e-lab
RESEARCH REPORTS

MIT LABORATORY FOR ENERGY AND THE ENVIRONMENT OCTOBER–DECEMBER 2002

Measuring Air Pollution, Emissions, and Human Exposures in Mexico City: A Prerequisite to Effective Cleanup

An international team led by Luisa and Mario Molina at MIT is working to help Mexican policy makers find ways to reduce Mexico City's severe and persistent air pollution. However, initial MIT analyses identified a major stumbling block: existing data on the city's air pollution and where it comes from are incomplete. The MIT researchers have therefore designed a novel field measurement program that will better characterize emissions sources, atmospheric concentrations, and human exposures in a coordinated and comprehensive way. In a two-week campaign during the winter of 2002, the researchers rode in a van carrying highly sophisticated, state-of-the-art instruments and followed cars, trucks, and buses, analyzing their exhaust plumes. To "map" the city's air quality and determine daily variations, they also parked the van at different locations, sometimes for 24 hours or more. Last summer and fall, they checked human exposures by carrying hand-held monitors while riding in commuter buses and delivery trucks. They also left monitors in bus and truck terminals for several days at a time. Already their data are showing the importance in Mexico City of formaldehyde—emitted by industrial facilities and vehicles—in triggering ozone formation. They are now using the new data in computer models that simulate ozone formation. By adding meteorological data gathered simultaneously by Mexican and US collaborators, they hope to clarify the combined atmospheric chemistry, dispersion, and transport processes that affect pollutants emitted within the Valley of Mexico. A five-week campaign beginning in April 2003 will continue the measurement effort, adding new instruments and measuring more chemical species. The field measurement campaigns are part of a multidisciplinary program that aims to provide policy

Mobile Laboratory Used in Field Measurement Campaign – Mexico City, 2002

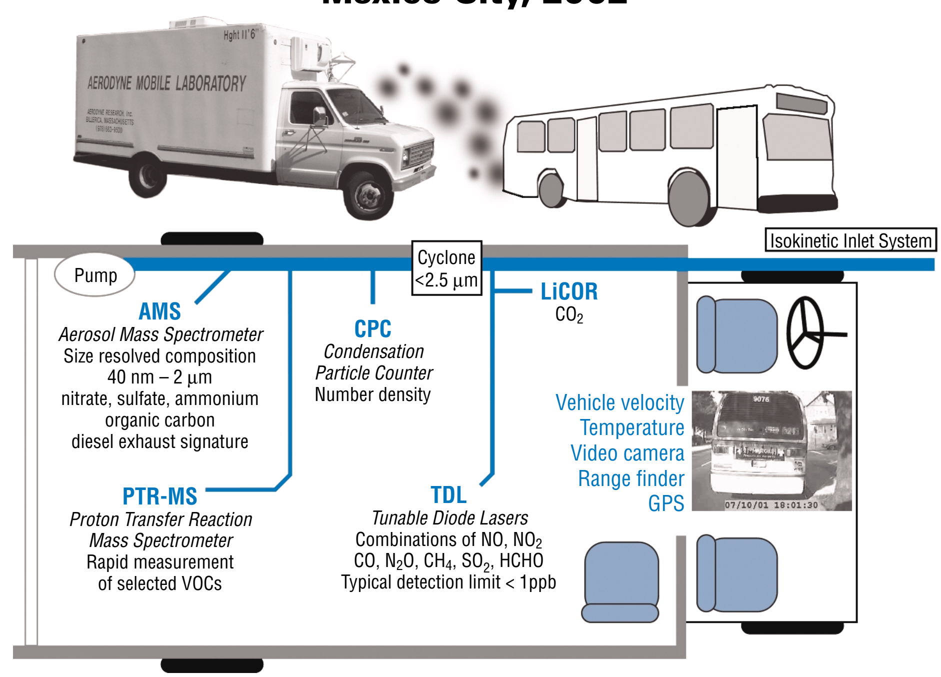


Diagram: Aerodyne Research Inc. and Mexico City Program makers in highly polluted cities with assessments of not only the potential effectiveness of emissions-control strategies but also their technical feasibility, cost-effectiveness, and social and political acceptability.

During the past three years, an international team of researchers affiliated with the Alliance for Global Sustainability (AGS) has been working with decision makers in Mexico City to consider practical strategies for reducing their city's severe air pollution—a problem that affects many rapidly growing cities, especially in developing countries. The goal of the project is to perform "integrated assessments" of different emissions-reduction strategies, considering not only scientific and technological factors but also the broader social, economic, and political dimensions of the problem and possible actions that could be taken. Directed by Dr. Luisa T. Molina and Professor Mario Molina, the multidisciplinary project involves investigators from across MIT, from the Harvard School of Public Health and other US and international institutions, and from more than a dozen institutions and government agencies in Mexico. (For further details, go to <http://eaps.mit.edu/megacities/> on the Web.)

