Pollution Prevention for Cleaner Air: EPA's Air and Energy Engineering Research Laboratory

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The U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory (AEERL) has been conducting studies for more than two decades to identify control strategies for pollutants and sources that contribute to poor air quality. Over the past few years, AEERL has increased its emphasis on pollution prevention as the preferred choice to reduce air emissions. AEERL's goal is to pursue research that will support the greatest possible reduction of air pollution for the lowest cost. This article defines AEERL's current pollution prevention research and its unique opportunity to make substantial contributions in the pollution prevention field.

FOR MORE THAN two decades, the U.S. Environmental Protection Agency's (EPA) 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 (NOs), and particulate control technologies for fossil fuel combustion sources. More recently, it has expanded its interest to areas that include indoor air quality, radon, organic 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. Its research projects are handled by AEERL staff, by contractors, or by universities. Much of the research is carried on cooperatively with the private sector or state and local government. AEERL designs its studies to fill critical data gaps, support EPA program offices, and catalyze air pollution control research by other groups. This article defines AEERL's current pollution prevention research and its unique opportunity to make substantial contributions in the pollution prevention field.

Consistent with Congress's mandate in the Pollution Prevention Act of 1990, AEERL executes research at all stages of the environmental protection hierarchy, beginning with source reduction and followed by recycling, treatment, and disposal. Pollution prevention research at AEERL is conducted primarily within four major programs: (1) stratospheric ozone protection, (2) global warming, (3) organics control, and (4) indoor air quality programs. Some research on new combustion

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techniques that result in reduced nitrogen oxide formation is also under way. The major programs are described in more detail below.

Stratospheric Ozone Protection

Stratospheric ozone is the dominant factor limiting the penetration of solar ultraviolet (UV)-B radiation to the Earth's surface. Recent data show significant decreases (about 3.5 percent at 45° N for the period 1979 to 1991) in the stratospheric ozone over the northern hemisphere in Spring and Summer, when the most people are likely to be exposed.[1] By the year 2000, it is estimated that ozone depletion will be between 5 percent and 10 percent in the summer. Greater exposure to solar radiation is predicted to cause up to a 26-percent increase in the number of nonmelanoma skin cancers. In addition, a higher UV-B radiation level is expected to raise the incidence of cataracts and may cause changes in the human immune system. This information has recently been widely publicized by the mass media, because it shows that stratospheric ozone is being depleted much more quickly than previously thought.

In response, the international community has accelerated the phaseout schedule for ozone-depleting chemicals under the Montreal Protocol.[2] Some companies have already acted independently to stay ahead of the Montreal Protocol. Former President George Bush recently announced an accelerated U.S. phaseout of chlorofluorocarbons (CFCs) by the end of 1995.

Ozone-depleting chemicals (ODCs) are used primarily as refrigerants, cleaning solvents, foam blowing agents, and fire extinguishing agents. Consumption of ODCs has already been reduced below 1986 levels, mostly by replacing ODCs used for flexible foam (such as the foam used to cushion furniture) blowing, fire protection, aerosol propellants, and cleaning solvents. [For more on the flexible foam industry, see the case studies in this issue and in *Pollution Prevention Review,* Summer 1992.] Recycling refrigerants used in commercial air conditioning, refrigeration, and automobile air conditioners has also reduced ODC emissions.

The AEERL program concentrates on identifying refrigerant replacements that have no ozone-depleting potential and reduce overall risk to human health and the environment, as required by the Clean Air Act Amendments.

Replacements are currently being developed for CFCs. Many of these replacements, however, are hydrochlorofluorocarbons (HCFCs), which have lower, but still significant, ozone-depleting potential. AEERL's research will help ensure that the United States has acceptable alternatives for current uses of CFCs and halons. As a result of the new information on stratospheric ozone depletion, emphasis is also being placed on identifying replacements for HCFCs. The AEERL program concentrates on identifying refrigerant replacements that have no ozone-depleting potential and reduce overall risk to human health and the environment, as required by the Clean Air Act Amendments. Therefore, global warming potential, toxicity, and carcinogenicity are also being considered. These new chemicals may be viable next-generation replacements for the HCFCs that, in many cases, are being used as short-term replacements for

CFCs. [Other articles on ozone-depleting chemicals appeared in the Spring 1992 and Summer 1992 issues of *Pollution Prevention Review*.]

