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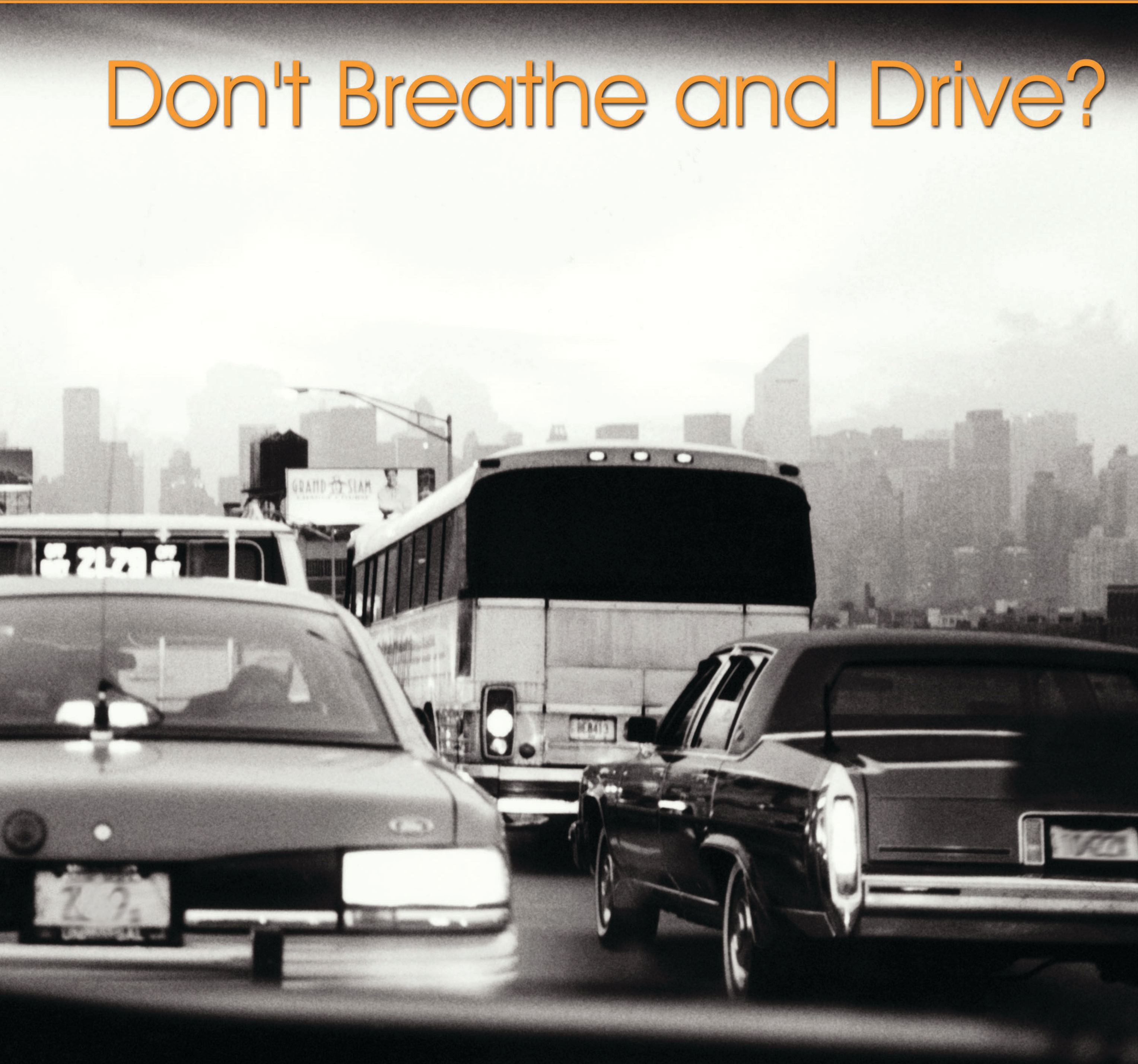
Pollutants Lurk inside Vehicles

At times it pays to live in the fast lane. Drivers motoring in freeway carpool lanes not only avoid the congestion of traffic in slower neighboring lanes, they may also avoid lung congestion from pollutants that seep into their vehicles as they creep along in bumper-to-bumper traffic. In-vehicle pollutants have been investigated in about two dozen studies over the past two decades, with consistent findings around the world: driving in tightly packed traffic leads to interior concentrations of pollutants that are up to 10 times higher than those in ambient city air.

