-VOC Coatings for Wood Furniture Finishing. The objective of this project is to determine the status of R&D and market development for very low-VOC coatings used for wood furniture finishing. Information has been gathered through contacts with resin suppliers, paint manufacturers, wood furniture manufacturers, and their trade associations. The technical barriers and concerns of industry about these coatings have been identified and addressed[5]. The final report will be available in December 1993.

2.1.2. Characterization of Surface Coating Industry Segments. This project has been proposed under EPA's Source Reduction Review Program (SRRP) for 1994. The objective of the SRRP is to ensure the consideration of P2 options during the development of air toxic (also known as MACT) regulations for 17 of the 174 source categories to be regulated under Title III of the CAAA by the year 2000. The purpose of this project is to:

1) Identify industry segments involved in surface coating;
2) Determine the types of surface coating processes;
3) Identify related non-surface coating processes; and
4) Determine the VOC and air toxic emissions from each type of process with the overall objective of helping to target the most significant processes for EPA's emissions reduction efforts.

2.1.3. Assessment of Pollution Prevention Opportunities in Five Industries. In this small, cooperative project with the South Coast Air Quality Management District (SCAQMD) in Los Angeles, California, emissions and P2 opportunities have been assessed for the following five industries, all of which use surface coatings:

1) Architectural and Industrial Maintenance (AIM) Coatings;
2) Consumer/Commercial Adhesives;
3) Rotogravure Printing;
4) Flexographic Printing; and
5) Graphic Arts.

The final report for this project is expected in December 1993.

2.1.4. Enhancing the Market Penetration of Waterborne and Other Low-Solvent Consumer/Commercial Adhesives. This project has been recently funded to identify, develop, and demonstrate new, innovative waterborne and low solvent adhesive systems using recently discovered and other innovative raw materials. During 1994, promising adhesive systems and potential industrial and academic partners will be identified.

2.1.5. SRRP Focus Groups. The purpose of this SRRP project is to identify P2 opportunities via focus group input for 3 of the 17 SRRP categories. Of the three, only one is a surface coating category (*i.e.*, Paper and Other Webs). The other categories are Reinforced Plastics and Integrated Iron and Steel Manufacturing. Focus groups have included the participation of industrial, governmental, and academic experts to achieve a broad perspective. Focus group summaries will be available in early 1994.

2.2. Technology Assessment and Development

2.2.1. Waterborne Two-Component Epoxy Topcoats for Wood Furniture Finishing. A two-component water-based epoxy resin coating system containing less than 0.08 lb/gal (10 g/l) VOC has been developed as both clear and white-pigmented topcoats. The VOC level, 0.08 lb/gal, is the minimum detection limit of the test procedure for VOC content. These topcoats have met most performance criteria including: 1) a VOC content of less than 0.08 lb/gal; 2) high gloss; 3) dry to touch in 10 minutes or less, and dry to handle in 15 minutes or less; and 4) a 2H pencil hardness. A paper describing this research was presented at the Low- and No-VOC Coatings Conference on May 26, 1993[6]. This project is cooperatively funded with SCAQMD. Research is planned for 1994 to develop a complete coating system (*i.e.*, sealer, stain, and topcoat) which utilizes these resins.

2.2.2. Accelerated Development and Market Penetration for Very Low-VOC/HAP Wood Furniture Coatings. This project will be initiated during 1994. It will build on the final project report described in Section 2.1.1. by selecting 10 promising coatings for further evaluation, developing a program to bring each of these to full marketability status, and testing these coatings in commercial facilities.

2.2.3. Innovative AIM Coatings Assessment. The goal of this 1994 project is to identify and target AIM coating applications with high environmental risks, identify potential research partners involved with these applications, solicit their participation, and demonstrate innovative, low-emitting coatings at their facilities.

2.2.4. Field Evaluation of an Innovative Coating Utilizing Reactive Diluents. This project's objective is to reduce volatile organic emissions from coating operations by demonstrating the technical and economic feasibility of using reactive diluents in alkyd and epoxy coating formulations. Organic emissions from coatings which are formulated with reactive diluents are less than those from traditional, solvent-based coatings since the reactive diluents react to form part of the coating and are not flashed off as carrier solvents. The reactive diluent, vernonia oil, has been successfully tested at the bench-scale at the Coatings Research Institute at Eastern Michigan University. Since vernonia oil is extracted from a rare African plant which is not readily cultivated, alternative reactive diluents derived from readily available soy and linseed oils to mimic the chemical and physical properties of vernonia oil have been developed. OCB will work with private paint researchers and coating retailers and users to field- or pilot-test innovative coatings using these diluents. This project is being performed cooperatively with SCAQMD.