While inputs from many disciplines are important, the process of designing air pollution policy must rest on a foundation of sound scientific information. What pollutants are in the atmosphere, and what are the key sources of those pollutants and of the precursors that form them? The Mexico City Metropolitan Area (MCMA) has been the subject of widespread air-pollution monitoring and development of "emissions inventories" (lists of specific sources and their emissions). However, initial computer simulations by the Molinas' team showed that the current emissions inventories did not fully explain the pollution that was measured in the atmosphere. Because the atmospheric chemistry used in the computer simulation is reasonably well understood, they believed the problem was in the meteorological and emissions data used as model inputs. Unless those data are accurate, it is impossible to predict how various emission-reduction strategies might actually improve air quality.

Professor and Dr. Molina have therefore undertaken an intensive field campaign to improve the quality of the available data. Designing their program posed several challenges. To get better results, the new program had to measure emissions, atmospheric concentrations, and even human exposures in a coordinated, integrated, and comprehensive way. The researchers had to deal with the special challenges of working in the field rather than in a laboratory where equipment and pollutants can be tested and retested under carefully controlled conditions. Finally, because pollution concentrations vary from place to place, from day to day, and even from hour to hour, their measurements had to be both continuous and widely dispersed across a city of 18 million people.

The Molinas have designed a monitoring program that meets all those challenges. They have already begun to collect data and to analyze it—a process that will take many months and will result in numerous refinements and technical publications. In the meantime, however, the novel design of the program itself is of interest and can begin to serve as a model for similar programs in other highly polluted cities.

Key to their methods of measuring ambient pollution and emissions is a "mobile laboratory" provided by Dr. Charles E. Kolb, a collaborator from Aerodyne Research Inc. The mobile laboratory consists of a van carrying a wide range of sophisticated, state-of-the-art instruments that include an aerosol mass spectrometer, tunable diode lasers, a proton transfer reaction mass spectrometer, and a fine particle monitor (see the drawing on page 1). Together the instruments can identify and measure species contained in both gases and particles. Important species are measured by several instruments for cross-checking. Many of the instruments involve spectroscopic monitoring techniques—an approach described in the article starting on page 5. And because the laboratory is on a mobile van, the researchers can move it from place to place as well as park it in one location for as long as necessary.

In February 2002 the MIT research team and collaborators from the MCMA's Metropolitan Environmental Commission and US and Mexican institutions undertook a two-week exploratory field measurement campaign involving the mobile laboratory. A major focus was on vehicular emissions, which are the single biggest contributor to the MCMA's air pollution. Using the van, the researchers performed what they call "chase experiments." They selected a vehicle on the road and drove behind it, monitoring its exhaust plume using all of the van's on-board equipment. Among the vehicles they followed were diesel trucks and buses (they tend to be heavy emitters of particulates), taxis (many emit carbon monoxide and other pollutants due to missing or malfunctioning catalytic converters), and micro-buses (some of which run on liquefied petroleum gas or natural gas). The mobile laboratory thus enabled the researchers to gather emissions information from a variety of everyday vehicles operating under normal conditions.

They used two approaches to improve the current picture of ambient pollutant concentrations. To account for spatial variability, they measured ambient concentrations in a wide variety of locations—an activity they called "mapping the city." And to account for changes over time, they parked the van at a single site for several days at a time. This "fixed site" approach enabled them to get better data on ozone formation, which depends on photochemical reactions and therefore changes over the course of the day.

In some locations, they took advantage of other, coordinated activities. For example, they parked near a tethered balloon that Mexican collaborators were using to measure meteorological data. Such data are critical to air pollution modeling because how pollutants change, disperse, and travel depends on wind speed, temperature, mixing, and relative humidity. In addition, the tethered balloon was connected to a canister that sampled concentrations of volatile organic compounds at various heights up to about 200 meters. The tethered balloon also measured the ozone profile at altitudes up to 1,000 meters—information that will help the researchers better understand ozone chemistry and mixing. Other fixed sites were located near automatic monitoring stations that are operated by the environmental authorities of Mexico City and are used as a basis for issuing public warnings of poor air quality and high pollutant levels. Using their sophisticated instruments, the researchers were able to calibrate the monitoring stations and in some cases identify minor adjustments that were needed.

To tackle the third aspect of the AGS program—determining the nature and level of pollutants people are exposed to—the researchers used different methods and equipment. During the summer of 2002 MIT student Lisa Grogan spent six weeks performing a "commuter study" in Mexico City. She and Mexican collaborators rode on public buses during rush hour carrying small monitors that measured carbon monoxide and polycyclic aromatic hydrocarbons, which are highly toxic and mutagenic species typically found in diesel emissions. In October 2002 the Molinas and collaborators from the Harvard School of Public Health set up equipment in commercial truck and bus terminals to measure a variety of species over a period of several days. In addition, a monitor-equipped investigator rode with a truck driver as he delivered goods to various facilities. The data collected should provide insights into what people actually inhale while they work and go about their daily routines.