Even with windows and vents closed, many people are exposed to these higher pollutant levels for longer periods than ever before, because it's getting harder to find uncongested lanes. Traffic congestion in U.S. cities continues to worsen, with the average delay in 68 urban areas more than three times longer in 1999 than in 1982, according to the *2001 Urban Mobility Report*, published by the Texas Transportation Institute of College Station.

Health effects from sitting through the daily thick and thin of traffic remain poorly understood, although some experts say they are significant. "It really is a pretty unhealthy place to spend a lot of time," says Scott Fruin, an air pollution specialist in the Research Division of the California Air Resources Board (CARB), a department of that state's Environmental Protection Agency. Many of the pollutants are suspected to be human carcinogens, and others may affect the neurologic, immune, and reproductive systems. Some may disrupt the endocrine system. While pollutant concentrations inside vehicles are usually within the

Don't Breathe and Drive?



few established outside air standards, health evaluations are difficult because there are no established standards for inside-vehicle air. Standards provide one benchmark against which to judge whether pollutant loads might adversely affect the health of a typical vehicle occupant. Even with benchmark standards, though, especially vulnerable people such as children, the elderly, and immunocompromised individuals may still be at risk. In addition, little is known about the combined effects of the pollutants that affect vehicle interiors.

Although U.S. agencies have no regulations addressing in-vehicle pollutants, officials are aware of the issue. "We're certainly interested in it, and we try to help the science along," says Ron Williams, a research chemist with the U.S. Environmental Protection Agency (EPA) National Exposure Research Laboratory. Vehicle manufacturers, however, appear to have the issue low on their priority list. "I haven't heard much about it," says Greg Dana, vice president of environmental affairs for the Washington, D.C.–based Alliance of Automobile Manufacturers.

Give Me Some Space, Man

While driving—and auto emissions—are a way of life in California, drivers and passengers likely assume that the shelter of their vehicles offers protection from polluted air. This is not the case, say the authors of a December 1998 report, *Measuring Concentrations of Selected Air Pollutants Inside California Vehicles*, prepared for the CARB.

For this study, researchers drove on freeways, arterial roads, and rural roads under a variety of conditions in Los Angeles and Sacramento, and measured pollutant levels in

Selected In-Vehicle Pollutants in Los Angeles, California

Pollutant	In-Vehicle	Ambient
	(min–max/mean value ranges for all driving scenarios)	
MTBE	20–90/31–60	10–26 ($\mu g/m^3$)
Benzene	10–22/13–17	3–7 ($\mu g/m^3$)
Toluene	23–58/30–51	10–40 ($\mu g/m^3$)
Formaldehyde	<MQL–24/7–20	7–21 ($\mu g/m^3$)
$PM_{2.5}$	23–107/32–83	21–64 ($\mu g/m^3$)
PM_{10}	23–111/36–89	54–103 ($\mu g/m^3$)
Carbon Monoxide	<MQL–1 (ppm), average	<MQL-4

Adapted from: Rodes C, Sheldon L, Whitaker D, Clayton A, Fitzgerald K, Flanagan J, DiGenova F, Hering S, Frazier C. Measuring concentrations of selected air pollutants inside California vehicles. Sacramento, CA:California Air Resources Board, 1998.
Abbreviations: <MQL, below quantification limit

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a 1991 Chevrolet Caprice, a 1997 Ford Taurus, a 1997 Ford Explorer, and a school bus. Based on 16 trips in Los Angeles and 13 in Sacramento during the fall of 1997, they found that in-vehicle concentrations of more than a dozen pollutants, including formaldehyde, benzene, toluene, and carbon monoxide, were consistently greater than the levels found in the zone within 20 feet of the roadway, and about 2–10 times those at a nearby ambient-air monitoring station, depending on location and weather conditions. Concentrations of a handful of metals, such as lead and chromium, typically were similar to or lower than those in roadside or ambient air, while sulfur concentrations were somewhat higher, although the authors caution that too few samples were detected to draw any conclusions.