2.2.5. Innovative Coatings and Adhesives Research Centers. Two research centers will be established at universities or non-profit research institutes during 1994 to develop and/or evaluate innovative adhesive and coating formulations.

2.2.6. Technical Barriers to the Use of Radiation-Cured and Waterborne Coatings. This project is part of the SRRP and is just underway. The use of radiation-cured (*e.g.*, ultraviolet [UV]-cured and electron-beam-cured) or waterborne coatings is a P2 option for several SRRP source categories. However, technical barriers to their broadened usage exist, including concerns about toxicity and the difficulty of coating complex parts using radiation-cured coatings. The objective of this project is to identify and characterize these technical barriers and to identify critical research to overcome them.

2.2.7. Basic R&D on Radiation-Cured Coatings. During 1994 under a proposed SRRP project, the results of the 'Barriers' project (Section 2.2.6.) will be used to target research opportunities for radiation-cured coatings. A mechanism will be established to pursue these opportunities.

2.2.8. Retrofit of Existing Solvent-based Flexible Substrate Coating Equipment to Use Water-based Coating Systems. The coated and laminated substrate manufacturing industry makes a wide variety of pressure sensitive products such as paper (masking), cloth (duct), and cellophane tapes, tags, labels, and a number of exotic laminated products. It was selected for study because of significant air emissions of methyl ethyl ketone (MEK) and toluene reported in the 1990 Toxics Release Inventory, *i.e.*, it is the No. 1 source for MEK (8,050 tons/yr [7,300 Mg/yr]) and the No. 3 source for toluene (13,000 tons/yr [11,800 Mg/yr]). A focus group, including members of the Pressure Sensitive Tape Council (PSTC), the Tag and Label Manufacturers Institute, and academic and state environmental experts, helped OCB identify opportunities for significant reductions of volatile organic toxic emissions in this industry.

The use of solventborne coatings (*e.g.*, adhesives) was identified as the primary source of the industry's toluene and MEK emissions. The objective of this project is to evaluate the quality and economic viability of waterborne adhesives when used to replace solventborne adhesives on flexible substrates by modifying existing coating equipment. A report documenting background issues for this project will be available in December 1993. The high level of industry participation through the PSTC has allowed EPA to obtain a profile of the industry's plans to change from solvent-based systems. Hot melt and radiation-cured coatings and solvent recovery compete with the water-based alternatives. Case studies will be completed during early 1994.

2.2.9. Innovative Ink Feed Systems. This project is also part of the SRRP and is just underway. The systems (*e.g.*, piping, tanks, and mixers) used to feed ink to printing presses and their subsequent cleaning requirements are the source of substantial volatile organic air toxic emissions. Alternative feed systems could substantially reduce these emissions.

2.2.10. Characterization and Modification of Microstructure in Waterborne Inks Stabilized by Polymeric Surfactants - Phase I. The objective of this project is to develop the use of polymeric surfactants to stabilize the microstructure in, and influence the physical properties of, waterborne inks. The focus will be on the enhancement of the performance of traditional inks, not the reformulation of inks. Specific research will include: 1) characterization of the microstructure of waterborne ink systems; 2) correlation of the microstructure with physical properties (*e.g.*, stability, viscosity, ink/substrate compatibility); 3) identification of the dominant structure-property relationships; and 4) modification of the microstructure by adjusting the molecular characteristics of polymeric surfactants to produce a system with the desired properties (*e.g.*, gloss, heat resistance, and opacity). VOC and air toxic emission reductions will result from this 1994 project if it is successful.