Preliminary mobile laboratory findings indicate the potential significance of the new measurements. One measurement site was an elementary school in the southwest MCMA. Measurements taken on the school grounds showed tremendous photochemical activity: ozone reached high peak concentrations on two consecutive afternoons, even though the weather was not unusually hot or sunny.

Measurements also showed that concentrations of formaldehyde—a key trigger of photochemical activity—built up significantly in the morning, peaking several hours before the high ozone levels occurred. Measurements at the MCMA's central urban and heavy industrial areas showed even higher morning levels of formaldehyde, which would be carried throughout the city by the southwest wind flows typical in this region. Data from the school site also showed a photochemical "bloom" of fine aerosol particles in the early afternoon, demonstrating that aerosol and ozone formation are closely connected and must be dealt with together, not separately.

The researchers are now planning an extensive field measurement campaign to start in April 2003. The five-week campaign is scheduled to include Holy Week, a time when activities in the MCMA dwindle, providing an opportunity for gathering good background measurements. The researchers plan to create a "super-site" that will bring together the van, the tethered balloon, and additional types of monitoring equipment that can both provide complementary measurements on chemical species already being measured and gather information on new species. They will also monitor additional potential emissions sources, notably gasoline stations, which may prove a significant source of the hydrocarbons that contribute to ozone formation. The campaign will benefit enormously from the participation of the US Department of Energy and AGS partners from the Swiss Federal Institute of Technology in Lausanne (EPFL) and from Chalmers University of Technology in Sweden, who plan to provide a variety of sophisticated monitoring instruments.

The researchers believe that the new measurements will open up a variety of opportunities. They will, of course, use their data in existing analytical models to examine the link between emissions estimates and measured pollutant concentrations. However, by adding the corresponding meteorological data, they hope to clarify the combined atmospheric chemistry, dispersion, and transport processes that affect pollutants emitted to the MCMA atmosphere. They plan to improve and extend the existing atmospheric chemistry model for ozone formation. A detailed understanding of the process whereby ozone forms under specific conditions is needed to design an effective and efficient emissions-reduction plan. Finally, they are going to develop a complementary model focusing on the emission and formation in the atmosphere of tiny particles, which are increasingly recognized as a human health threat.

The researchers emphasize that sound scientific information alone cannot produce an effective emissions-reduction strategy. Such a strategy must be economically and politically viable and socially acceptable as well as aimed at the problematic emissions, emissions sources, and atmospheric pollutants. Nevertheless, the Mexico City field measurement campaign, its findings, and the refined and extended computer models that should result can serve as groundwork to support integrated assessments for improved environmental decision-making in Mexico as well as in other countries.

The Mexico City Program is the first case study being carried out under the Integrated Program on Urban, Regional, and Global Air Pollution. Luisa T. Molina is the executive director of the Integrated Program. Mario Molina is an Institute Professor. Charles E. Kolb is an atmospheric chemist and president of Aerodyne Research Inc. (Billerica, Massachusetts). Lisa Grogan is a master's degree candidate in the Engineering Systems Division. *This research was an activity of the Integrated Program on Urban, Regional, and Global Air Pollution with funds provided by the Comisión Ambiental Metropolitana (Fideicomiso Ambiental del Valle de México), the MIT Alliance for Global Sustainability, and the National Science Foundation.* *The program has already published a book entitled* Air Quality in the Mexico Megacity: An Integrated Assessment, *which provides an overview of the current understanding of the air pollution problem and lessons learned from air-quality management programs to date (see reference 1 in the Publications and References section of this issue). Publications on the field measurements and integrated scenario analysis are forthcoming.*

Trace Gases in the Atmosphere: Spectroscopic Techniques for Field Measurement and Laboratory Analysis

The earth's atmosphere contains a variety of trace gases that contribute to global climate change, smog formation, acid rain, and ozone depletion. But monitoring those trace gases in the air and examining their behavior in the lab are difficult because they occur in such low concentrations. Now, teams of researchers affiliated with the Alliance for Global Sustainability (AGS) are using spectroscopy to make progress on both fronts. A team at MIT has demonstrated a laboratory device that can measure atmospheric trace gases at parts per billion levels. Their new device will enable them to examine selected species to determine detailed properties including global-warming potential. It will also allow them to define clearer spectroscopic "fingerprints" for field monitoring systems to look for. Another AGS team of researchers from Chalmers University of Technology (Sweden) is using a spectroscopic technique to identify and measure trace gases in Shanghai's air without taking chemical samples—the traditional time-consuming and sometimes ineffective approach. Already the Chalmers researchers have identified an unexpected sulfur compound and pinpointed its likely source: a smokestack 200 meters away. Ultimately, they plan to develop a low-cost network of monitors that will measure and map trace pollutants citywide. The research teams from MIT and Chalmers are part of a broad AGS program under which four collaborating institutions are developing a variety of innovative, ultrasensitive spectroscopic techniques for monitoring trace species and examining their properties and behavior.

