e-lab

Energy Laboratory research and related activities at the Massachusetts Institute of Technology

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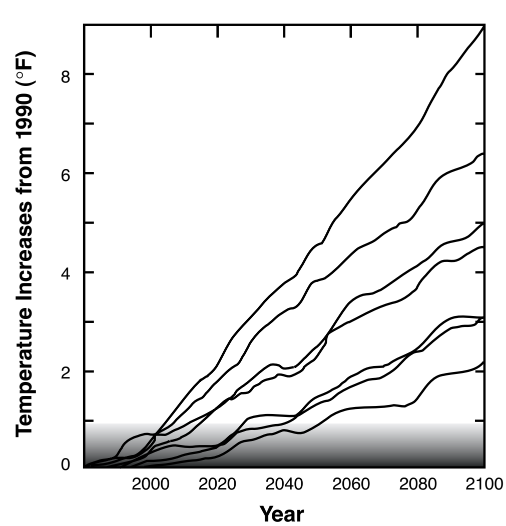
Dealing With Global Warming: The Need for Long-Term Actions

In recent years, intense international negotiations have focused on how much each of the developed nations should limit their emissions of carbon dioxide (CO_2). Now researchers in MIT's Joint Program on the Science and Policy of Global Change warn that setting such limits will not by itself be a sufficient response if the threat of global warming proves real. Analyses using their "Integrated Global System Model" suggest that even the toughest current proposal for limiting emissions from developed nations will reduce projected warming in 2100 by only about 20%. Further, the analyses show that developed countries alone cannot reduce emissions enough to stabilize atmospheric CO_2 concentrations at levels now proposed as "safe." The rapidly growing emissions from developing nations must also be curbed. There are even more challenging tasks for the long-term future. First, we should develop "greenhouse-friendly" technologies that permit emissions reductions without threatening economic health. Second, we should design broad international climate agreements that can evolve over time and that address all issues, from sources and sinks of all greenhouse gases to emissions monitoring and enforcement. Finally, we should develop an international system that can, if necessary, transfer substantial funds to developing countries to support their emissions-control efforts. These long-term undertakings should be tackled with the same fervor that characterizes current negotiations on near-term emissions limits.

The signing of the Berlin Mandate in 1995 initiated intense international negotiations to develop a response to potential climate change. Under the mandate, diplomats were instructed to devise a set of national ceilings for greenhouse gas emissions for the early years of the next century. To make agreement more likely, developing countries were not to be asked to control emissions, although they account for roughly half the greenhouse emissions now and will emit a larger share in coming decades. The near-term focus is on emissions of carbon dioxide (CO_2), recognized as the most important human contributor to potential global warming. Results of the negotiations were the focus of the international conference on

Forecasts of Temperature Increases



This figure shows different current forecasts of increases in global temperature, as predicted by MIT's global climate change model. The variation in forecasts results from using different "reasonable" assumptions about future economic development and fundamental climate processes. The shaded area near the bottom indicates the estimated natural variability in global mean temperature during the course of a century. The greater the eventual warming, the sooner observed temperatures will rise above that natural level of variability, indicating a human influence on temperature.

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climate change that was held in Kyoto, Japan, in December 1997.

As a result of the Berlin Mandate, climate change debate during the past two years has focused on a single question: how much will each of the developed nations promise to cut CO_2 emissions by 2010? Preoccupation with that question worries researchers in the MIT Joint Program on the Science and Policy of Global Change. Achieving near-term limits on CO_2 emissions is important, agree Professors Henry D. Jacoby, Ronald G. Prinn, and Richard L. Schmalensee. But negotiations toward that goal may be counterproductive if they delay actions necessary to mount and sustain a broader and longer-term global effort to deal with the threat of potential climate change.