2.3. Demonstration

2.3.1. Reduction of Solvent Emissions from Automobile Body Refinishing. The objective of this 1994 project is to demonstrate P2 technology to reduce volatile organic emissions from automobile body refinishing operations. Promising technologies, such as high-volume/low-pressure spray guns, low VOC paints and primers, water-based primers, and short wavelength infrared curing, are available for this area. The demonstration will focus on technologies which can prevent emissions from small, dispersed, stationary area-sources. The results of these tests will be made available to small companies that previously have not had access to control or prevention technologies. Work is expected to be underway during 1994.

2.3.2. Evaluation of Ultra Low Volume (ULV) Spray Gun System. The objective of this project is to evaluate an ULV spray gun system. Tests have been completed cooperatively with the U.S. Air Force at Warner Robins Air Force Base, Georgia. Qualitative results of the test are promising. An improvement of paint utilization efficiency was attributed to the enhanced paint laydown provided by the gun. This and the ability to spray high viscosity paints (which contain fewer solvents) have led to a 50% reduction in VOC emissions. The final project report is under review by the U.S. Air Force and has not yet been released.

2.3.3. Application of Department of Defense (DoD) Powder Coating Expertise to Civilian Applications. The objective of this 1994 project is to improve the competitiveness of small businesses by allowing them to coat their products more efficiently by using powder coatings whenever that is technically and economically feasible. Paint in powder form is electrostatically charged and applied to oppositely charged metal or electrically conductive parts. Overspray is collected and reused. The powder coated parts are then cured with heat or UV radiation. The process eliminates VOC emissions and avoids generation of paint booth wastewater. The powder coating expertise developed by the DoD will be applied to civilian applications to achieve this goal.

2.3.4. Partitioned, Recirculating Spray Booth. This project is presented even though it is not P2 since it complements OCB's P2 projects in surface coating. Recirculation in paint spray booths has been recognized for many years as a means of reducing the volume of spray booth exhaust. This allows the use of a smaller control device, hence reducing air pollution control costs (*i.e.*, equipment and energy costs). Partitioning of the spray booth exhaust stream takes advantage of the VOC concentration gradient that exists vertically across the booth exit. VOCs stratify in the booth and their concentration is greatest closer to the floor. By pulling the booth exhaust stream from the bottom portion of the booth and the recirculating stream from the top portion of the booth, the concentration of the exhaust stream can be enhanced, perhaps removing the same mass of pollutants in a smaller exhaust volume than is possible in a traditional recirculating booth. Preliminary field tests have shown the feasibility of reducing controlled air volumes by 50-75% below non-recirculating booths.

A demonstration of the stratified recirculation concept is planned for 1994 at the U.S. Marine Corps Maintenance Depot near Barstow, California. The demonstration will be completed cooperatively with the Marine Corps and Pennsylvania State University. During the demonstration, an existing spray booth will be modified to use both recirculation and partitioning. A movable plenum will be used to evaluate the optimum height for flow partitioning. An end-of-pipe control technology will be evaluated in conjunction with the spray booth demonstration. Spray booth exhaust will feed to a control device which uses UV light to destroy organic compounds absorbed on a catalytic substrate, scrubbing with ozonated water, and a final activated carbon polishing step.

2.4. Technology Transfer

2.4.1. The Surface-Coating-Free Materials Workshop. This workshop was held July 1991, to explore the potential for development and use of materials that would not need to be coated during manufacture or recoated during use. If such materials were to come into widespread use, VOC and air toxic emissions associated with surface preparation (cleaning), coating, and paint stripping before recoating could be avoided. The proceedings of this workshop are available[7].

2.4.2. The Pollution Prevention Conferences on Low- and No-VOC Coating Technologies. The first conference was held in San Diego, California, May 25-27, 1993, to provide a forum for exchanging technical information on innovative coating technology and to allow EPA to interact with industry, academia, and others interested in surface coating technology. Conference proceedings will be available late in 1993. A second conference has been scheduled for early 1995 and will be held in the Raleigh-Durham, North Carolina, area.

2.4.3. Coatings Alternatives Guide (CAGE). CAGE will summarize information on new and innovative coating technologies along with their potential applications. The first version of CAGE will be a hard-copy summary of technologies that OCB has encountered to date. CAGE will then be computerized using proposed 1994 SRRP funding and placed into a user friendly information

system. This system will be modeled after the Solvent Alternative Guide which is described in Section 3.4.1. CAGE will expand to handle new data as they become available.