Congested traffic conditions led to similarly high concentrations on both freeways and arterial roads in both cities, although congestion occurred less frequently in Sacramento. The concentrations measured when driving in a Los Angeles freeway carpool lane tended to be lower in almost all instances than the readings for any of the rush-hour or off-peak freeway and arterial scenarios. However, even the carpool readings usually were 3–4 times higher for many of the pollutants than those of the ambient Los Angeles air.

On Sacramento's rural roads, concentrations of in-vehicle pollutants tended to be much lower than those on the city's freeway and arterial roads, but still were generally higher than those at the side of the road. The one significant exception in both Sacramento and Los Angeles was particulate matter. That concentration inside vehicles usually was equal to or up to 40% lower than that in the roadside zone or in ambient air, likely because particulates were partially filtered out as they entered the vehicle. Overall, drivers in Los Angeles had a substantially higher burden of pollutants than those in Sacramento. That's likely due to the closer vehicle spacing in Los Angeles and higher pollutant concentrations in the ambient air.

Regardless of the city, researchers found that the type of vehicle and its ventilation settings made little difference. However, they did observe that several other variables could dramatically affect the level of in-vehicle pollutants. One of the prime influences was the quantity of exhaust emitted immediately in front of a vehicle. Researchers found that exhaust from a diesel-powered bus or truck could quickly double some short-term particulate levels inside a closely trailing vehicle. Older and out-of-tune gasoline-powered vehicles also significantly increased pollutant levels in a closely trailing vehicle. In contrast, buses powered by ethanol or compressed natural gas spewed far less particulates and black carbon. Substantial winds also were effective pollutant reducers, sweeping away emissions from all types of vehicles and sharply reducing levels inside trailing vehicles.

Driving Forces

A 1994 investigation in South Korea showed that the problem of in-vehicle pollution is not limited to the United States. Researchers measured concentrations of benzene, toluene, ethylbenzene, *m/p*-xylene, *o*-xylene, and total volatile organic compounds (VOCs) during 70 winter trips—evenly split between buses and 1990 Hyundai Excels—in the vicinity of Taegu, a metropolitan area of about 2.5 million people. The study, published in the August 1996 issue of the *Journal of the Air & Waste Management Association*, found that with windows and vents closed in all vehicles (except when buses opened their doors for passengers), total concentrations of VOCs in urban settings were 63–93% higher than in the suburbs, and were about 33% higher in cars than in buses. The researchers speculate that the car–bus differential may occur because a car's air intake is closer to the ground and thus may draw in more pollutants, and because opening the doors of a bus may allow some inside VOCs to escape. The study did not compare in-vehicle concentrations with those for roadside areas.

Another study, published in the February 1995 issue of the *Journal of the Air & Waste Management Association*, analyzed a range of pollutants in vehicles in and around Paris. From October 1991 to September 1992, researchers measured carbon monoxide and six monocyclic aromatic hydrocarbons (MAHs), such as benzene and toluene, during 58 trips of about one and a half hours each. The researchers sampled air inside vehicles, buses, and subways, as well as from zones used by pedestrians and bicycle riders. The study found that someone driving a car all day in urban areas likely would exceed U.S. and World Health Organization (WHO) standards for exposure to carbon monoxide—the average measurement of 12 ppm was higher than both the WHO's eight-hour standard of 10 ppm and the EPA's eight-hour standard of 9 ppm. (The EPA's one-hour standard is 35 ppm.)

