

## Laboratory for Energy and the Environment

The Laboratory for Energy and the Environment (LFEE) brings together collaborating faculty and staff from 14 departments to address the complex, long-term, multifaceted problems of energy supply and use and of sustainable development. LFEE multidisciplinary teams work not only on technological solutions but also on the economic, political, and social aspects associated with their realization. LFEE aims to foster constructive relationships between industry, governments, academia, and the public to understand and seek solutions to long-range energy and environment issues. LFEE works to build better understanding of the many issues between and among developed and developing nations that arise in the context of meeting global energy supply and environmental challenges. A central theme running through all of LFEE's initiatives is the role of science and technology in shaping better energy and environmental policy at all levels, in both the public and private sectors. The education program of LFEE is committed to educating the next generation of energy and environmental leaders worldwide via joint projects, locally and nationally, and through participation in international education programs with our partners around the world.

LFEE is codirected by Professor David H. Marks of the Engineering Systems Division (ESD) and the Department of Civil and Environmental Engineering (CEE) and Professor Ernest Moniz, also of ESD and of the Department of Physics. They are supported by Professor Jeffrey Steinfield (Chemistry), director of the LFEE Education Program; Stephen Connors, coordinator of multidisciplinary research; Dr. Teresa Hill, assistant director for communications and programs; and administrative officer John O'Brien.

### Highlights

In May 2006, the Institute community participated in a daylong energy forum showcasing MIT energy research. The MIT Energy Research Council (ERC) distributed its report, the result of months of intensive work by the 16-member group chaired by Professor Moniz and Professor Robert C. Armstrong (Chemical Engineering). The report recommended multidisciplinary, multi-investigator, multiyear research programs that address important energy supply and use issues and that build on MIT's strengths in science, engineering, and policy. It also made organizational recommendations to facilitate effective implementation of the energy research programs. Details of the Energy Forum and the full text of the report, along with other news regarding energy studies at MIT, may be found at the ERC website <http://web.mit.edu/erc/>.

The ERC also sponsored a series of colloquia in which leading commentators on the future of energy were invited to orient MIT faculty, students, and staff about facts and positions characterizing the national discussion. Speakers in LFEE-cosponsored colloquia included Steve Koonin, chief scientist at British Petroleum ; Lee Lynd, professor of engineering at Dartmouth College, who discussed the potential of biomass; and Amory Lovins, founder and CEO of the Rocky Mountain Institute, a nonprofit organization fostering the efficient and restorative use of resources. In addition, the ERC cosponsored the Chemical Engineering department's annual Hottel Lecture, delivered this year by Samuel Bodman, US Secretary of Energy.

The appointment of Professor Moniz to the LFEE codirectorship, the establishment of the ERC, and the organization of the AGS Near-Term Pathways to a Sustainable Future Program reflect MIT's new focus on growing international concerns about the sources and uses of energy to meet increased demand while protecting the environment. LFEE-affiliated scholars in a variety of disciplines have been at work on the complex interrelationships between energy and the environment as well as other global environmental challenges to sustainable development since the Lab's founding in 2001.

In December 2005 the MIT Industrial Liaison Program sponsored the 2005 MIT Energy Challenges Workshop: Igniting New Ideas for Sustainable Energy. The workshop was structured as a vehicle for industry to provide input to the ERC. Over 130 participants from industry and academia met to exchange ideas on how to meet future energy demands while reducing greenhouse gases. They considered single technologies in depth and also across technologies to see how their use and improvement might lead to better management and policy formation.

In January 2006 Richard A. Sears joined LFEE for three years as visiting scientist from Shell International Exploration and Development. This appointment will strengthen ties between the MIT and Shell research communities and enhance opportunities to develop innovative solutions to the world's energy problems. Shell has committed roughly \$4 million in research funding to MIT in areas related to exploration and production. Sears, who has served most recently as Shell's vice president for exploration and deep-water technical evaluation, has been an enthusiastic and valuable participant in LFEE events since his arrival.