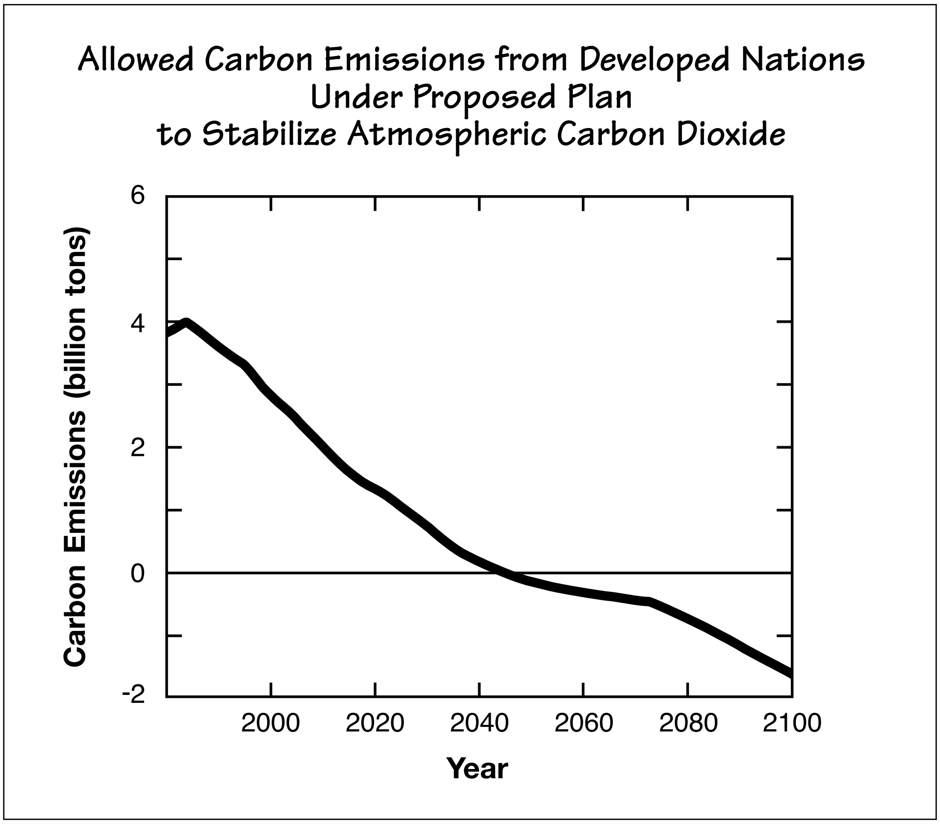
The researchers' concern arises in part from their ongoing investigations into uncertainties that plague predictions of human influences on climate. Experts agree that concentrations of CO_2 and other greenhouse gases in the atmosphere have increased substantially over the past century and that the presence of those gases will tend to trap the sun's infrared energy, raising temperatures at the Earth's surface. But other aspects are controversial. The impact of changes in temperature on our climate depends on complicated, interacting phenomena in the atmosphere, the oceans, and land ecosystems, all of which are poorly understood. Long-term emissions of greenhouse gases are themselves highly uncertain because they depend on economic, technological, and political forces that are hard to predict. And least of all is known about how changes in climate may affect people, society, and natural systems.

To help analyze and quantify the uncertainty associated with climate forecasts, a group of MIT scientists and economists including Professors Jacoby, Prinn, and Schmalensee have formulated a computer model that couples global economic development, climate processes, and ecosystem behavior. Unlike other models in this field, the Integrated Global System Model (IGSM) combines detailed treatments of the relevant natural and economic processes (see *e-lab*, January–March 1997). Using the model, the researchers have explored the consequences of a range of "reasonable" assumptions about future economic development and fundamental climate processes. Their results provide guidance for both policymaking and future research directions.

One important conclusion is that the range of plausible outcomes is enormous. The figure on page 1 shows how using various sets of assumptions about future human activities and about natural processes affects predictions of the change in global average surface temperature between 1990 and 2100. (The predictions assume that future greenhouse gas emissions are not restricted by regulation.) The assumptions are all reasonable, but they produce widely varying results. For example, using the most optimistic assumptions, the predicted increase in temperature by the year 2100 is only 2°F. However, using the "worst-case" assumptions, the predicted increase is fully 9°F. Two-thirds of the difference in those predictions is due to uncertainty about climate processes; the other third reflects uncertainty about emissions. The lowest predicted pathway in the figure would probably do little harm, but the highest predicted pathway would almost certainly threaten important natural processes as well as agriculture and other human activities.

Clearly, scientists must continue research to improve emissions forecasts, climate models, and impact estimates. In addition, they must continue to watch for evidence that human activities are indeed influencing climate. Many scientists now believe that it may be a decade or more before human effects can be discerned from natural variations in climate. Nevertheless, continued vigilance is critical, as demonstrated in the figure. The shaded region at the bottom represents an estimate of how much global mean temperatures vary naturally during the course of a century. An increase in actual temperatures greater than that natural variability provides evidence that human activities are affecting climate. Looking at the various forecasts, it is clear that the sooner the observed temperatures rise above that range of natural variability, the greater the eventual predicted warming, and the more important it will be to take quick and dramatic action to forestall large climate impacts.