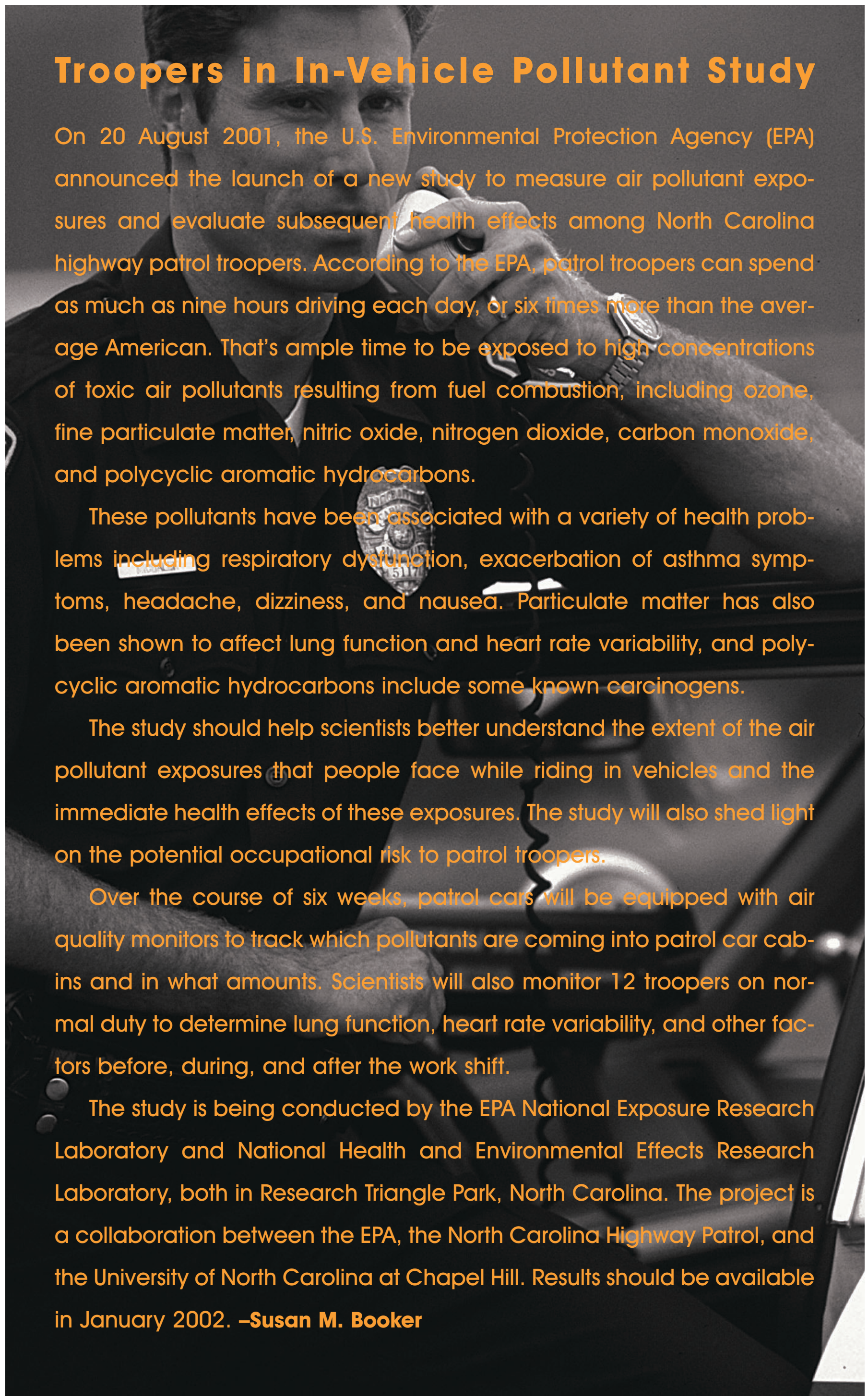
In the Paris study, carbon monoxide and MAHs were 6–8 times higher inside cars than in the ambient air in the heart of the city. Compared to an earlier study in Raleigh, North Carolina, levels of benzene and other sampled MAHs were much higher for comparable carbon monoxide concentrations, possibly because catalytic converters weren't in wide use in France. Researchers also found that the air inside a vehicle was contaminated by the vehicle's own exhaust when it was idling.