Dr. Daniel R. Cohn, senior research scientist and head of the Plasma Technology Division at the MIT Plasma Science and Fusion Center, has recently joined LFEE through a joint appointment. His research interests include plasma-enhanced reformation of hydrocarbon fuels into hydrogen; compact plasmatron fuel reformers; applications of onboard generation of hydrogen for diesel engine emissions reduction and clean, high efficiency gasoline engine operation; and plasma-enhanced reforming of biofuels. At LFEE, he has initiated work on infrastructure required for diesel exhaust cleanup and on direct use of biomass.

The LFEE research volume for FY2005 was \$6.6 million including sponsored research and fund accounts. LFEE research programs engage over 50 MIT faculty members and over 100 students annually. The Lab occupies the fourth floor of Building E40, along with the Center for Energy and Environmental Policy Research (CEEPR), the Joint Program on the Science and Policy of Global Change, the Materials Systems Laboratory (MSL), and workspace for 57 graduate students. In AY2005 LFEE attracted new faculty and additional resources to support multidisciplinary research programs and expanded its educational initiatives both locally and internationally.

Building synergy across the Institute, LFEE codirector Professor Marks cochairs the Council on the Environment with MIT's chancellor, Professor Phillip L. Clay. The Lab's weekly seminar series on global environment and sustainability issues draws participants from many research groups. The seminar series includes presentations

of work in progress on environmental challenges and technology options as well as discussions of timely issues by invited guests.

Professors Moniz and Marks are also working to advance a partnership between LFEE and a developing research center on energy, water, and environment in Cyprus. The center is intended to be part of a larger research and educational institution that will serve as a bridge between the European Union and eastern Mediterranean/Middle East region. A memorandum of understanding has been agreed on that establishes a five-year program at MIT with the central purpose of training young researchers who might subsequently join the Cyprus center.

In 2005, Melanie A. Kenerdine (vice president of the Energy Council of America) and Professor Moniz published an article on “Technology Development and Energy Security” in *Energy and Security: Toward a New Foreign Policy Strategy*, edited by Jan H. Kalicki and David L. Goldwyn. Kenerdine and Moniz describe ways in which updated security concerns must be integrated into the complex energy market and outline some priorities for action.

LFEE administers the jointly listed graduate course Sustainable Energy (22.811J/10.391J/ESD66/11/371J/1.818J/3.564J), offered for the eighth time in the spring 2006 term. Based on their research and teaching experience, course faculty including Professors Jefferson Tester (CE), Michael J. Driscoll (Nuclear Engineering), and Michael W. Golay (Nuclear Science and Engineering), Dr. Elisabeth M. Drake, and William A. Peters published an 872-page textbook *Sustainable Energy: Choosing Among Options*. LFEE faculty lectures were broadcast to Cambridge University in support of the Cambridge–MIT Institute’s MPhil in Engineering for Sustainable Development and in Technology Policy.

The Summer Air Quality Symposium Series held annually at Endicott House is also affiliated with LFEE. Proceedings from the symposia are posted on the LFEE website.

LFEE includes both core component and affiliated programs. The component programs in LFEE for FY2006 were AGS (international focus), the MIT/AGS Consortium on Environmental Challenges (focus on science and technology in environmental decision making), the Carbon Management and Sequestration Program, the Analysis Group for Regional Electricity Alternatives (AGREA), and the Political Economy and Technology Policy Group. Affiliated research programs are also supported in the Center for Advanced Nuclear Energy Systems (CANES), the Sloan Automotive Laboratory, the Building Technology Program (BTP), the Center for Energy and Environmental Policy Research (CEEPR), the MSL, and the MIT Center for International Studies.

The LFEE Education Program develops sustainability curricula and programs at Institute, local, national, and international levels. LFEE administers both the Martin Family Society of Fellows in Sustainability and the Future Energy Fellows, established in 2004 with support from Electrical Engineering and Computer Science graduates Charlene (1979) and Dirk Kabcenell (1975).