Most of the air we breathe consists of nitrogen, oxygen, argon, carbon dioxide, and water vapor. Mixed in, however, are trace species such as ozone, sulfur dioxide, nitrogen dioxide, and methane. While those species account for only about 0.0002% of the total, they can significantly affect our environment and our health. On a global scale, trace species influence chemical reactions in the atmosphere and act as greenhouse gases, thereby contributing to climate change. On a local scale, they are hazardous air pollutants that can affect human, animal, and plant health. As energy use and mobility continue to expand worldwide, it becomes increasingly clear that attaining sustainable development will require understanding and controlling the trace gas content of the atmosphere.

Several international research teams have joined forces through the AGS to tackle that challenge. The collaborators are based at the MIT Laboratory for Energy and the Environment (LFEE), the Swiss Federal Institute of Technology in Zürich (ETH) and in Lausanne (EPFL), the University of Tokyo, and Chalmers University of Technology. Their work involves three complementary approaches. They are developing laboratory techniques for investigating how specific trace species form and behave and how they can be recognized and measured in the atmosphere. They are developing sensitive optical techniques for monitoring such species in the field. And they are performing theoretical calculations delving into the structure and properties of molecular species of concern.

Using their new methods, the AGS teams are figuring out what is present in the atmosphere, determining where it comes from, calculating how it chemically reacts in the atmosphere, and estimating how it may contribute to climate change. Their results should prove valuable to experts who are modeling atmospheric chemistry and climate change as well as to policy makers who must establish and enforce rational air quality regulations.

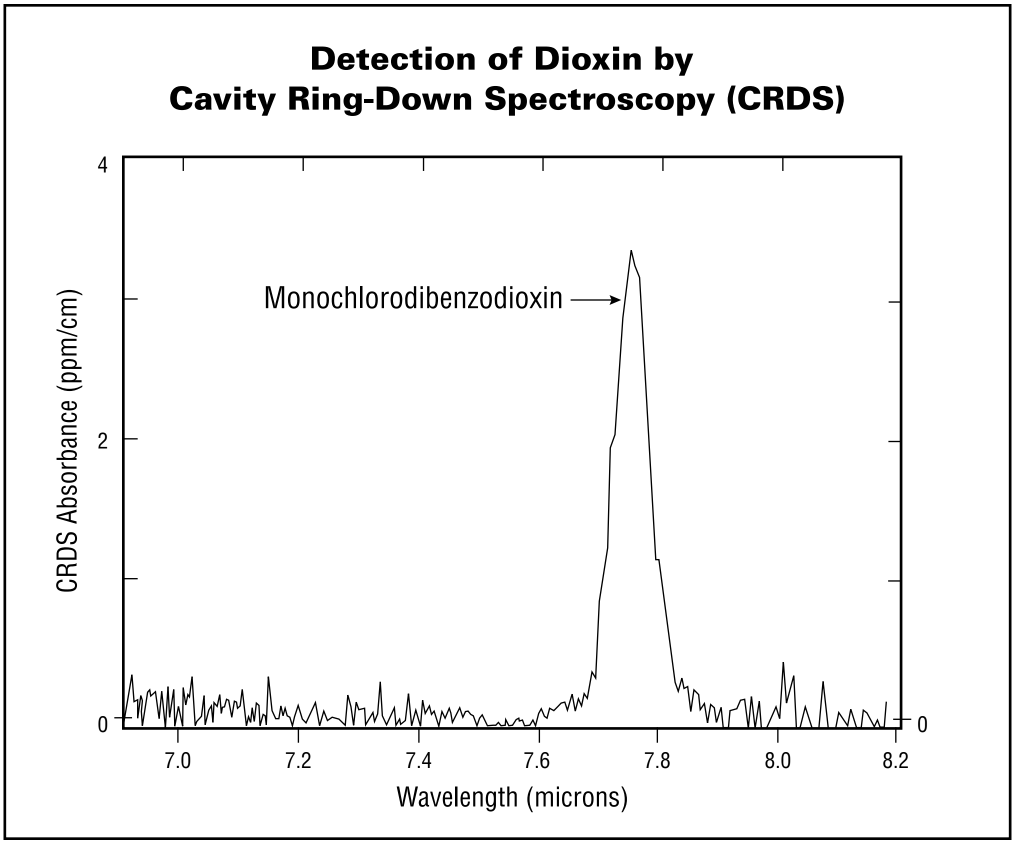
The analytical techniques used in the AGS laboratory and field work vary widely, but they share one common feature: they all use spectroscopy. Developed first in the 1800s, spectroscopy is a method of identifying and measuring specific chemical species based on how they interact with light. When atoms and molecules absorb light, they become "excited." Electrons may jump from one energy state to another, for example, or the molecules may begin to vibrate or rotate. A specific type of atom or molecule will absorb light at only certain wavelengths. The chemical make-up of a gas can therefore be identified by passing light through it and seeing what wavelengths are missing from the spectrum measured at the other end. While specific methods of using spectroscopy vary, this general approach coupled with sophisticated mathematical analysis provides a highly sensitive means of detecting, measuring, and examining chemical species.