Pedestrians and those riding bicycles, buses, or the subway generally were exposed to lower levels of pollutants than car or truck occupants. However, researchers speculate that someone exercising heavily, such as a bicycle rider, would presumably inhale larger volumes of air, and thus might have a total exposure similar to that of a car or truck occupant. Similarly, bus and subway riders, who tend to have a longer commuting time and thus longer exposures than a vehicle occupant, might also be expected to have a total exposure only somewhat lower than that of a car or truck occupant.

The Paris, Taegu, California, and 20 other in-vehicle pollution studies were reviewed by the International Center for Technology Assessment (ICTA), a Washington, D.C.–based advocacy organization, in its July 2000 report *In-Car Air Pollution: The Hidden Threat to Automobile Drivers*. The ICTA found similar trends in all the studies, with in-vehicle pollutant concentrations generally being significantly higher than those for both roadside and ambient air.

Additional studies are under way. For instance, the National Exposure Research Laboratory, in collaboration with the National Health and Environmental Effects Research Laboratory and the University of North Carolina at Chapel Hill, is conducting the EPA's first in-vehicle analysis, studying both pollutant exposures and health effects for about a dozen North Carolina state highway patrol troopers as they go about their daily routine [see "Troopers in In-Vehicle Pollutant Study," p. A425]. The Health Effects Institute, a Boston, Massachusetts, organization sponsored by both the EPA and the auto industry, is overseeing a study that includes analysis of concentrations of 17 carbonyl compounds in air inside vehicles in New Jersey, Texas, and California cities. And the CARB is continuing its work, taking a closer look at air inside school buses.

While the studies already completed show consistent trends, regardless of vehicle model or age, researchers caution that each study has had a small sample size, and that broader studies are needed to help understand some of the variables already mentioned above, as well as a number of others. For instance, pollutants were noticeably higher



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Troopers in In-Vehicle Pollutant Study

On 20 August 2001, the U.S. Environmental Protection Agency (EPA) announced the launch of a new study to measure air pollutant exposures and evaluate subsequent health effects among North Carolina highway patrol troopers. According to the EPA, patrol troopers can spend as much as nine hours driving each day, or six times more than the average American. That's ample time to be exposed to high concentrations of toxic air pollutants resulting from fuel combustion, including ozone, fine particulate matter, nitric oxide, nitrogen dioxide, carbon monoxide, and polycyclic aromatic hydrocarbons.

These pollutants have been associated with a variety of health problems including respiratory dysfunction, exacerbation of asthma symptoms, headache, dizziness, and nausea. Particulate matter has also been shown to affect lung function and heart rate variability, and polycyclic aromatic hydrocarbons include some known carcinogens.

The study should help scientists better understand the extent of the air pollutant exposures that people face while riding in vehicles and the immediate health effects of these exposures. The study will also shed light on the potential occupational risk to patrol troopers.

Over the course of six weeks, patrol cars will be equipped with air quality monitors to track which pollutants are coming into patrol car cabins and in what amounts. Scientists will also monitor 12 troopers on normal duty to determine lung function, heart rate variability, and other factors before, during, and after the work shift.

The study is being conducted by the EPA National Exposure Research Laboratory and National Health and Environmental Effects Research Laboratory, both in Research Triangle Park, North Carolina. The project is a collaboration between the EPA, the North Carolina Highway Patrol, and the University of North Carolina at Chapel Hill. Results should be available in January 2002. **–Susan M. Booker** during the one rain event encountered in the 1997 California study, but researchers don't know why. Another variable is altitude. In an article published in the 15 April 2001 issue of *Environmental Science & Technology*, researchers reported that nitrogen oxide levels emitted by diesel trucks are about 60% higher in Denver than in Los Angeles. That finding is in line with a few studies conducted earlier that found that carbon monoxide and hydrocarbon emissions increase at higher altitudes. Additional variables include the specific vehicle emission control requirements of an area and local climate conditions, including seasonal variations.

That New Car Smell

In addition to pollutants that are drawn into a vehicle from outside, hidden pollutants may lurk inside as well, particularly as emissions from materials used to construct the vehicle. While there are very limited publicly available data, a few sources indicate that the familiar "new car smell" is laden with VOCs and other pollutants emitted from materials such as plastics, foams, adhesives, and carpet. Typical vehicle contaminants include acetonitrile, decanol, formaldehyde, naphthalene, and carbon disulfide, according to Air Quality Sciences, an Atlanta, Georgia–based testing laboratory.