## Component Programs

### Alliance for Global Sustainability

Research and educational activities supported by AGS bring together scholars from the four partner universities (MIT, the Swiss Federal Institute of Technology [ETH], the University of Tokyo [UT], and Chalmers University of Technology, Sweden) and stakeholders from industry, NGOs, government, and other leading academic institutions to address complex environmental problems that transcend geographical and disciplinary boundaries. In March 2006 UT, in collaboration with the Asian Institute of Technology, hosted the annual meeting of AGS in Bangkok, Thailand. Approximately 300 participants attended.

AGS projects have traditionally fallen within three major focus areas: water, energy, and mobility. In addition, many of these projects addressed multidisciplinary topics such as urban systems, cleaner technologies, policies and institutions, and communications and outreach in support of sustainable development. AGS project leaders have raised more than \$20 million to supplement these projects and related sustainability research at the partner universities.

Building upon past integrated, collaborative research activities, the AGS has inaugurated a large-scale research program focused on near- and medium-term energy scenarios. The first Flagship Program, Near-Term Pathways to a Sustainable Energy Future, is comprised of a set of regional projects that focus on key energy sectors. These projects are looking in detail at how alternative portfolios of technologies and policies can affect the development of a region's energy infrastructure. The AGS has already invested in sustainability-focused energy research and can present a credible worldwide analysis while at the same time providing a neutral forum for the development of integrated scenarios that will require political and regulatory action. To increase the profile of the AGS and promote synergy among Near-Term Pathways research activities, the program will also include crosscutting communication, outreach, and learning initiatives. At the 2006 Annual, the AGS introduced plans for a second Flagship Program on food and water, Secure Ecosystem Services for a Nourished World. The program will identify development paths for social and technical systems in addressing critical issues of food and water for a burgeoning world population over the next 5 to 15 years.

In addition to its research programs, the AGS supports education and outreach initiatives to raise awareness of the important role of science and technology in meeting the sustainability challenge to future development and to equip the next generation of leaders with the knowledge and skills they need to address sustainability issues throughout their careers. The major AGS educational activity this year was the development of "Teaching Energy and Climate in the Short Course Format." In this joint project, MIT, Chalmers, UT, and ETH will each offer a one-week short course on energy and climate, with each university targeting a distinct audience. LFEE planned and offered its short course Energy and Climate: Toward Sustainable Systems for advanced undergraduate students from 10 US universities on the MIT campus in June 2006. LFEE coordinated MIT student and faculty participation in the ETH/AGS-supported international Youth Encounter on Sustainability and the UT-sponsored Intensive

Program on Sustainability. Professors David Marks and Jeffrey Steinfeld are the MIT coordinators for the AGS.

### **MIT/AGS Consortium on Environmental Challenges**

This year, the MIT/AGS worked with the international AGS program primarily in the area of energy futures and transport, with substantial support from the Ford Motor Company. Highlights of their work include the following:

- AGS Flagship Program participation at MIT places particular emphasis on sustainable mobility. Stephen Connors (AGREA) is coordinating that effort.
- Professor John Heywood, head of the Sloan Automotive Lab, has been working on analyzing the conditions that must be met to field a robust fleet of hydrogen-powered vehicles. He has also worked on other types of alternatives, including the continuing refinement of internal combustion engines. The environmental impacts and efficiency of such engines has been rising steadily.
- Professor Kenneth Oye (Political Science) has been working on what incentive structure would be most likely to encourage a major “first mover” to devote serious resources to developing diesel transport technologies.
- Howard Herzog’s program on carbon sequestration technologies continues to draw increasing amounts of attention from industry and government as a solution to controlling CO<sub>2</sub> emissions into the atmosphere at various stages of petroleum extraction and use.
- Visiting Scholar Simon Pitts of Ford Motor Company and Paul Killgoar, also of Ford, have been working with the Joint Program on the Science and Policy of Global Change (see below) on greenhouse-gas markets.
- Visiting Scientist Richard Sears of Royal Dutch Shell is working on imaging and data analysis techniques for energy exploration and development.
- The Cambridge/MIT Alliance project on energy security and competitiveness in the UK has also received Ford support.