If global warming does turn out to be a problem, IGSM analyses suggest that the emissions reductions agreed to at the Kyoto meeting will not—by themselves—do much to solve it. The researchers considered one of the toughest proposals that was considered at Kyoto: the call by the European Union (EU) to reduce CO_2 emissions from "Annex I" countries to 15% below 1990 levels by 2010—fully 9% more than in the final agreement. (Annex I countries are those subject to emissions limits, namely the members of the Organization for Economic Cooperation and Development as of 1990, plus Eastern Europe and most of the former Soviet Union.) Achieving such a large reduction in CO_2 emissions in little more than a decade would be expensive, and maintaining the



The European Union proposes that an ultimate level of 550 ppm of CO_2 in the atmosphere would avoid "danger" to economies and ecosystems. Using their climate model, the MIT researchers calculated how much carbon the so-called Annex I developed nations could emit during the next century without exceeding that 550 ppm, if the developing nations continue to emit CO_2 without restriction. As shown above, if the developing nations do not limit *their* emissions, the developed nations' carbon emissions would have to go negative in about 50 years!

proposed 2010 level of emissions for the rest of the century would be even more difficult. Yet even under the assumptions of the mid-range MIT forecast in the first figure, IGSM analyses show that this effort by Annex I countries would reduce the projected warming in 2100 by only about 20%, largely because of projected emissions growth in developing countries—growth that is not restricted by the Kyoto agreement. If climate change turns out to be a serious threat, this response would be inadequate; if it turns out not to be a threat, it would be a large-scale waste of resources.

A longer-term goal involves stabilizing atmospheric concentrations of greenhouse gases. The EU and others have recommended stabilizing concentrations of CO_2 at 550 ppm (roughly twice pre-industrial levels), and the Intergovernmental Panel on Climate Change (IPCC) has outlined an emissions-reduction strategy for achieving that goal. Based on an IGSM analysis, the MIT researchers predict that following that strategy would lower the mid-range warming forecast by only about 30% in 2100. Moreover, the Annex I nations could not accomplish the called-for emissions reductions by themselves. The figure on this page shows the maximum Annex I emissions consistent with the EU's proposed target (based on assumptions corresponding to the mid-range of the forecasts in the figure on page 1). The non-Annex I nations are assumed to continue emitting CO_2 without restriction, and their forecasted emissions are simply subtracted from the global total that the EU proposal allows, as calculated by the IPCC. Without participation by the developing world, following the proposed emissions-reduction strategy would require that emissions by the Annex I nations somehow become negative around the middle of the next century!

One conclusion seems clear: unless scientists discover soon that greenhouse warming is definitely not a threat, the struggle to devise a global response will occupy not just our generation but future generations as well. The MIT researchers identify three actions that should be taken now to help future generations cope. The first is to develop better technical options that could, if necessary, permit us to control greenhouse gas emissions while maintaining economic growth. A serious attempt to produce important new technological options would be cheap relative to the cost of controlling emissions resulting from the use of current technologies. The best route to achieving such advances is not clear. Marketplace incentives appear important for stimulating private sector R&D, while public expenditure may be needed on basic research and fundamental technologies. The latter will require a major turnabout of today's minimal commitment to developing greenhouse-friendly technology.

The second action is to begin developing institutions and policies that allow us to mount and sustain a very long-term global effort to control climate change. We need to establish an institutional structure for managing global emissions agreements that can evolve easily over time. Useful insights can be gained from the international trade regime developed under the General Agreement on Tariffs and Trade (GATT), now the World Trade Organization. This organization has grown and evolved over time, adding countries and goods along the way, peacefully resolving substantial conflicts in national economic interests, and contributing to global economic growth. (Unfortunately, achieving that success required fifty years of hard work.) In addition, policies limiting CO_2 emissions should be just one part of a larger, carefully designed set of international agreements that address all the issues involved. For example, agreements must cover not just CO_2 produced from fossil fuels but also all the important sources and sinks of significant greenhouse gases. They also need to provide for reliable emissions monitoring and for some system of sanctions for those who violate their obligations.

The third area that warrants attention concerns the inclusion of non-Annex I nations. Making significant reductions in global emissions will require global participation. Therefore, Annex I targets and timetables must be designed to facilitate the inclusion of non-Annex I nations. In many cases, these nations will not be able to afford voluntary abatement much before the end of the next century. Thus, if the rich countries want to stabilize greenhouse gas concentrations, they must not only control their own emissions but also pay poor countries to reduce *their* emissions. Rough estimates of the costs that would be involved imply international transfers of wealth on a scale well beyond anything in recorded history. We need to create an international system that can transfer substantial sums to developing countries to support their participation in an emissions-control effort.