In a paper presented in 1995 at a scientific symposium in New Jersey, company officials from Scientific Instrument Services reported that they found more than 100 VOCs, such as dodecane, styrene, and phenol, in a new 1995 Lincoln Continental. The concentrations dropped substantially over a two-month period, but still were readily detectable, and continued to increase from morning to midday as temperatures rose in the car.

Chuck Licari, a spokesman for General Motors, downplays the issue. "GM certainly does not view that whole thing as any kind of a problem whatsoever," he says. The company has investigated material emissions off and on, says Steve Swarin, an analytical chemist with the company, but has concluded that a vehicle's high air exchange rates mitigate any potential problems.

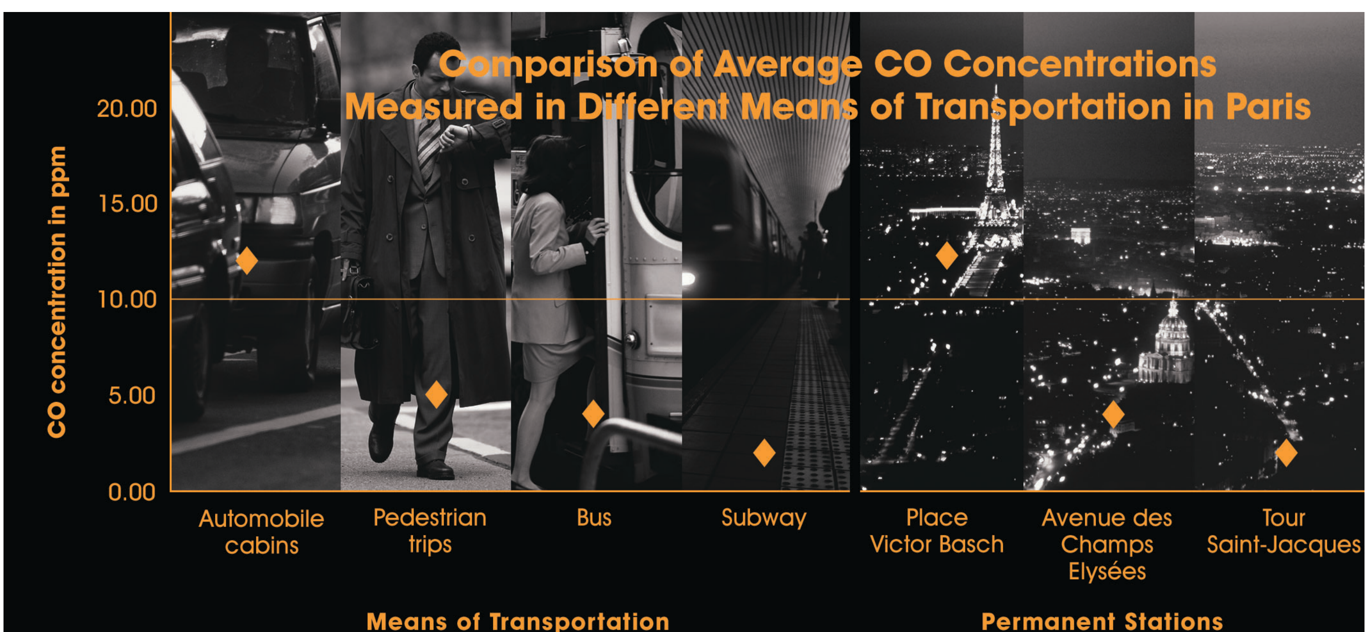
This may be true for interior emissions; however, air exchange introduces the further potential for exposure to contaminants from outside the vehicle. Even with the windows and vents closed, air circulation rates in vehicles are typically high, especially at high speeds. For instance, in the 1997 California study, the air exchange rate in a 1997 Ford Explorer standing still with the vents on the "recirculate" setting and the fan on "low" was 1.8 air changes per hour, more than in the average home. When driven at 55 mph with the vents and fan on the same settings, the rate inside the car increased to 13.5 air changes per hour. The 1991 Chevrolet Caprice, driven at 55 mph and with similar vent and fan settings, had nearly triple the Explorer's airflow, with 39 air changes per hour.