Through their collaboration, the AGS researchers at the four institutions can examine the same species using different techniques, crosscheck their findings, and exchange information that can guide future efforts. As a sampling of the activities included, we focus here on two specific projects: a laboratory effort being undertaken at MIT and a major monitoring campaign being performed in China by colleagues from Chalmers University of Technology.

Tools for Laboratory Studies

Spectroscopy-based laboratory methods are ideal for determining critical properties of gases such as their global-warming potential, which indicates their contribution to the greenhouse effect and is a critical input to climate change simulations. However, in the atmosphere the trace species of concern typically occur in concentrations of parts per billion or less. In such a low-concentration gas, light must travel a long distance before it will have encountered enough absorbing molecules to undergo measurable attenuation. Measurements of such trace species in the field frequently involve "path lengths" of thousands of kilometers—not easily achieved in the laboratory setting. Increasing the concentration of the sample inside the lab container could shorten the necessary path length; but it would also dramatically increase the number of collisions and interactions among the molecules, changing the properties of interest.

To solve that problem, MIT researchers led by Professor Jeffrey I. Steinfeld are using an approach called "cavity ring-down" spectroscopy



This figure demonstrates the ability of a new spectroscopy-based laboratory device to detect extremely low concentrations of dioxin, a highly toxic trace gas that results from combustion of chlorine-containing organic materials. The researchers place a sample of pure dioxin in the device and pulse a laser beam through it, gradually varying the laser wavelength while measuring how much light is absorbed. Absorbance peaks at a wavelength of just over 7.7 microns—a characteristic spectroscopic indicator for dioxin. Even then, only about 0.001% of the beam is absorbed by each centimeter of gas it encounters. The change is tiny but clearly evident in the signal. Adapted for field use, this device should provide a means of detecting dioxin and other worrisome trace gases in real time, without the delays and inaccuracies involved in collecting and analyzing samples.

(CRDS). They place their low-concentration sample into a container that has high-reflectivity mirrors at each end. They set a laser to a specific wavelength and pulse a beam into the container, where it is trapped, bouncing between the two mirrors. A small amount of light escapes through one mirror and is measured by an optical detector located behind the mirror. The decline in the leaked light over time indicates the effectiveness with which the sample absorbs the particular wavelength of the laser pulse.

Using this CRDS detection system, the MIT researchers have achieved a sensitivity equal to that of an atmospheric path length of several thousand kilometers but in a controlled laboratory environment in which they can specify and vary the pressure, temperature, and composition of the sample. Because the emerging light is at a single wavelength, no complex optics are required; a single detector will suffice. The laser source is an optical parametric oscillator whose wavelength can be varied. By performing a series of tests using different wavelengths, the researchers can identify the precise wavelength or wavelengths at which a given species absorbs energy.

Professor Steinfeld and his colleagues have used their CRDS system with well-characterized calibration samples at realistically low concentrations. They have successfully detected a range of molecular species including nitroaromatic vapors, volatile organic compounds from household and personal products, and dioxins. As an example, the figure to the left shows measurements of the absorption of dioxin, a highly toxic chemical, at a range of infrared wavelengths. Absorption clearly peaks at a wavelength of just over 7.7 microns. However, even at that peak less than 4 parts per million—less than 0.001%—of the light is absorbed over each centimeter of path length. Detecting such a small change requires hundreds of meters of path length. Using cavity ring-down, the researchers essentially fold up that necessary path length within the small CRDS container. Professor Steinfeld estimates that with signal processing, the CRDS system could detect concentrations as low as 50 parts per billion.

The researchers are continuing their work with the CRDS detection system. They are performing experiments with carefully prepared reference samples to establish clear spectroscopic "fingerprints" needed for the improved remote sensing of trace species in the atmosphere. They are focusing especially on target compounds that are known to be hazardous air pollutants but have been neglected in past monitoring endeavors. And they are continuing to improve the CRDS system itself. A primary goal is to develop a prototype instrument suitable for use in the field. A CRDS system made with solid-state components could be small enough to put onto a tabletop or into the back of a truck. A remaining challenge is to develop methods of sorting out the measurements taken. In a real field sample, dioxin will be mixed in with many other species. Highly sophisticated pattern recognition and other software will be needed to disentangle the interfering signals. The CRDS technique is also being investigated in the laboratory of one of the project partners, Professor Martin Quack at ETH-Zürich.

In related work, the MIT team is developing an "intra-cavity" laser absorption spectrometer. In this device a transparent container holding a sample is placed inside the cavity where the laser itself operates. As the laser radiation is being generated, molecules in the sample get in the way and absorb energy in their characteristic fashion. Analyzing the laser output with a spectrometer and nonlinear mathematical equations yields the identity of the gas in the sample. This device is proving even more sensitive than the CRDS system. Already it has measured weakly absorbing atmospheric gases including highly reactive molecular fragments that play a key role in the formation and removal of nitrogen oxides (NO_X) and ammonia in the atmosphere.