Including the developing countries in that effort will affect another important financial factor: the global cost of controlling emissions. Many of the cheapest emissions-abatement opportunities are in developing countries, and exploiting those opportunities first would minimize the global cost of achieving a given reduction in emissions. To take advantage of those opportunities, some observers have proposed establishing a system of emissions trading—the approach that has dramatically reduced sulfur dioxide pollution in the United States (see *e-lab*, January–March 1997). Emissions trading is not included in the Kyoto agreement. But even if it is adopted in later agreements, it will work effectively only if all countries have agreed to emissions limits. If the developing countries do not participate, the advantages of trading are drastically reduced.

Henry D. Jacoby and Ronald G. Prinn are co-directors of the MIT Joint Program on the Science and Policy of Global Change. Professor Jacoby is William F. Pounds Professor of Management. Professor Prinn is TEPCO Professor of Atmospheric Chemistry and director of the Center for Global Change Science. Richard L. Schmalensee is Gordon Y Billard Professor of Management and Economics, director of the MIT Center for Energy and Environmental Policy Research, and associate dean of the MIT Sloan School of Management. *This research was supported by a government-industry partnership including the US Department of Energy, the National Science Foundation, the US National Oceanic and Atmospheric Administration, the US Environmental Protection Agency, the Royal Norwegian Ministries of Energy and Industry and Foreign Affairs, and a group of corporate sponsors from the United States, Europe, and Japan. Further information can be found in references 1–7.*

Reducing Indoor Air Pollution and Saving Energy, Too

Researchers in MIT's Building Technology Program and the Energy Laboratory are studying an approach to ventilation that is radically different from that now used in the United States and could both improve indoor air quality and save energy. While conventional ventilation systems mix large quantities of newly conditioned air into the air in a room, "displacement ventilation" systems prevent mixing by injecting limited amounts of air, slowly and near the floor. Pollutants and heat that are produced by people and equipment rise naturally to ceiling exhaust vents, and the fresh air rises into the breathing space. The difficulty is that the precise system specifications—air temperature, velocity, and so on—must be tailored to the space being ventilated or occupants may be uncomfortable. The MIT researchers are developing tools that can help. They have formulated a computer model that calculates how different system specifications affect airflows and heat and pollutant dispersion in a well-defined room. And they have built a full-size experimental room in which they can test the effects of different ventilation strategies in various situations (an office with two "people" in front of computers, a classroom with "students" behind desks). The model predictions and experimental results agree quite well, and both confirm that a well-designed displacement ventilation system can provide clean air and comfort and also reduce the amount of ventilation air that must be heated or cooled—now a major consumer of energy in commercial buildings.

To reduce energy use, owners and designers of buildings seal up leaks, maximize insulation, and install ventilation systems meant to provide occupants with clean, conditioned air. However, those ventilation systems don't always work as planned. In some cases, airborne contaminants and heat generated indoors by building materials and equipment—and even normal human "effluents" such as carbon dioxide—become trapped. The impact on the comfort, health, and productivity of occupants can be serious. Numerous "sick buildings" have required evacuation and repair, even state-of-the-art new construction such as the headquarters of the US Environmental Protection Agency.

The traditional approach to ventilation does pose potential problems. The goal in conventional "mixed-flow" ventilation is to mix up all the air in the room, producing an even temperature throughout the space and diluting any pollutants. Typically, ventilation air is injected at high velocity at or near the ceiling. If mixing is not sufficient, stagnant areas can occur in the "occupied zone" nearer the floor. And while mixing does dilute pollutants, it also sweeps them away from their sources and distributes them throughout the room, exposing all occupants. In addition, mixed-flow ventilation requires large quantities of air that must be heated or cooled by energy-consuming devices.

During the past three years, Professors Qingyan Chen and Leon R. Glicksman and their coworkers in the Building Technology Program and the Energy Laboratory have been studying a radically different approach to ventilation. The approach, called displacement ventilation, seeks to prevent mixing rather than cause it. Cool, clean air enters a room at a low level at low velocity, flooding the floor much as water would. Heat and contaminants emanating from people and equipment tend to occur in isolated "plumes" hovering above individual sources. In the absence of mixing, those plumes of warm, contaminated air rise naturally toward the ceiling, where they are vented. As they rise, the plumes entrain the surrounding air, lifting the cool ventilation air to the breathing level of the occupants. Because the clean air is supplied directly to the lower, occupied area rather than mixed throughout the whole room, less air is required. Moreover, the entire room need not be as cold to provide a comfortable air-conditioning effect. The result is reduced energy use. (Most commercial buildings require cooling even in winter. However, conventional heating systems can be used simultaneously as needed.)