### **Carbon Capture and Sequestration Technologies Program**

The field of carbon capture and sequestration is attracting much interest due to increasing concerns about global climate change. Our continuing work on carbon sequestration technologies focuses on three areas: assessment, education/outreach, and basic research. Howard Herzog leads this effort. Some key research thrusts include:

- An integrative assessment of carbon sequestration technologies in collaboration with Professor Jacoby and the Joint Program. The focus of the current project in this area is investigating potential penetration rates of sequestration technologies.
- The Carbon Sequestration Initiative, an industrial consortium on carbon management. Our 14 members are Alstom Power, American Electric Power, American Petroleum Institute, Aramco Services, ChevronTexaco, Electricite France, EPRI, ExxonMobil, Ford Motor Company, General Motors, Marathon Oil, Peabody Energy, Schlumberger, and Southern Company.

- An investigation of social and political factors that will affect the future of carbon capture and sequestration technologies. These factors involve siting, permitting, regulatory and environmental justice, and the like. The investigation includes an effort to develop a carbon sequestration information system (using a geographic information system [GIS] as a platform).
- A survey to determine the attitudes toward global warming and climate-change mitigation technologies, the level of public understanding of global warming and the carbon cycle, and public awareness of carbon dioxide capture and storage (or carbon sequestration). Over 1,200 people, representing a general population sample of the US, have responded.
- An economic analysis of the concept of “capture-ready” power plants.

In addition, the program has been involved in many national and international efforts related to carbon capture and sequestration. Specifically, Howard Herzog is a coordinating lead author for the Intergovernmental Panel on Climate Change Special Report on Carbon Capture and Storage, released in September 2005. He has also been designated as one of the two US technical group members for the Carbon Sequestration Leadership Forum, a ministerial-level agreement between about 20 countries to promote research into carbon sequestration technologies.

Funding for the program comes from a diverse number of sources including the US Department of Energy, private industry, NGOs, and AGS. Additional information can be found on the program website at <http://sequestration.mit.edu/>.

### **Analysis Group for Regional Energy Alternatives**

LFEE research in the area of strategic planning for energy infrastructures and environmental performance is centered in AGREA, led by Stephen Connors. The scenario-based multi-attribute tradeoff-analysis approach, developed in the 1980s by the Department of Energy’s National Renewal Energy Laboratory researchers, is the primary tool used by AGREA. Recent research projects have included the AGS China Energy Technology Program, the Mexico City Air Quality Integrated Assessment, Avoided Emissions from Solar Power Generation in the US, and a resource assessment of offshore wind energy potential in the northeastern US.

Current projects include Alternatives for the Transition to Sustainable Energy Services (TRANSES, in collaboration with Chalmers and the Norwegian University of Science and Technology in Norway), identifying long-term, low-carbon strategies for Scandinavia, and long-term energy security and environmental strategies for the United Kingdom. These and past research efforts comprise the primary toolkit being incorporated into AGS’s new Flagship Energy Research Program, described above.

To develop these and other research activities, Mr. Connors also supervises students looking at the fuel consumption and emissions impacts worsening traffic congestion, behavioral barriers to the widespread deployment of distributed generation technologies, the institutional challenges to electrification in Africa, and the application of real options to the challenge of redirecting energy investments to address the

combined challenges of climate change, economic growth, and energy security. To reflect its broadening research portfolio, AGREA changed its name from “electricity alternatives” to “energy alternatives” in 2005.

### **Political Economy and Technology Policy Group**

The Political Economy and Technology Policy Group, led by Professor Kenneth Oye, is a joint program of the LFEE and the Center for International Studies. Its purpose is to identify means to improve the quality of public and private responses to critical environmental problems by combining expertise on problems of political economy with fundamental understanding of scientific and technical issues. The group’s research focuses on two key areas for improving environmental decision making.