Identifying and Measuring Trace Gases in the Field

Measuring concentrations of trace gases in the atmosphere is critical to setting and enforcing emissions standards, establishing the environmental performance of new technologies, and generally protecting people and the environment. Current US Environmental Protection Agency (EPA) rules for establishing compliance with standards require the use of traditional techniques that typically involve collecting samples and then testing them at an EPA-certified facility. But some trace species of interest are highly reactive and do not survive sampling and subsequent analysis. Furthermore, the process can take days. By the time results are available, any detected plume of pollutants has long since passed.

AGS researchers at Chalmers University, led by Professor Bo Galle, have been demonstrating an alternative approach that permits remote monitoring in real time. They use a method called differential optical absorption spectroscopy, or DOAS. This method involves transmitting a beam of light from a broadband source (thus, light that consists of many wavelengths) to a distant reflector. The reflector bounces the beam back to a spectrometer located near the light source, thereby creating a long, open pathway in the atmosphere. Analysis of the frequencies in the received beam identifies the species present and their concentrations.

The Chalmers researchers are testing their DOAS detector in China, where urban air pollution is a serious concern and the need for nationwide measurements of a range of compounds is critical. In their project, known as "China Sky," they use a telescope located on the 14th floor of a building in Shanghai to transmit an intense beam toward a reflector placed on a building some 700 meters away, generating a total optical path length of 1,400 meters. They use a spectrometer and sophisticated data processing software to sort out the signals that return. To pinpoint a particular chemical species, they monitor the received light at the frequency or set of frequencies at which that species is known to absorb.

Initial tests of their first DOAS prototype ran from October 2001 to April 2002. They successfully gathered data on atmospheric pollutants including ozone, NO_X, sulfur oxides (SO_X), and aromatics such as toluene and benzene. Analyses of short-term trends showed that their measurements correlated as expected with changes in weather and in daily traffic patterns. For several weeks in March, the researchers compared data from the China Sky DOAS with data gathered by a nearby point monitor operated by Shanghai's environmental protection authority. Simultaneous measurements of NO_2, sulfur dioxide (SO_2), and ozone agreed well. Differences that were evident could be explained by the different air masses being measured by the two techniques.

One unexpected finding was the presence of carbon disulfide (CS_2), a low-concentration species that acts as a source of atmospheric sulfur. To identify possible sources of CS_2, the researchers evaluated SO_2 and CS_2 concentrations and found that there was a strong correlation between them when the wind came from a particular direction. They investigated possible local emission sources in that direction and concluded that the pollutants were coming from a 50-meter-high chimney located about 200 meters from the measurement site. The researchers believe that they are the first to report measurements of CS_2 from smokestack emissions using an optical remote sensing technique.

The ultimate goal of China Sky is to set up a network of high-quality air-monitoring stations in China at an affordable cost. The researchers hope to have 500 instruments in operation within five years. The DOAS system is a good means of mapping distributions of pollutants over a wide area. A single light source and detection setup at a central location can be used to take readings from reflectors in many different directions. However, the cost of the DOAS equipment is now too high to allow its widespread use in developing countries. The researchers are therefore developing a less-expensive prototype that is made with Chinese components and includes mass production and operator training in China. The monitoring network will take advantage of recent advances in solid-state optical detectors as well as in computers and communication technology.

Interaction, Collaboration, Synergy

Throughout their work, the MIT, Chalmers, and ETH-Zürich teams cooperate closely, exchanging information that helps cross-validate their new laboratory and field techniques. For example, they can compare in detail spectral data for the same chemical species obtained by two independent systems, one equipped with a laser and the other with a broadband light source. The information exchange helps the research teams interpret their field measurements and select topics for closer examination under controlled laboratory conditions.

Such interaction is one of the key features of the overall AGS program on innovative spectroscopic techniques for studying and monitoring atmospheric trace gases. While the individual groups located worldwide are making significant gains, their efforts are leveraged by exchanges of information and personnel with one another. Already they are demonstrating the practical value of their innovative techniques by generating new fundamental understanding and monitoring data that can help improve pollution forecasting, climate change modeling, and policy and decision making.

Jeffrey I. Steinfeld is a professor of chemistry at MIT. Bo Galle is a professor at Chalmers University of Technology. *This research was supported by the Alliance for Global Sustainability.* *Further information about the CRDS research can be found in references 2–9 (see Publications and References section). Publications from the China Sky project are forthcoming.*

News Items

On October 28, 2002, the **Education Program of the Laboratory for Energy and the Environment** (LFEE) held a welcome luncheon for new and returning members of LFEE's Environmental Fellows Programs. The fellows were greeted by MIT Chancellor Phillip Clay, LFEE Director David Marks, and Wallenberg-MIT Fellowship Steering Committee Chair Jeffrey Steinfeld. Discussion that followed focused on gathering and disseminating information on sustainability, mentoring undergraduates, networking with outside professionals, and supporting interaction among members of MIT's environmental fellowship programs. LFEE oversees two programs. The **Wallenberg Foundation Postdoctoral Fellowships in the Environment and Sustainability** brings outstanding young Swedish scientists, engineers, and policy makers to MIT for one to two years of study and research relating to environmental preservation and sustainable development. The **Martin Family Society of Fellows for Sustainability** brings together and supports MIT's top graduate students in environmental studies and fosters opportunities for multidisciplinary collaboration in both the short and long term. In both programs, environmental fellows at MIT not only deepen their understanding of sustainability but also establish long-lasting interdisciplinary ties with an international network of colleagues working on complex multidimensional environmental issues. For information on each of this year's 34 fellows, go to <http://lfee.mit.edu/education/fellowships>.