Many vehicle manufacturers acknowledge that mold is a perennial problem in automobile ventilation systems, particularly those with air conditioners driven in humid climates. Some molds are linked with adverse health effects such as asthma, breathing difficulties, memory and hearing loss, bleeding in the lungs, and even death. Periodic disinfection can help minimize levels, as can design techniques that reduce trapped condensation or kill mold on critical internal surfaces. Honda revised some of its early-1990s model vehicles after noticing excess mold buildup in their ventilation systems. Lexus is currently using an unspecified antibacterial resin in the ventilation systems of some of its models.

Vehicle occupants can also create some of their own pollutant burden. Cigarette smoking adds substantially to the air pollutant load inside a vehicle, according to a 1992 study of commuters in Riyadh, Saudi Arabia. Researchers there found that carbon monoxide levels were 34 times higher than the one-hour WHO or U.S. EPA standards.

Specific health effects from in-vehicle exposures remain uncertain, because few health data are available for most of the in-vehicle pollutants. For the few outside air pollutants that do have exposure standards, concentrations measured in the studies conducted to date tend to fall below the standard most of the time. For particulates less than 10 µm in diameter, for instance, concentrations measured in the 1997 California study ranged from 2 to 111 $\mu g/m^3$, below the EPA's 24-hour standard of 150 $\mu g/m^3$. But in a 1995 Amsterdam study reviewed by the ICTA, levels ran as high as 194 $\mu g/m^3$.

One in-vehicle air pollutant, benzene, is a known human carcinogen. Low-level, long-term exposure to benzene also can damage the blood and immune systems. While maximum benzene exposures documented during in-vehicle studies are at least 40 times lower than the U.S. Occupational Safety and Health Administration (OSHA)



Adapted from: Dor F, Le Moullec Y, Festy B. Exposure of city residents to carbon monoxide and monocyclic aromatic hydrocarbons during commuting trips in the Paris metropolitan area. J Air Waste Manage Assoc 45:109 (1995).

PhotoDisc, Corbis, Reuther/EHP

Potential Remedies for In-Vehicle Pollution

Individual Actions
- Drive in less-congested areas or, when in congested areas, in less-congested lanes.
- Avoid closely trailing obviously polluting vehicles or diesel vehicles.
- Don't smoke inside a vehicle.
- Use a vehicle that doesn't have a "new car smell."
- Use a vehicle that has a ventilation system designed to reduce mold buildup. Disinfect the ventilation system with a less-toxic product if mold does develop.
- Use a vehicle in which particulate and carbon filters are installed or can be installed, or acquire a portable in-cabin filter. Maintain filters.
- Keep your vehicle well tuned.
- Ride mass transit or a bicycle, or walk.

Institutional Actions
- Conduct additional research to clarify problems and solutions.
- Pursue development of power systems that don't require combustion of petroleum products.
- Phase out older vehicles and encourage use of well-tuned vehicles.
- Encourage mass transit, bicycles, and pedestrian traffic.

Digital Stock

standard of 1 ppm, OSHA standards are sometimes several times higher than those recommended by organizations such as the National Institute for Occupational Safety and Health and the American Conference of Governmental Industrial Hygienists.

Filtering Vehicles . . . and Information

Of half a dozen major vehicle manufacturers queried about air quality inside vehicles, most were reluctant to discuss the issue. Representatives from Ford, Toyota, Honda, and Volkswagen suggested that their companies were aware of the issue and were taking some steps to reduce problems, but declined to release any results from research they may have undertaken regarding either the presence of pollutants or the company's solutions. A spokesman for DaimlerChrysler declined to offer any information at all.

General Motors officials noted that in-vehicle air quality is under discussion by the Society of Automotive Engineers, a network of engineers, business executives, educators, and students. A set of recommended standards focusing on carbon monoxide levels may be published early in 2002, says Ward Atkinson, chairman of the society's Interior Climate Control Standards Committee. Other pollutants may be difficult to control, he adds, because vehicles are driving in a corridor of contaminants.