2.4.4. Adhesives Alternatives Guide (AAGE). This project has been proposed for 1994 under the SRRP. Its objectives are similar to those of CAGE except that it will focus on alternative adhesives.

3. SOLVENT CLEANING

3.1. Scoping

3.1.1. Evaluation and Pollution Prevention Analysis at the Warner Robins Air Force Base, Georgia. The objective of this project is to assess the types and quantities of emissions from various cleaning and reconditioning processes at the Air Force Base and to identify the types and quantities of emissions and the potential benefit of P2 approaches. A summary report for this effort will be available during mid-1994. Funding has been requested to demonstrate these approaches in 1994.

3.1.2. Evaluation and Pollution Prevention Analysis at the U.S. Marine Corps Maintenance Depot, Albany, Georgia. The objective of this 1994 project is to assess the types and quantities of emissions from various cleaning and reconditioning processes at the Maintenance Depot and to identify the types and quantities of emissions and the potential benefit of P2 approaches. Funding is available to demonstrate these approaches.

3.2. Technology Assessment and Development

3.2.1. Pollution Prevention Regulatory Support for Degreasing MACT. The purpose of this project is to evaluate alternative degreaser designs in support of the regulation scheduled for promulgation during 1993. The impacted industries, types and quantities of emissions, and potential benefit of prevention approaches will be assessed. The final report of this project will be available in February 1994.

3.2.2. Surface Cleaning Research -- Cleaning Testing and Evaluation. This project will test alternative cleaners and cleaning equipment. It will develop a standardized scale for determining the level of cleanliness required for various applications. A status report for this project will be available during late 1994.

3.2.3. Evaluation of Alternative Paint Stripping Technologies Used In Aircraft and Space Vehicles. Low toxicity and low-VOC paint stripper alternatives for metal reworking will be identified, evaluated, and compiled in this proposed 1994 SRRP project under an interagency agreement with the National Aeronautics and Space Administration (NASA).

3.2.4. Evaluation of Alternative Dry Cleaning Techniques. The purpose of this project is to evaluate dry cleaning techniques which do not use toxic solvents. Work will be underway early in 1994.

3.3. Demonstration

3.3.1. Coated and Laminated Paper Equipment Cleaning. The rationale for this project is similar to that for the "retrofit" project described earlier under in Section 2.2.8. However, the focus of this project is on the second largest source of MEK and toluene emissions in the industry, equipment cleaning. The objectives of this project are to identify and evaluate improved methods for cleaning process equipment surfaces, recommend candidate demonstration projects, conduct demonstrations, and transfer technical findings to the small businesses in the industry. A report detailing emissions characterization and P2 opportunities will be available in December 1993. The demonstration report should be available early in 1994.

3.3.2. Demonstration of Solvent-Free Precision and Non-Precision Surface Cleaning Techniques. The purpose of this project is to identify candidate industrial processes in which conventional cleaning solvents can be replaced by non-organic solvents or by solventless technology, to demonstrate the alternative techniques, and then to compare them to conventional cleaning. Two reports detailing these demonstrations will be available in January and February 1994. A demonstration of the use of carbon dioxide (CO_2) snow at an automotive parts manufacturer is scheduled for 1994.

3.3.3. Spray Gun Cleaning. The purpose of this project is to compare emissions from two types of paint spray gun cleaning equipment (*e.g.*, open- and closed-systems) to each other and to those of current cleaning practices. This project, which will be completed during the Fall of 1993, is being done to support the EPA's Control Technology Center (CTC). The CTC provides technical support to local, state, and EPA Regional environmental personnel, small businesses, and international clients. It is co-sponsored by AEERL and EPA's Office of Air Quality Planning and Standards. The final report will be available in December 1993.

3.4. Technology Transfer

3.4.1. The Solvent Alternatives Guide (SAGE). SAGE is an information system which identifies low-pollution surface cleaning alternatives, given the substrate to be cleaned, the type of soil, and the degree of cleanliness desired. The objective of this project is to develop SAGE as an analytical tool, to make the tool accessible and useful to small business users, and to identify emerging cleaning technologies. SAGE Version 1.1 is publicly available on computer diskette and through downloading from the CTC bulletin board[8]. SAGE Version 2.0 will be released during early 1994. Funding is available to develop Version 3.0 during 1994-95.