The third annual **MIT Carbon Sequestration Forum**, entitled "**Moving Toward a Regulatory Regime**," was held on November 13–14, 2002, in Cambridge, Massachusetts. Sessions focused on the following topics: geologic storage of carbon dioxide—lessons from history; the potential for leaks from geologic reservoirs; public reaction to the Hawaii field study on ocean sequestration (see *e-lab*, July–September 2002); and the costs of capture and storage. Two additional sessions involved a panel discussion of gasification and a series of updates on projects now under way at four institutions. Attendees included about 100 people from academia, industry, and governments, including regulatory agencies. The forum was held as part of the MIT LFEE's Carbon Sequestration Initiative, an industrial consortium supporting research and information exchange on carbon sequestration technologies (on the Web at <http://sequestration.mit.edu>).

On November 17–19, the **Alliance for Global Sustainability** (AGS) held its 2002 technical meeting, "**Building Research Partnerships for Sustainable Development**." The meeting was designed as a forum in which stakeholders could openly discuss ongoing and potential AGS activities relevant to their own interests. In the keynote address, Dr. Paul Tebo of DuPont discussed private sector/academic partnerships for sustainable development. Drawing on their research and stressing corporate relevance, AGS investigators then discussed four topics: technology and the future of sustainable development, implications of cross-national variation in regulations, the role of R&D in promoting sustainable corporations, and new insights into climate change and its effects on corporations. Simultaneous afternoon workshops focused on new materials for sustainable development; tools for managing megacities; mountain waters: resource and risk; and strategies for changing course. A fifth workshop, focusing on the social and political aspects of carbon management, took place a few days before the AGS meeting convened. At a special workshop on education, more than 20 AGS participants discussed needs in sustainability education and generated a rich menu of possible directions for the AGS education agenda. Suggested strategies included an intensive faculty retreat on sustainability teaching and research and a mentoring program for young sustainability scholars and professionals. The AGS meeting was attended by more than 130 people including representatives from the four AGS member institutions—MIT, the University of Tokyo, the Swiss Federal Institute of Technology, and Chalmers University of Technology—and from the private sector and other academic institutions worldwide.

Fifty-two participants from industry, government, and academia attended the **fall workshop** of the **Center for Energy and Environmental Policy Research**, held on December 5–6. Topics included the MIT project on the future of nuclear power; natural gas price volatility; automobiles and the National Academy of Sciences CAFE Study; the meaning of energy security; the Federal Energy Regulatory Commission's Standard Market Design initiative; and how to move to a lower cap on sulfur dioxide emissions. In a lunchtime presentation, Professor Michael S. Scott Morton described the Cambridge-MIT Institute and its activities; and during dinner, Guy F. Caruso, administrator of the Energy Information Administration, discussed the recently released *Annual Energy Outlook*.

LFEE graduate student **Ralph P. Hall** has received the prestigious **Wootan Award from the Council of University Transportation Centers** for his thesis, *Introducing the Concept of Sustainable Transportation to the US DOT Through the Reauthorization of TEA-21* (see reference 10 in the Publications and References section). His thesis was also selected as best master's thesis for 2002 by MIT's Technology and Policy Program. Mr. Hall is now a PhD candidate focusing on understanding and applying the concept of sustainable transportation to transportation planning processes in the United States. In addition, as part of the new Cambridge-MIT Institute, Mr. Hall is working closely with Dr. William J. Nuttall, course director of the MPhil in Technology Policy at the University of Cambridge, to develop new course material in the areas of sustainable transportation and the long-term management of radioactive wastes. Mr. Hall is a member of the Martin Family Society of Fellows for Sustainability for 2002–2003.

Last summer, the LFEE was invited to provide images and accompanying text for the covers of the **MIT telephone directories**. The new faculty and staff directory features several LFEE projects relating to building design, while the student directory focuses on automotive engines and transportation systems. Release of the directories was announced on MIT's home page with information about the LFEE covers, including two on-line videos. One video shows results from a computational fluid dynamics analysis of airflows around the MIT campus. In the other video, laser-induced fluorescence images show the changing thickness of the oil layer on the side of a piston in a specially designed internal combustion engine. To see the directory covers and videos on the Web, go to <http://web.mit.edu/spotlight/phonebook/>.