Lexus, a division of Toyota, is taking steps on a number of fronts, says spokesman Doug Murtha. In addition to the use of an antibacterial resin in the ventilation system to reduce mold growth, various models have air filters, sensing devices to automatically adjust vent settings, and, in one model, an in-cabin filter behind the rear seat. However, Murtha declined to release any supporting data on the effectiveness of those systems.

Spot checks at vehicle dealerships have shown that many manufacturers have offered some type of particulate or charcoal filter on selected models in the past 3–4 years; some, such as Saab, have offered them since at least the mid-1980s. Portable air filters that plug into the cigarette lighter, made by manufacturers such as E. L. Foust and AllerMed, also have been available for several decades.

Some in-vehicle filters are installed at the factory, others are a dealer-installed option, and some vehicles aren't designed to allow for either type of installation. Some filters are inexpensive and easy to change, others are costly and difficult to change. Filters likely aren't effective in removing fine particulates, as well as a number of other pollutants, because they must have mesh large enough to allow sufficient airflow. Also, to trap pollutants such as VOCs and carbon monoxide would require filters to be made of materials other than the currently used meshes. The few people who request filters tend to do so to help reduce obvious allergy symptoms from pollens rather than less-obvious symptoms from chemical pollutants, say a number of vehicle salespeople.

Filtration is only a remedy of last resort, though. Reducing the infiltration of pollutants in the first place is a more effective solution. In the short term, vehicle occupants can do that in part by traveling in less-congested lanes when possible. Vehicle manufacturers and oversight agencies can continue their work to reduce tailpipe emissions and mold, and to instigate more research on emissions from interior materials.

As research continues, some health officials remain uncertain about the risks involved. "We all drive," says Sharon Wilbur, an environmental health scientist with the U.S. Agency for Toxic Substances and Disease Registry and a specialist in benzene and formaldehyde. "I hope it's not dangerous."

Bob Weinhold

National Institute of Environmental Health Sciences
National Institutes of Health

Toxicogenomics Symposium on Gene Expression and Proteomics in Environmental Health

Natcher Center
National Institutes of Health
Bethesda, Maryland

December 3–4, 2001

The goal of the symposium is to bring together experts in the fields of functional genomics, proteomics, toxicology, informatics and database development. The new science of toxicogenomics aims to discover mechanisms by combining clinical, genomic, and proteomic knowledge into a common framework of biochemical and genetic pathways to disease. The meeting format will consist of a keynote address, a special lecture, and presentations by invited speakers as well as panel discussions and audience participation to facilitate a free exchange of information

Symposium Topics:

- Gene Expression
- Proteomics, Biomarkers
- Toxicogenomics
- Environmental Genomics
- Ethical, Legal, Social Issues

Symposium Co-Chairs:

Leona D. Samson, Massachusetts Institute of Technology
Raymond W. Tennant, National Institute of Environmental Health Sciences
James K. Selkirk, National Institute of Environmental Health Sciences

Program Participants:

Cynthia A. Afshari
Chris A. Bradfield
David C. Christiani
Edwin A. Clark
David Duggan
Stephen H. Friend
Carol S. Giometti
Dave R. Goodlett
Denis F. Hochstrasser
Leroy E. Hood (Keynote Address)
Michael Karin (Special Lecture)
Gary Marchant
Daniel W. Nebert
Deborah A. Nickerson
Kenneth Olden
George Orphanides
Richard S. Paules
Emmanuel Petricoin
Bing Ren
Denise Robinson
Mark A. Rothstein
Leona D. Samson
Richard Sharp
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Roger R. Ulrich
Cheryl L. Walker
Robert B. Weiss
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To receive Registration Information, please contact Dr. James Selkirk or Ms. Sandy Sandberg at the National Institute of Environmental Health Sciences, **(919) 541-2548** or **541-3464**. Additional information and an agenda can be found at **http://www.niehs.nih.gov/nct/**