4. CONSUMER/COMMERCIAL PRODUCTS

4.1. Scoping

4.1.1. Consumer/Commercial Products Report to Congress Support. Information on non-process solvent use was evaluated for 15 industrial and commercial source categories to characterize VOC emissions and identify P2 opportunities. Non-process solvents are used by industry, commercial operations, and/or individual consumers; they are not incorporated into a product or chemically modified as part of the manufacturing process. Project results will support a Report to Congress, required by §183(e) of the CAAA, which addresses emissions of VOCs from consumer or commercial products. The report summarizing the 15 categories will be available in November 1993.

As a result of the 15-category evaluation, five categories were selected for further study:

1) Textile Manufacturing,
2) Furniture Repair and Refinishing,
3) Roofing,
4) Mold Release Agents, and
5) Heating, Ventilation and Air-Conditioning Coil and Parts Cleaning.

For each category, a more detailed evaluation of emissions, emission sources, and P2 opportunities is being completed. Four of these categories--Furniture Repair and Refinishing; Roofing; Textile Manufacturing (*e.g.,* screen printing); and Mold Release Agents--incorporate surface coatings. All of the categories use surface cleaning. Reports detailing emissions and P2 opportunities for the five categories are expected in December 1993.

4.2. Technology Assessment and Development

4.2.1. Consumer Product Test Methods Development for VOC Content. The purpose of this project is to develop test methods for the VOC content of a wide variety of consumer products, validate the test method(s), and establish a standard test for use by state and local agencies, industry, and others. Several reports and papers are available[9]. A report detailing the final test method will be available in January 1994.

5. SUMMARY AND CONCLUSIONS

EPA's OCB has a P2 program which involves industries which have significant VOC and air toxic emissions from coating and cleaning operations. These industries include wood furniture manufacturing, coated and laminated substrate manufacturing, and printing and publishing. Each of these industries has common concerns, and it is hoped that the results of EPA's work with one industry will be useful to others. This paper summarizes surface coating, solvent cleaning, and consumer product activities in OCB. The input of a broad spectrum

of industry, academic, and other experts, such as the attendees at this symposium, is needed to continue to enhance the focus, quality, and content of OCB's current and future research activities.

REFERENCES

1. Shaver, E.M., "Pollution Prevention for Cleaner Air: EPA's Air and Energy Engineering Research Laboratory," Pollution Prevention Review, Winter 1992-93, pp.41-50.

2. Ponder, W.H., "A Study of the Occurrence of Photochemical Smog with Emphasis on Temperature Effects." Master's Thesis, Department of Chemical Engineering, Clemson University, Clemson, South Carolina, January 1965.

3. Pollution Prevention Act of 1990, §6602(b).

4. Memorandum, F.H. Habicht II (U.S. EPA, Washington, D.C.) to All EPA Personnel, "EPA Definition of 'Pollution Prevention'," May 28, 1992.

5. McMinn, B.W., C.R. Newman, R.C. McCrillis, and M. Kosusko, "VOC Prevention Options for Surface Coating," Paper Number IU 6B.07, Presented to the 9th World Clean Air Congress, Montreal, Quebec, Canada, August 30 - September 4, 1992.

6. Huang, E.W., L. Watkins, and R.C. McCrillis, "Development of Ultra-low VOC Wood Furniture Coatings," Proceedings: Pollution Prevention Conference on Low- and No-VOC Coating Technologies, 1993, pp. 291-300.

7. Northeim, C.M., M.W. Moore, and J.L. Warren, Surface-Coating-Free Materials Workshop - Summary Report, EPA-600/R-92-159 (NTIS PB93-101160), August 1992.

8. **S**olvent **A**lternatives **G**uid**E** (SAGE), Beta Test Version 1.1, Control Technology Center, U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, MD-61, Research Triangle Park, North Carolina 27711, July 1993.

9. Kosusko, M., J.T. Bursey, R.G. Merrill, Jr., T.P. Heil, and F. DeMartin, "Test Methods for the Determination of Volatile Organic Compounds in Consumer Products," Paper Number 91-73.1, Air & Waste Management Association Annual Meeting, Vancouver, British Columbia, Canada, June 1991.