Publications and References

The following publications covering Laboratory for Energy and the Environment (LFEE) and related research became available during the past period or are cited as references in this issue. Center for Advanced Nuclear Energy Systems (CANES) reports are available from Michael Messina, MIT Department of Nuclear Engineering, Room 24-212, Cambridge, MA 02139-4307 (tel.: 617-253-3808). MIT theses may be ordered from the Libraries Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from LFEE Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, only if a price is assigned and only if prepaid by check payable to "MIT Laboratory for Energy and the Environment." Prices are postpaid surface mail. For air delivery, add 15% to US, Canada, and Mexico, and 30% elsewhere. A list of publications is available on request.

Publications marked by an asterisk (*) can be found or are forthcoming on-line via the following addresses:

Laboratory for Energy and the Environment:
http://lfee.mit.edu

Center for Energy and Environmental Policy Research:
http://web.mit.edu/ceepr/www/

Joint Program on the Science and Policy of Global Change:
http://web.mit.edu/globalchange/www/

Instructions for ordering paper copies of the reports and working papers are also available at the sites listed previously or by telephoning 617-258-0307 for LFEE publications, 617-253-3551 for Center publications, and 617-253-7492 for Joint Program publications.

Reports and Working Papers

Babiker, M., J. Reilly, and L. Viguier. *Is International Emissions Trading Always Beneficial?* Joint Program on the Science and Policy of Global Change Report No. 93. 30 pages. December 2002.*

Carlen, B. *Exclusionary Manipulation of Carbon Permit Markets: A Laboratory Test*. Joint Program on the Science and Policy of Global Change Report No. 91. 35 pages. November 2002.*

Felzer, B., D. Kicklighter, J. Melillo, C. Wang, Q. Zhuang, and R. Prinn. *Ozone Effects on Net Primary Production and Carbon Sequestration in the Conterminous United States Using a Biogeochemistry Model*. Joint Program on the Science and Policy of Global Change Report No. 90. 19 pages. November 2002.*

Final Report: EPA Center for Airborne Organics. MIT LFEE 2002-003 RP. 88 pages. September 2002.*

Finon, D. *Introducing Competition in the French Electricity Supply Industry: The Destabilisation of a Public Hierarchy in an Open Institutional Environment*. Center for Energy and Environmental Policy Research Working Paper No. WP-2002-009. 23 pages. November 2002.*

Glachant, J.-M., and V. Pignon. *Nordic Electricity Congestion's Arrangement as a Model for Europe: Physical Constraints or Operators' Opportunism?* Center for Energy and Environmental Policy Research Working Paper No. WP-2002-006. 26 pages. October 2002.*

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NEW AND RENEWED PROJECTS, OCTOBER–DECEMBER 2002

Topic	Donor or Sponsor	Investigators *(Department)*
GIFTS AND CONTRIBUTIONS		
Center for Energy and Environmental Policy Research membership	ALSTOM Power (France); ChevronTexaco; Electric Power Development Co., Ltd; Tennessee Valley Authority; Tractebel SA	
Joint Program on the Science and Policy of Global Change membership	ALSTOM Power (France); ChevronTexaco; Electric Power Development Co., Ltd.; Tennessee Valley Authority; The G. Unger Vetlesen Foundation	
NEW PROJECTS		
Integrated Assessment of Multiple Greenhouse Gases and Policy Study	US Environmental Protection Agency	J. Reilly *(Laboratory for Energy and the Environment)*
MIT Alliance for Global Sustainability (AGS)	Alliance for Global Sustainability International	
Microstructural Modeling of the Ultrasonic Metal Welding Process		W. Carter *(Materials Science and Engineering)*
Platinum Group Elements from Automobile Emissions		H. Hemond *(Civil and Environmental Engineering)*
Isolated Rural Distribution Networks		S. Connors *(Laboratory for Energy and the Environment)*
The Origin and Potential Control of Air Pollution in Katmandu Valley, Nepal		R. Prinn *(Earth, Atmospheric and Planetary Science)*

Webster, M., C. Forest, J. Reilly, M. Babiker, D. Kicklighter, M. Mayer, R. Prinn, M. Sarofim, A. Sokolov, P. Stone, and C. Wang. *Uncertainty Analysis of Climate Change and Policy Response*. Joint Program on the Science and Policy of Global Change Report No. 95. 25 pages. December 2002.*

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NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators *(Department)*
RENEWED PROJECTS		
Bismuth Reactor	Bechtel BWXT Idaho, LLC	N. Todreas *(Nuclear Engineering)*
Advanced Nuclear Fuel Cycles for Enhanced Proliferation Resistance	Bechtel BWXT Idaho, LLC	M. Kazimi *(Nuclear Engineering)*
Carbon Management CIS	Energy Choices Consortium (multi-sponsored)	H. Herzog *(Laboratory for Energy and the Environment)*

de Figueiredo, M. *The Hawaii Carbon Dioxide Ocean Sequestration Field Experiment: A Case Study in Public Perceptions and Institutional Effectiveness*. MS thesis. MIT Department of Civil and Environmental Engineering. June 2002. Available on-line at <http://sequestration.mit.edu/bibliography/>.

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