New chemicals

AEERL's new chemicals program is designed to identify, synthesize, and evaluate chemicals that are potential replacements for ozone-depleting chemicals. Several promising candidate chemicals have been found with thermodynamic properties that are similar to those of currently-used chemicals. Each of these potential replacements has a zero ozone-depletion potential. Work is under way to further characterize these chemicals for environmental effects, such as toxicity and carcinogenicity. Other functional characteristics, including lubricating oil compatibility and flammability, will also be determined.

Household and commercial refrigeration

In 1991, approximately 31 percent of all CFCs worldwide were used as refrigerants (almost 260,000 tons).[3] These refrigerants are used in a wide variety of refrigeration applications, including automobile air conditioners, heat pumps, commercial refrigerators and chillers, and home refrigerators. AEERL's refrigeration research is primarily focused on finding permanent alternatives, both refrigerants and hardware, but AEERL is also evaluating the potential for near-drop-in replacements for CFC refrigerants that will work in existing equipment.

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AEERL is evaluating new refrigeration systems for home refrigerators. Promising alternative refrigerants developed in the new chemicals program are being evaluated. Different refrigeration cycles are being explored to allow optimum utilization of these refrigerants. Different types and sizes of compressors will also be tested.

Supermarkets account for 10 percent of the commercial sector electrical use in the U.S.[4] Their refrigeration systems are charged with large quantities of refrigerants and are very susceptible to leaks. Research is under way to identify replacements for these refrigerants that will minimize stratospheric ozone depletion and optimize energy efficiency.

Development of superinsulating panels

Foam insulation manufactured with CFCs is an important part of refrigerator cabinets. This insulation improves the energy efficiency of the refrigerator and reduces the size of the compressor. Unlike most foams used for other purposes, such as furniture, insulating foam must still be made with ODCs. During the foaming process, the ODCs become trapped in the foam's cells, where they serve as insulating material. Therefore, ODCs are released during the manufacture, aging, and disposal of the foam. The non-ozone depleting alternative blowing agents used to make other types of foam are not good insulators, so they cannot be used in insulation.

AEERL is working to accelerate the commercialization of superinsulating panels for home refrigerator cabinets. These panels have the potential to increase energy efficiency by 15 percent to 20 percent, while eliminating the CFCs currently used in insulating foam. [See the article on pollution prevention options in flexible foam manufacturing on p. 13 of this issue.]

Under the Clean Air Act Amendments of 1990, the manufacture of the CFCs and HCFCs used in residential heat pumps and air conditioning systems must be phased out by 2015. This deadline may be accelerated by amendments to the Montreal Protocol and by U.S. regulations. Therefore, suitable replacements for these refrigerants must be found. AEERL is seeking replacements for HCFCs in space heating and cooling.

Home heat pumps, air conditioners, and auto air conditioners

AEERL is exploring potential replacements for HCFCs used in household heat pumps and air conditioners. This research includes optimizing the performance of heat pumps to increase energy efficiency. AEERL has also completed research to determine acceptable purity standards for recycled CFCs used in automobile air conditioners.

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Fire protection for North Slope oil facilities

Halons are ozone-depleting chemicals that are widely used as fire extinguishing and explosion prevention agents. Because they contain bromine, halons are more potent ozone-depleting agents than CFCs. In fact, each molecule of Halon 1301 released into the stratosphere will cause approximately sixteen times more stratospheric ozone depletion than each molecule of CFC-11.[5] However, the Clean Air Act Amendments exempt halons from the phaseout requirements until 1999 if they are needed for use in fire suppression and explosion prevention, because no safe and effective substitute has been found.

Several fire extinguishing systems are available that do not contain halons, but they are not suitable for all uses. There are currently no available replacements for certain safety-related applications, such as controlling explosions in enclosed work spaces like Alaskan North Slope oil processing facilities and submarines. The use of Halon 1301 for fire and explosion inertion in enclosed North Slope oil facilities is critical to the safety of employees. When there is a leak of combustible material inside one of these oil-processing facilities, the explosion inertion system quickly disperses halon throughout the room to stop the chain reaction before it becomes an explosion. The halons fulfill this function without causing toxicity problems for the workers in the facility. No alternatives for this system are currently available. Although halons are being phased out for other uses, this use may be exempted from the phaseout if no replacement is found.