Displacement ventilation originated in Scandinavia and is now used widely in Europe. However, in the United States it has been installed at only a few experimental sites. Today's US building regulations are based on mixed-flow ventilation and require more air than is typically delivered by displacement ventilation systems. Moreover, there is little pressure to change those regulations, largely because of serious concerns about comfort. With displacement ventilation, fresh air flows directly into the occupied zone. If the air is too cold, moving too fast, or fluctuating in velocity, people get cold feet. Also, the air at an occupant's feet is cooler than that at his or her head. If the difference is too large, the occupant is uncomfortable. Discomfort may be more of a problem in US buildings than in European buildings because the former generally have higher cooling loads than the latter.

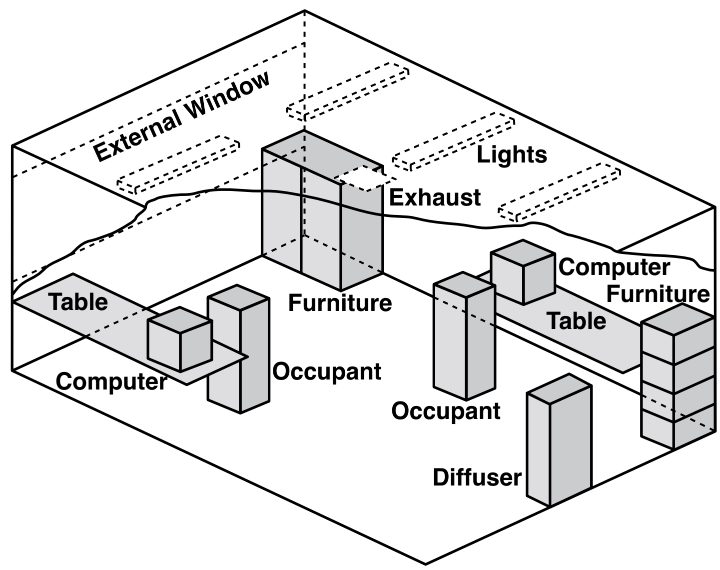
Recognizing the potential benefits of displacement ventilation, the MIT researchers are working to examine and ensure its effectiveness using two coordinated approaches: they are developing new computer models that can simulate conditions in a room with displacement ventilation, and they are gathering data in a full-size experimental room.

Designing a displacement ventilation system for a given space involves many decisions. For example, what type and how many diffusers should be used to distribute the air, and where should they be located? What should the temperature, velocity, and humidity of the input air be? The optimal specifications depend on the size and configuration of the room; the number, location, and types of heat and pollution sources (people, equipment, lights, furniture, and so on); and many other factors. An appropriate computer model would enable a designer to analyze the ventilation needs of a specific space and to define a system that would ensure good air quality, comfort, and energy efficiency.

To identify a suitable model, Professor Chen and his colleagues examined standard "computational fluid dynamics" (CFD) models that describe turbulent flows like those that occur in rooms with displacement ventilation systems. However, the standard models proved inadequate. In general, they are designed for smaller-scale applications such as airflows in fans or over aircraft wings. In addition, they cannot accurately simulate the behavior of buoyant plumes—a behavior critical to the flows of air, heat, and pollutants in a room with displacement ventilation.

Professor Chen's group has now developed a CFD model that incorporates a new, simplified technique to simulate the turbulent airflows in buoyant plumes. For a given situation and ventilation system, the model predicts distributions of air velocity, temperature, and contaminant concentrations throughout a room. The new model can be put on a personal computer and in less than an hour's time produce a good first prediction of air circulation patterns—a marked contrast to traditional

Experimental Room for Testing Displacement Ventilation Systems: Configuration for Simulating a Small Office in Summertime



A new type of ventilation system could provide cleaner air, comfort, and energy savings; but tailoring it to the space being ventilated is critical to its success. MIT researchers have built a full-size, heavily instrumented experimental room in which they can test the effectiveness of "displacement ventilation." Here the room is set up as a small office containing two model people, equipment, lights, furniture, and an external window, all designed to emit heat and contaminants and affect airflows as they might in a real office situation. The researchers inject air with controlled properties (temperature, velocity, humidity) through the diffuser. They can then both measure and observe directly how changes in those properties affect airflows and heat and pollutant dispersion throughout the room.