The first area is the use of scientific information in public policy making. The intent is to identify methods for more robust and integrated assessment of policy options and for credible assessment of risk in areas of environmental policy controversy, and to improve the capacity of political institutions to adapt to new information. Research has been conducted on the improvement of responses to uncertainty associated with the environmental, security, and economic effects of rapid technological change; the private effects of public environmental policies, with specific attention to the competitive position of firms, sectors, and nations; and links among regulation, the utilization of technologies, and industrial structure.

Additionally, the group has worked with scientists and engineers to ensure that assessments of technical options include analyses of political and economic constraints and opportunities. Members of the group worked with the LFEE project on Carbon Sequestration and with the Joint Program on Science and Policy of Climate Change assessment of developing country CO<sub>2</sub> options.

### **Affiliated Groups**

Faculty in several MIT centers, programs, and laboratories pursuing interdisciplinary energy and environmental activities are affiliated with LFEE through the financial administration of some projects, and through research and educational activities shared through the LFEE component programs listed above.

### **Building Technology Program**

Research in the Building Technology Program (BTP) has as its principal focus energy efficiency and sustainable design for buildings. In the US, buildings consume almost 40 percent of the total energy and more than two-thirds of all electricity used. The long life of buildings and the difficulty of renovation mean that mistakes in today’s buildings will create energy and environmental problems for much of this century. In many instances, investment in new energy efficiency technologies for buildings is more cost-effective than investment in new energy production facilities. If done properly, energy-efficient and sustainable design will also lead to better indoor health, comfort, and productivity. It has been frustrating to deal with the lack of focus from the federal government in this area. MIT facilities also need attention. There is a growing consensus to develop leading-edge economic, energy-efficient buildings on the MIT campus.

Four of the five faculty members in the program have had input into our energy research and teaching: Professors Marilyn Andersen, John Fernandez, Leon Glicksman, and Les Norford, all of the Department of Architecture. Professor Andrew Scott of the Architecture faculty is also a member of our group and is active in many of our projects. Many of the activities involve substantial joint efforts with faculty members and students in CEE, Electrical Engineering and Computer Science, and Mechanical Engineering as well as Harvard School of Public Health, Cambridge (UK), Chalmers (Sweden), ETH (Switzerland), and Tsinghua University (China). Typically we have 15 to 20 graduate students carrying out building technology research. Some students receive degrees in the Department of Architecture, others in the School of Engineering.

Several major projects, discussed below, are under way or were recently completed.

### ***Natural Ventilation of Commercial Buildings***

When natural ventilation is properly designed and operated, indoor air quality is improved and a substantial portion of the energy used for cooling can be saved (typically 33–50 percent in Boston and up to 100 percent in the UK). A joint project with Cambridge University under the Cambridge-MIT Institute program includes the development of basic models to predict the airflow and thermal conditions in complex open plan buildings under buoyancy and wind forces. In addition, BTP faculty members have done one of the first detailed monitorings of a large commercial naturally ventilated building during occupancy, and are developing proper similitude rules to allow small-scale experiments to closely simulate large buildings. We have also developed methods for in situ measurement, modeling, and control of building performance, with the goal of optimally cooling buildings when outdoor temperatures permit, as is often the case at night.

### ***Design Tools***

Currently, energy studies are lengthy and costly and typically are not undertaken until a building's design is near finalized form. Simple web-based tools are under development that will allow designers to get realtime feedback of design scenarios during the conceptual design phase. Advanced technologies such as double skin facades and natural ventilation are simulated in the tool. Recent additions include a real time (one to two minute running time) optimizer that considers the optimum choice of up to 30 different design parameters to yield the lowest yearly energy consumption for heating, cooling, and lighting. In a parallel effort, a design tool is being developed for material selection that allows a designer to screen conventional and newly developed materials and trade off characteristics such as embodied energy and nonrenewable content.