If safe and effective substitutes can be found for these critical fire

and explosion suppression systems, the halon phaseout can proceed. Because of halons' high ozone-depleting potential, this will make a significant reduction in overall ozone depletion.

AEERL is working with a consortium of two oil companies, British Petroleum and ARCO, and the U.S. Coast Guard to find suitable replacements.

Global Warming

Emissions of greenhouse gases resulting from the activities of the rapidly expanding global population are considered a major factor in global warming. EPA has estimated that by the year 2030, nearly half of the human contribution to greenhouse warming will be carbon dioxide emissions from fossil fuel combustion. Another 25 percent will result from deforestation and biomass combustion. Methane releases from landfills, pipelines, coal mines, and agriculture/animal husbandry will account for an additional 15 percent.[6]

Electric power generation is a significant source of greenhouse gases, as well as more conventional air pollutants such as sulfur dioxide and particulate matter. Improving the energy efficiency of electric equipment can help reduce the future demand for electricity, resulting in decreased emissions of these pollutants.

Emissions of greenhouse gases from many of these activities can be reduced by engineering better ways to produce and use energy. Biomass fuels can replace fossil fuels and provide an incentive for reforestation; other renewable sources of energy can replace fossil fuels; conservation can reduce energy demand; and methane waste streams can be recovered and used as a source of energy. These areas are the focus of AEERL's global warming research program.

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Fuzzy logic motor controller

Electric motors consume approximately 70 percent of all electrical power generated in this country.[7] Electric motors are very efficient when operated at full load capacity; however, most motors do not operate under full load because the demand varies. This results in average energy losses of between 20 percent and 25 percent. Improving the efficiency of these motors can reduce the amount of electricity required to operate them and have a large impact on electric power needs and, therefore, on global warming.

AEERL is working on the development of an inexpensive controller chip to optimize motor performance under varying loads. This controller will be directed initially at the large, industrial alternating-current induction motors that use the greatest amount of electricity. The estimated payback period for retrofitting an existing variable speed drive motor with this chip is less than one year. The chip will use a form of artificial intelligence called "fuzzy logic" to optimize power consumption. Fuzzy logic, also known as approximate reasoning, is a branch of mathematics that can represent complex, difficult-to-model systems with linguistic approximations.[8]

Fuel cells for methane recovery

Methane is a by-product of many human activities. It is formed when organic matter decomposes in the absence of air. This occurs in landfills and sewage treatment plants. Methane is also emitted from coal mines and during oil production and natural gas processing. It may be possible to capture many of these methane waste streams and recycle them. This would reduce their global warming potential and displace the additional fuel needed to produce electricity.

AEERL is planning to test fuel cells for generating electricity using methane recovered from a municipal landfill. Researchers will evaluate the degree of gas cleanup needed for the gas to be used in the fuel cell. The feasibility of using the fuel cell to provide electricity to the landfill operation will also be evaluated. Plans also include testing the fuel cell for use at a wastewater treatment plant using anaerobic digester gas.

Solar energy applications

AEERL is promoting the development and commercialization of photovoltaic solar applications for demand-side management to reduce the peak power load of residential and commercial buildings.

The use of renewable energy sources in the place of fossil fuels reduces the accumulation of greenhouse gases. Solar energy is one form of renewable energy that derives energy directly from the sun. In solar energy applications, solar radiation is converted directly into either heat or electricity, displacing the need for fossil fuels and eliminating the carbon dioxide emissions from burning those fuels.

AEERL is promoting the development and commercialization of photovoltaic solar applications for demand-side management to reduce the peak power load of residential and commercial buildings. As part of the project, seventeen photovoltaic systems will be installed in ten different geographical locations. The performance and reliability of these systems will be measured and tracked.

Biomass fuels

Biomass fuels are renewable energy sources that originally derive their energy from the sun, then store it through photosynthesis. Biomass can be either burned directly or converted into other fuels. Although biomass fuels do release carbon dioxide during burning, the carbon dioxide is reabsorbed by new plantings of the biomass crop. This creates a "carbon cycle" that prevents the buildup of excess carbon dioxide in the atmosphere.