CFD models, which require large-capacity computers and extensive computing time.

To validate the model under a variety of well-defined conditions, Professors Chen and Glicksman have built a special facility at MIT—a full-size room with a controllable environment. The room is about 5 m long, 3.5 m wide, and 2.5 m high. It is built inside another room, enabling the researchers to select and maintain a constant wall temperature, change the building materials, and add windows as needed to simulate different external situations. The researchers can use a variety of diffusers with different designs and can control the properties of the ventilation air. Instruments located throughout the room measure temperature, humidity, velocity, and velocity fluctuations. To observe patterns of air circulation directly, the researchers create a plane of light cutting across the room by shining a powerful slide projector through a narrow slit or by using a rapidly oscillating laser beam. They then inject puffs of smoke into the room and capture images of the smoke's movement using video recording equipment placed perpendicular to the plane of light. Finally, they can inject a tracer gas at various locations to mimic a pollutant being given off by a person or machine. The compositions of samples collected at various locations show how the tracer gas disperses throughout the room.

The space outside the experimental room houses the controls—a variety of computer displays that allow the user to select conditions and observe effects in on-screen diagrams of the room. The controls are designed both for ease of operation and for use as a teaching facility.

To simulate specific situations, the researchers "furnish" the experimental room in various ways. For example, the figure on page 6 shows the room as a small two-person office. Sitting at tables are two "occupants"—square models with heat sources inside. In front of them are computers and monitors that generate heat. Typical office lights are overhead, and one wall contains an external window. In another setup, the room represents a section of a large office that contains two occupants sitting on opposite sides of a partitioned cubicle. And in another, the room is a quarter of a large classroom. Six "students" sit at tables facing the front of the room. In each case, the setup is altered to reflect summer and winter conditions, with the latter including a heat source and a cold exterior window.

In a series of tests, the researchers operated the experimental room and the new CFD model under similar conditions. In most cases, the model's predictions match the experimental results well. The calculated and measured temperatures and velocities throughout the room agree closely. Predictions of velocity fluctuations are not as good, in part because velocities are so low that measuring fluctuations is difficult. Predictions of the tracer gas concentrations are reasonably accurate, though large discrepancies occur at some locations. Smoke-visualization tests show the incoming air falling gently to the floor and then slowly drifting upward. Plumes of smoke appear above people and equipment, swirling and rising like smoke coming out of a chimney. In general, the studies confirm that a properly designed displacement ventilation system can indeed provide both clean air and comfort.

The researchers are continuing to use the model to simulate different situations. They are now performing tests in a privately owned facility that replicates a large industrial workshop. They are also using the model and parallel experiments to measure the airflow in fume hoods, including those used in biology laboratories at MIT. Results show that the hoods use airflows higher than required to ensure removal of contaminants—a significant loss of energy. In addition, they are looking into health-care applications. If displacement ventilation systems were used in hospitals and shelters, germs from patients with communicable diseases would rise to the ceiling rather than being spread to other patients.

Meanwhile, they are expanding the capabilities of the model. They are adding equations that describe chemical interactions among airborne contaminants. Thus modified, the model will be able to predict what reaction products will form and where substantial buildup may occur. And they have developed computer codes that calculate energy use associated with a given simulation. Already they are analyzing the energy use and costs associated with designing, installing, and operating displacement ventilation systems versus conventional mixed-flow ventilation systems. Ultimately, they plan to develop a set of design guidelines that they hope will reduce the amount of airflow required under today's building regulations—a change that could produce substantial energy savings nationwide.

Qingyan Chen is assistant professor of building technology. Leon R. Glicksman is professor of building technology and director of MIT's Building Technology Program. *This research was supported by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers; Halton, Inc.; Trox GmbH; and the National Science Foundation. Further information can be found in references 8–14.*

News Items

The quarterly ***e-lab*** newsletter is now on the **World Wide Web**! The URL for the home page is <**http://web.mit.edu/energylab/www/e-lab/elab.html**>. The three previous 1997 issues are posted already. This issue will be posted within a few weeks. Mary Gallagher, Energy Laboratory staff member, and Ion Bita, MIT undergraduate student, were instrumental in designing the Web format and making it easy to access and read. Thanks for visiting.