### ***Fault Detection, Monitoring, and Control***

Studies in Texas have shown that better commissioning of HVAC equipment and ongoing detection of major problems reduced energy consumption by over 20 percent in over 100 buildings. BTP researchers are working with EECs Professor Steven Leeb on techniques to detect faults in and monitor the performance of a wide range of HVAC equipment in buildings and ships, using high-speed electrical measurements and signal processing.



### ***Sustainable Buildings for Developing Countries***

The largest increase in energy use and CO<sub>2</sub> production is occurring in the developing world. Each year China is building upwards of 10 million housing units. In a recently completed project we worked with Chinese developers, architects, and academics at Tsinghua to develop technical solutions and building designs appropriate to Chinese buildings. This was supplemented by design workshops in China, and will culminate in a book to be published by the end of this year.

In earlier projects in the developing world, BTP scholars developed a low-cost retrofit insulation that could be used in the mountainous regions of Pakistan. They also analyzed village houses in India, where lack of kitchen ventilation poses a serious problem to women and children.

### ***Daylighting***

Energy for lighting is the larger segment of energy use in a commercial building. The level of daylight in the outdoors is one to two orders of magnitude higher than that required within a building. A new faculty member is leading our efforts to develop innovative materials and systems to bring daylighting deeper into commercial buildings. In most cases this would be more efficient than using photovoltaics to generate electricity for conventional lighting systems.

### ***Real Options***

Option theory has been applied to determine the value of flexibility in the initial building design. This flexibility allows the option of less costly future renovations such as the installation of chillers to supplement natural ventilation if global warming causes more severe summer conditions.

### ***MIT Facilities***

Several design projects have been carried out to evaluate advanced techniques to substantially improve the energy efficiency and performance of MIT buildings. These include control optimization, exterior wind conditions around the Stata Center, and use of displacement ventilation (based on the US design guidelines for this technology developed by the BTP group).

### ***Education***

Our group offers a number of subjects with an energy focus to both graduate and undergraduates. These include lecture, laboratory subjects, and design workshops.

### ***Center for Advanced Nuclear Energy Systems***

LFEE administers two research projects in the Center for Advanced Nuclear Energy Systems (CANES). Dr. Pavel Hejzlar is investigating fundamental thermal-hydraulic phenomena for advanced gas-cooled reactor applications. Professor Jacopo Buongiorno is studying water-based nanofluids for nuclear systems applications. Both projects are sponsored by Battelle Energy Alliance, LLC.

CANES develops research concepts for nuclear energy systems that promise more favorable economics, safety, proliferation resistance, and environmental impact. The Center's programs involve development and application of methods for the design, operation, and regulation of current and advanced nuclear reactors and fuel cycles. Professor Mujid S. Kazimi is the founding and present director of CANES. Information on CANES extensive research and outreach activities may be found at <http://web.mit.edu/canes/>.

A two-day symposium on Innovative Nuclear Technology was held in November 2005, and a two-day symposium on the R&D Needs of Advanced Nuclear Energy Systems was conducted in March 2005. (Electronic proceedings can be ordered on the web at <http://web.mit.edu/>

[canes/symposia/symposia.html](http://web.mit.edu/canes/symposia/symposia.html).) CANES faculty also offered three short summer courses on Nuclear Plant Safety, Reactor Technology for Utility Executives, and Reliability in Operational Decision Making on Degradation of Materials in Radiation Environments.

### **Sloan Automotive Laboratory**

A significant amount of LFEE's research volume supports work at the Sloan Lab. Many of the laboratory's projects involve quantitative and crossdisciplinary study of complex energy and environmental systems. The laboratory is directed by Professor John Heywood, with participation from Professors Wai Cheng, Doug Hart, James Keck, and William Green, and Dr. David Schmidt, Dr. Tian Tian, and Dr. Victor Wong. It continues to pursue promising research to improve engine performance, efficiency, and fuel utilization in internal combustion engines and reduce adverse emissions.