Research has been conducted at AEERL to gasify biomass and determine its compatibility with power-generating turbines. Different types of biomass have been tested, including wood wastes and switch grass. The next step in this project will be to set up a demonstration of this technology.

AEERL is also evaluating a process for producing methanol from biomass for use as a transportation fuel. This process also generates a carbon black by-product that can be used as a cleaner substitute for coal, as it contains no sulfur or ash.

Organics Control

In 1990, more than 62 million people lived in counties in the United States where ozone levels were above the national standards.[9] This ozone is formed by a chemical reaction between volatile organic compounds (VOCs) and NOx in the presence of light. In addition, more than 2.4 billion pounds (1.1 billion kilograms) of toxic chemicals were released to the ambient air in 1989.[10] Many of the same organic chemicals are both air toxics and ozone precursors. AEERL's Organics Control Branch conducts research to concurrently reduce emissions of air toxics and ozone precursors.

A large number of different organic chemicals are emitted into the ambient air every day. These chemicals come from a variety of different sources that occur naturally from human activities. These sources include automobiles, industries, small businesses, household consumer products, wood stoves, and vegetation. Many of these sources are poorly characterized, so it is very difficult to select the most important areas for research.

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For the near term, AEERL has set its organic emissions prevention research priorities based on industrial emissions of the chemicals that are the focus of EPA's 33/50 initiative.[11] The goal of the 33/50 initiative is to obtain voluntary commitments from industry to reduce emissions of seventeen commonly-used chemicals. EPA's Toxics Release Inventory, a data base containing industry-reported releases of toxic materials, shows that five of the seventeen chemicals were released in quantities much larger than the rest. These chemicals are methyl ethyl ketone, methylene chloride, toluene, 1,1,1,-trichloroethane, and xylene. The industrial processes primarily responsible for these emissions are solvent cleaning, surface coating, chemical/refinery, pharmaceutical, and polymers and resins. AEERL has selected its near-term focus from these processes. In consultation with industry focus groups, projects have been initiated in solvent cleaning and surface coating.

Evaluation of solvent alternatives and reduced VOC coatings

AEERL is compiling and examining existing information on the use of alternative cleaning processes. Promising alternative cleaning systems will be tested and evaluated to provide potential users with information on available options. Inexpensive means for retrofitting existing solvent cleaning equipment to handle solvent alternatives will be investigated.

AEERL is evaluating emerging low- and no-VOC coating technologies for wood furniture and auto body refinishing.

Consumer products

The use of many consumer products (e.g., aerosols, lighter fluids, and cleaning compounds) is responsible for air emissions of organic chemicals. The cumulative effect of millions of people using these consumer products can be a significant part of an urban area's ozone

nonattainment problem. AEERL is conducting research to help reduce organic emissions from consumer products with a focus on helping industry reduce the VOC content of consumer products. The first part of this work is developing a standard test method for determining the VOC content of consumer products. This test will help manufacturers identify the highest-emitting products, so they can look for lower-VOC substitutes. AEERL is also coordinating with EPA's regional office in San Francisco to sponsor demonstrations of emerging low-VOC alternatives for automobile care products and aerosols.

Indoor Air Quality

Recent studies have shown that exposure to indoor air pollutants is a major contributor to human health risk.[12] Complaints of "sick building syndrome" have risen dramatically in the past few years. Moreover, poor indoor air quality can have adverse health and economic impacts. With few exceptions, such as radon, indoor air pollutants arise from sources within the indoor environment.

A substantial part of AEERL's indoor air research and development program . . . focuses on developing guidance to building designers, owners, and operators on how to prevent the conditions that cause health problems.

Many indoor air quality problems can be prevented by the proper design and selection of indoor materials and proper operating procedures. These procedures include cleaning, maintenance, and ventilation systems operation. A substantial part of AEERL's indoor air research and development program, therefore, focuses on developing guidance to building designers, owners, and operators on how to prevent the conditions that cause health problems.

The amount and type of indoor air pollution depends to a large extent on building materials selected by an architect and/or builder and products purchased for indoor use by building occupants. The specific product selected for a given purpose depends on many factors. Because information is not generally available, however, indoor air impacts are seldom considered. Given that architects and builders constitute the largest decision-making groups responsible for the selection of materials used indoors in commercial, industrial, and residential buildings, their decision to use low-emitting materials can act as a driving force to persuade industry to produce these materials.