On September 29–October 1, the **Joint Program on the Science and Policy of Global Change** held its **twelfth Global Change Forum** in Boston. The theme of the forum was "**Effects of Global Change on Natural and Human Systems**." Welcoming remarks by Professor Joel Moses, provost of MIT, were followed by a keynote address delivered by Professor Abram Chayes of Harvard University. Sessions on the second day considered the effects of potential climate change on health, agriculture and forestry, water supply and quality, and biodiversity and ecosystem function. A special evening discussion considered national programs for assessing climate effects and was led by Mr. Nick Reynard of the United Kingdom's Department of the Environment and Dr. Jerry Melillo of the Ecosystems Center of the Marine Biological Laboratory in Woods Hole, Massachusetts. On the last day participants considered how to integrate global change effects into policy analysis and public communication. A final panel discussion considered prospects for negotiation and agreement at the climate change conference to be held in Kyoto, Japan, in December. Participants in the forum included about 120 scientists, analysts, policymakers, and experts from industry, government, and academia.

A **workshop** to launch a new collaborative research initiative, the **Program on Energy Choices in a Greenhouse Gas Constrained World**, was held on November 2–4 at Endicott House, MIT's off-campus conference center. The workshop was attended by 66 people, about half from MIT and the other half representing major companies, foundations, government organizations, and foreign universities. The meeting was organized and hosted by the Energy Laboratory under the leadership of Professor Jefferson W. Tester and Dr. Elisabeth M. Drake, director and associate director of the Laboratory, respectively. The purpose of the workshop was to form partnerships among a select group of industry, academic, and policymaking colleagues to begin a focused collaborative research and outreach program based at MIT. The goals of the program are to build a credible, knowledge-based framework for assessing promising energy technology options and uncertainties, and to identify and pursue opportunities for strategic technology innovation—all aimed at responding effectively to the increasing atmospheric concentrations of greenhouse gases and the consequent threats of climate change. The workshop discussions served to clarify the priorities of the various stakeholders and are helping MIT define specific research proposals responsive to those priorities.

On November 13–14, the **Center for Energy and Environmental Policy Research** held its **fall workshop**. Topics included an update on sulfur dioxide emissions trading and compliance with Title IV of the 1990 Clean Air Act Amendments, long-term trends in energy prices, oil revenue and public finance in oil-exporting nations, market power issues in electricity markets, improvements in coal mining productivity, and the role of OPEC. Guest speakers were Olivier Blanchard, MIT professor of economics, who discussed economic policies of the new French government, and Henry D. Jacoby, William F. Pounds Professor of Management, who talked about expectations for the upcoming global warming conference in Kyoto. The workshop was attended by more than 90 academic, industrial, and governmental representatives, national and international.

On December 2, the **Electric Utility Program** (EUP) held an interim workshop at MIT for the EUP consortium project, "**Development and Application of Biophysical Mechanism Theory: Ruling Out Electric and Magnetic Field Exposure Conditions for Biological Effects Due to Electric Power Use**." The workshop focused on the current assessment being conducted by the National Institute of Environmental Health Sciences (NIEHS) of the risk associated with electromagnetic field (EMF) exposure. The consortium is supporting research on how biophysical mechanisms may or may not be affected by exposure to EMFs—a topic directly related to the NIEHS review. Workshop participants discussed the "state of the EMF debate," and investigators funded by the consortium described their current and planned research on biophysical mechanisms. Central to the discussions was the timely completion of ongoing research so that it would be available to the NIEHS in its deliberations. The ten participants in the workshop came from academia, industry, several electric utilities, and NIEHS. Director of the consortium is Professor James C. Weaver of the Harvard-MIT Division of Health Sciences and Technology; and current sponsors are Allegheny Energy, Electricité de France, Ontario Hydro, and Southern California Edison Company.

On December 3–4, researchers from **MIT and McGill University** held a workshop at MIT focusing on research supported by the consortium "**Transmission Provision and Pricing Under Open Access**." Sessions focused on various technical and policy issues raised by the need to provide reliable transmission services to all participants in a competitive electric industry. Topics included allocation of line losses among generators of electric power, system reliability and congestion management, linking short-term operational requirements to long-term enhancements to the grid, equity and market power issues, and merchant power plant strategies under market uncertainty. The attendees included a dozen researchers from MIT and McGill and about 25 representatives from the electric industry. The consortium is led by Dr. Marija Ilic of MIT's Department of Electrical Engineering and Computer Science and Dr. Francisco D. Galiana of McGill University's Department of Electrical Engineering. Current consortium sponsors are Allegheny Energy, Edison Electric Institute, Electricité de France, and the Electric Power Research Institute.