Focusing on new engine and fuel technologies, the Engine and Fuels Research Consortium continues to explore critical fuel/air mixture preparation and emission formation mechanisms in developing engine concepts, with potential application to both gasoline and diesel engines. Complementing the engine and fuels studies, the Consortium on Lubrication in Internal Combustion Engines involves major engine component and lubricant manufacturers in addressing issues in oil consumption and engine friction reduction. Members in these consortia also sponsor separate research projects on related topics of specific application to the individual sponsors. For example, Professors Wai Cheng and John Heywood work with Ford Motor Company on three projects related to engine transients: fuel/air mixture preparation behavior during start up, emission benefits of engine operation in hybrid electric vehicles, and actual in-use vehicle emissions in stop-and-go traffic. A new consortium with 10 members, focused on developing low ash-producing lubricants to enable significantly improved diesel emission control, has been formed with strong support from the diesel engine industry.

Sloan Laboratory researchers are also involved in multidisciplinary studies assessing new vehicle and propulsion system technologies for future road transportation use. For example, Dr. Daniel R. Cohn, Professor Heywood, Dr. Leslie Bromberg, and others in LFEE and the Plasma Science and Fusion Center have been working on a half-sized

gasoline engine with fuel and emissions efficiency close to today's hybrid engines at a much lower cost using a new ethanol technology.

### **Center for 21st Century Energy**

Also directed by Professor Heywood, the Center for 21st Century Energy is part of the Department of Mechanical Engineering. The Center is encouraging scholars to undertake research in technologies likely to contribute to the broad-based, multidisciplinary assessments and analyses undertaken at LFEE. According to Professor Heywood, "There needs to be a steady stream of people who get involved, especially new people who bring different engineering expertise to these multidisciplinary activities."

An example of how Center and LFEE activities interact is in the assessment of hydrogen infrastructure issues now underway at LFEE. Professor Yang Shao-Horn's research on fuel cells and advanced batteries and Professor Heywood's expertise on the comparative advantages of vehicle technologies using hydrogen are essential to this study.

### **Center for Energy and Environmental Policy Research**

The Center for Energy and Environmental Policy Research (CEEPR) is an activity jointly sponsored at MIT by LFEE, the Department of Economics, and the MIT Sloan School of Management. CEEPR funds policy-related research in energy and environmental economics. The center receives financial support from corporate sponsors and government agencies such as the US Environmental Protection Agency and the US National Oceanic & Atmospheric Administration.

CEEPR research, administered through LFEE, is focused on evaluating the functioning and performance of markets created for environmental services and for electricity and associated network services. Past environmental research has been concerned with emissions trading, with particular attention to the US SO<sub>2</sub> Allowance Trading Program and the Northeastern NO<sub>x</sub> Budget Program. Recent work includes analysis of the market for carbon created under the European Emissions Trading System. The electricity research is concerned with restructuring decisions with respect to asset ownership, transmission access, and customer choice. CEEPR is also involved in evaluating the future of nuclear and coal energy, and in the development of markets for oil and natural gas and renewables. Research includes analysis of financing large-scale investments as well as the price dynamics and risk in these markets.

### **Joint Program on the Science and Policy of Global Change**

This program, codirected by Professor Jacoby of the MIT Sloan School of Management and Professor Prinn of the Department of Earth, Atmospheric, and Planetary Sciences, draws on MIT's traditional strengths in science and economics to conduct the serious interdisciplinary work needed to provide a basis for global climate policy. Currently administered through LFEE, the now 15-year-old Joint Program is one of the world's leading centers for the integrated assessment of climate change. An MIT Integrated Global Systems Model, developed by program researchers, provides a facility for research on the climate issue and assessment of policy proposals. An interdisciplinary team of faculty, professional staff, and graduate students carries out the work, and it

produces a continuing flow of reports, articles, student theses, and professional and public presentations on the science and policy of global warming. Five US government agencies, 23 corporate sponsors in North America, Europe, and Japan, and one foundation support the work.