Therefore, AEERL is compiling information for these potential users on the emission characteristics of various building materials and other indoor products. In addition to providing users with information on the indoor air impacts of products, pollution prevention research can widen the choice of materials with low indoor emissions. AEERL is working with manufacturers to reduce the use in their products of materials that have adverse indoor air quality impacts.

Catalogue of data on indoor air emissions

AEERL is collecting and cataloguing constituent and emissions data from indoor air sources. The goal is to provide this information to potential users, such as home builders, in an understandable format, to help them make more informed choices. This information will be shared with the National Association of Home Builders.

Environmental resource guide

Laboratory staff are working cooperatively with the American Institute of Architects to publish an "Environmental Resource Guide." The guide will provide information for architects and building designers on the environmental and indoor air impacts of building materials.

A project is under way to implement pollution prevention practices in the manufacturing of office work station partitions. The main goal is to reduce indoor emissions from the panels. This project should also reduce volatile organic and toxic emissions from manufacturing the panels.

AEERL is also developing and testing methods to reduce the growth and reproduction of biocontaminants in the indoor environment. These biocontaminants include bacteria, molds, fungi, and dust mites. Measures being tested include humidity control and bioresistant materials that create a poor environment for the growth and dispersion of bacteria and fungi.

Although a product itself may be responsible for indoor air quality impacts, the manner in which the product is used and stored can also be very important. AEERL is studying the impact of various building operation and maintenance practices on indoor air quality. Examples are cleaning operations, ventilation system operation, and equipment maintenance. Guidance will be developed outlining practices that reduce indoor emissions.

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Looking to the Future

Many of the most pressing air pollution problems of the 1990s (indoor air pollution, global warming, and stratospheric ozone depletion) will rely heavily on source reduction as the preferred solution. Although the AEERL research described above is already making substantial contributions, it represents only a fraction of the potential source reduction research that could be conducted.

Over the next five years, AEERL plans to increase its emphasis on source reduction research to support implementation of the 1990 Clean Air Act Amendments. In particular, it will focus on developing technologies that will result in source reduction of hazardous air pollutants. Emphasis will also be placed on research support for the development of standards for emissions of hazardous air pollutants, and key EPA initiatives such as the Source Reduction Review Project, which targets specific industries subject to regulations from several program offices (air, water, and hazardous waste) that will be developing standards stressing source reduction. The increased emphasis on source reduction research will ensure that AEERL continues to play a leadership role in identifying the engineering solutions needed to meet the air pollution challenges of the next decade.

Whenever possible, the research described above will be conducted cooperatively with the private sector to ensure that innovative approaches under investigation are commercialized as quickly as possible. ◆

Notes

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2. Id.

3. Id.

4. Electric Power Research Institute, presentation at Supermarket Design Review Panel Meeting, Palo Alto, CA, April 4-5, 1991.

5. Synthesis of Reports (cited in note 1).

6. U.S. Environmental Protection Agency, *Policy Options for Stabilizing Global Climate,* Draft Report to Congress (GPO No. 055-000-00282-7), August 1990.

7. Masher, D.P., and J.S. Smith, "Impact of Advanced Power Semiconductor Systems on Utilities and Industry," Electric Power Research Institute, EM-2112, Palo Alto, CA, 1981.

8. For more information on fuzzy logic, see Armstrong, L., "Software That Can Dethrone 'Computer Tyranny,'" *Business Week,* April 6, 1992, pp. 90-91; and Berardins, L.A., "Clear Thinking on Fuzzy Logic," *Machine Design,* April 23, 1992, pp. 46-52.

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10. U.S. Environmental Protection Agency, *Toxics in the Community, The 1989 Toxics Release Inventory National Report,* p. 2 (EPA-560/4-91-014; GPO No. 055-000-00387-4; ISBN 0-16-035873-6), September 1991.

11. U.S. Environmental Protection Agency, *Pollution Prevention 1991, Progress on Reducing Industrial Pollutants,* p. 139 (EPA 21P-3003), October 1991.

12. For several references, see U.S. Environmental Protection Agency, *EPA Indoor Air Quality Implementation Plan,* Appendix E—Indoor Air Reference Database (EPA-600/8-87-016; NTIS No. PB87-210761), June 1987.