Jackie Y. Ying, the Raymond A. and Helen E. St. Laurent Career Development Assistant Professor of Chemical Engineering, has won the **American Chemical Society's Faculty Fellowship Award in Solid State Chemistry**, sponsored by Exxon Corporation. The $10,000 prize is awarded by the ACS Division of Inorganic Chemistry and presented to a nontenured faculty member based on past and current contributions to knowledge of synthesis, reactivity, structure, and bonding in solids. Professor Ying's award recognizes her work on synthesis and catalytic properties of nanocrystalline, nonstoichiometric oxide catalysts; derivation of a novel class of transition metal oxide molecular sieves; and structure and properties of layered transmission metal molybdates. Professor Ying's research on using tailored catalysts in the photocatalytic cleanup of organic wastes was described in the July–December 1996 issue of *e-lab*.

Last summer the **Liberty Science Center,** located in Jersey City opposite the Statue of Liberty, asked the Energy Laboratory to help in planning a new permanent exhibit on energy and in reviewing the accuracy of its content. The exhibit, funded by a $1 million donation from Exxon, was to be interactive, learning-oriented, robust (hordes of schoolchildren would be coming through), and exciting. Dr. Elisabeth Drake, associate director of the Energy Laboratory, contributed by working as part of the team that planned the exhibit. The **"E-Quest" exhibit** opened November 18. It has five modules: atmospheric energy (solar, wind); biosphere (fossil, biomass); geological (geothermal, hot dry rock, magma); nuclear (fission, fusion); and water (hydro, tidal, wave, ocean thermal). The water exhibit, for example, contains a 20-foot wave tank with a hand-cranked wave generator. Along the tank are hand-controlled energy conversion devices such as an underflow variable-depth-and-pitch waterwheel and a bobbing "duck." Both devices are connected to meters that show energy-generation rates. Ralph Appelbaum, designer of the Holocaust Museum, managed the design of the exhibit. The exhibit is staffed by retirees from Exxon who volunteer their time.

PUBLICATIONS AND REFERENCES

The following publications of Energy Laboratory and related research were released during the past period or are cited as references in this issue. An order form for the **MIT Joint Program on the Science and Policy of Global Change** is available by request to the MIT Joint Program on the Science and Policy of Global Change, Publications, Room E40-271, Cambridge, MA 02139-4307, tel.: 617-253-7492; fax: 617-253-9845; e-mail: tzh@mit.edu. **MIT theses** may be ordered from the Library Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from Energy Laboratory Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, *only* if a price is assigned and *only* if prepaid by check payable to "MIT Energy Laboratory." 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.

Reports and Working Papers

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NEW AND RENEWED PROJECTS, OCTOBER–DECEMBER 1997

Topic	**Donor or Sponsor**	**Investigators (*Department*)**
GIFTS AND CONTRIBUTIONS		
CEEPR membership	Texaco, Inc.; Tractebel SA	
NEW PROJECTS		
Comparative Study on Energy R&D Performance Case Studies	Central Research Institute of Electric Power Industry	H. Herzog *(Energy Laboratory)*
CONTINUING PROJECTS		
Center for Airborne Organic Compounds Symposium (July 1997)	Exxon Corp.; Health Effects Institute; Shell Oil Co.	J. Howard *(Chemical Engineering)*
Consortium on Lubrication in Internal Combustion Engines	Dana Corp.; Mahle GmbH; PSA-Renault	V. Wong *(Energy Laboratory)* J. Heywood *(Mechanical Engineering)*
Sloan Lab Consortium	General Motors Corp.	J. Heywood *(Mechanical Engineering)*
Synthesis and Optimization of Chemical Processes	US Department of Energy (DOE)	P. Barton L. Evans *(Chemical Engineering)*
National Advanced Drilling and Excavation Technologies (NADET) Program	US DOE	J. Tester *(Energy Laboratory and Chemical Engineering)*
Research Study on Ocean Disposal of CO_2	US DOE	E. Adams *(Civil and Environmental Engineering)* H. Herzog *(Energy Laboratory)*
Experimental Investigation of the Fuel Distribution in Gasoline SI Engines	Sandia National Laboratories	S. Hochgreb J. Heywood W. Cheng *(Mechanical Engineering)*

Note: CEEPR = Center for Energy and Environmental Policy Research

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Massachusetts Institute of Technology
Energy Laboratory
Room E40-479
Cambridge, Massachusetts 02139-4307

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