### Education and Curriculum Initiatives

The mission of the LFEE Education Program is to enhance energy and environmental literacy and to deepen multidisciplinary knowledge on energy and the environment, particularly among the leaders of tomorrow's science and technology communities. The program is dedicated to increasing awareness of the complexity of energy, environmental, and sustainability challenges, and to increasing society's capacity to respond effectively to these challenges. A special challenge of the mission of the LFEE Education Program is to ensure that environmental issues and concerns are part of the education of every MIT student, not just those who will become environmental scientists, engineers, and planners. Professor Jeffrey Steinfeld (Chemistry) directs the LFEE Education Program; Dr. Amanda Graham is program manager.

Major campus initiatives during the past year include:

- Establishing the Martin Family UROP program to support undergraduate research on sustainability issues in coordination with graduate Martin Fellows. Up to 10 undergraduate student UROP semesters will be supported each year for the next three academic years. Martin Family UROP students will participate in the annual Martin Fellows induction dinner and share findings from their work at a spring poster event.
- Planning and Implementing Energy and Climate: Toward Sustainable Systems, a one-week short course for advanced undergraduates from 10 US universities, sponsored by AGS.
- Developing and launching EnergyClasses, a web-based listing of energy classes, in coordination with the Education Subcommittee of the Energy Research Council, viewable at <http://energyclasses.mit.edu/>.
- Completing the first Campus Sustainability UROP project in cooperation with the Environmental Programs Office and Professor Leon Glicksman. Monica Lewis (2006) completed "The Case for Green: NW35 at MIT," and presented findings of her work researching green dorms to MIT housing administrators and facilities representatives.
- Advising first-year students via the Freshman Advising Seminar 1.A25 Greening Our Garbage: Talking Trash at MIT.
- Offering an IAP class exploring the challenges of local climate change policy. LFEE Education Program coordinator Beth Conlin and Dr. Graham cotaught the IAP course Energy and Climate in Cambridge (formerly Implementing the Cambridge Climate Protection Plan) for the fourth consecutive year. The students researched the feasibility of small-scale wind and biodiesel conversion projects for the MIT campus and presented their analysis and recommendations.

- Bringing together leaders from 13 MIT student groups related to energy, environment, and sustainability to network and plan for future collaboration.
- Preparing Energy, Environment and Society, a pilot project based subject for first-year students with support from the d'Arbelloff Fund for Excellence in Education. The subject will be offered in spring 2007 and will involve students in all aspects of community-based energy management projects.

In addition, the Program continues to:

- Manage fellowship programs for scholars in sustainability, including the Martin Family Society of Fellows for Sustainability, for outstanding upper-level MIT graduate students. Professor of Chemistry and 2003 winner of the Italgas Prize for Energy and the Environment Daniel Nocera addressed the Martin Fellows at their annual induction dinner in September. The program coordinates an Environmental Fellows Group to engage all environmental fellows at MIT; activities this year included a retreat on offshore wind energy at the Woods Hole Oceanographic Institute and a fellow-to-fellow research exchange.
- Support efforts by the MIT Council on the Environment to improve coordination and coherence among academic, research, and activity offerings for undergraduates, including coordinating with Admissions, Careers, and Orientation to better serve prospective students and future alumni. The Program co-hosted MIT's second Environmental Careers Panel in January with the MIT Career Office.
- Upgrade and maintain enviroClasses, a web-based index of MIT subjects with environmental content, viewable at <http://enviroclasses.mit.edu/>.
- Support and participate in the development of subjects and programs for environmental majors and graduate students.
- Participate in campus-wide events such as the International Development Forum, Campus Preview Weekend, and MIT's Earth Day celebration, and serve as MIT host for community events such as the Junior Solar Sprint.

**David H. Marks, Codirector and Morton and Claire Goulder Family Professor of Engineering Systems and Civil and Environmental Engineering**

**Ernest J. Moniz, Codirector and Cecil and Ida Green Professor of Physics and Engineering Systems**

*More information about the Laboratory for Energy and the Environment can be found at <http://lfee.mit.edu/>.*