

MIT Energy Initiative

The MIT Energy Initiative (MITEI) is an Institute-wide initiative designed to help transform the global energy system to meet the challenges of the future. In its first three years of operation, MITEI has attracted more than \$300 million from industry and public partners as well as private donors to fund critical energy research and education to enhance the environmental performance of conventional energy sources and to enable a sustainable energy future through transformational technologies.

Fiscal year 2010 was another year of institutional growth and expanded activity for MITEI. Key achievements included:

- Building robust research partnerships and networks with 59 industry and public MITEI members, 24 of which signed in the past fiscal year
- Attracting sponsored research and other research support totaling approximately \$300 million in commitments over five years
- Winning six awards—the most of any university—in the first three rounds of Advanced Research Program Agency-Energy (ARPA-E) funding for transformational research in energy
- Leading MIT's participation in proposals for all three of the first Department of Energy (DOE) Energy Innovation Hubs (Hubs)
- Coordinating MIT's efforts for the Energy Frontier Research Center DOE program, with MIT receiving two large, high-impact awards
- Supporting through its Seed Grant Program 67 early-stage research proposals, with total funding of more than \$8.4 million
- Releasing the interim report, *Future of Natural Gas*, to decision makers at a press conference in Washington, DC
- Growing the Society of Energy Fellows at MIT to more than 120 members with the designation of the 2010–2011 cohort of graduate students representing 19 departments and all five schools
- Launching the energy minor at MIT, enhancing the energy educational opportunities for MIT students
- Initiating the Low Carbon Energy University Alliance (LCEUA), a three-way collaborative research initiative with Cambridge University and Tsinghua University
- Building the Sustainable Energy Revolutions Program, a multifaceted program within MITEI that supports renewable low-carbon energy research and related integrated policy studies
- Pursuing partnerships in energy education and research with China, India, and the developing world
- Opening the headquarters for the Eni-MITEI Solar Frontiers Research Center

- Producing, in whole or as co-sponsor, some 30 energy-related seminars, colloquia, and special events including a visit to MIT by President Barack Obama
- Supporting a range of student projects to improve energy and environmental management

MITEI seeks support from partners in industry, private donors, and some public institutions to support a broad portfolio of energy research. Private support of energy research is a key link in the research value chain, as is federal funding of energy research. Cooperation among academia, industry, and government is essential for meeting global energy needs, addressing climate change from fossil fuel combustion, and transforming global energy systems.

MIT president Susan Hockfield is actively engaged at the national level in raising awareness of the importance of federal investment in energy research and development in the United States. The Institute—with its outstanding students, faculty, and staff, its commitment to excellence and innovation, and its exceptional capabilities—is well positioned to make a major contribution to meeting global energy and environmental needs. These impacts would be enhanced if the pool of energy research dollars were to grow.

MITEI's leadership team includes its director, professor Ernest Moniz (Physics and Engineering Systems); its deputy director, professor Robert Armstrong (Chemical Engineering); its executive director, Melanie Kenderdine; and its associate director, Robert Stoner. The directors are members of the Energy Council that helps shape MITEI policy directions. The council also includes professor Angela M. Belcher (Materials Science and Engineering and Biological Engineering), professor Vladimir Bulovic (Electrical Engineering and Computer Science [EECS]), Institute Professor John M. Deutch (Chemistry), professor Leon R. Glicksman (Architecture and Mechanical Engineering [ME]), and professor Richard Schmalensee (Sloan School of Management).

The External Advisory Board provides strategic direction for MITEI and MIT's energy research. The board, composed of industry, academic, nonprofit, and public sector leaders, is chaired by George Shultz. The board met for the third time in October 2009.

Mission

MITEI is designed to mobilize the Institute's research and educational capabilities to help meet the world's most pressing energy challenges. MITEI's interdisciplinary research program and related education and campus-wide activities focus on:

- Innovative technologies and underlying policy analysis that will improve how we produce, distribute, and consume conventional energy
- Transformational technologies to develop alternative energy sources that can supplement and displace fossil fuels, including the economic, management, social science, and policy dimensions needed for this transformation

- Global systems to meet energy and environmental challenges through a multidisciplinary systems approach that integrates policy, design, and technology development
- Tools to enable innovation, transformation, and simulation of global energy systems through strategic basic research

Industry Research Partnerships

Consistent with MIT's history of engaging with industry, MITEI reflects the understanding that robust research partnerships between academia and industry are highly effective vehicles for transforming the global energy marketplace.

Achieving these outcomes through specific research programs involves multiple academic disciplines and personnel, supported by an infrastructure that maximizes opportunities for MITEI's industry partners. MITEI aggregates MIT's research capability, innovation, expertise, and experience in successful industry collaborations to help meet its research partners' key strategic objectives. A multitiered membership structure enables private-sector partners to sponsor multidisciplinary, multiple-faculty "flagship" research programs; contribute to a range of energy-focused MIT labs, programs, and centers; support innovative energy concepts from proposals solicited across the campus; participate in MITEI-organized seminars, lectures, and colloquia; and fund critical energy fellowships. In the past year, in addition to 16 new affiliate members, MITEI has welcomed sustaining members Lockheed Martin, Saudi Aramco, and Weatherford International and associate members Hess, Cummins, Entergy, and the Agencia Nacional de Hidrocarburos–Colombia.

In the past year, MITEI selected the fourth and fifth groups of projects submitted by MIT faculty and senior researchers to receive Seed Fund Program research grants. In the June 2010 round of seed funding, MITEI awarded a total of \$1.9 million to 13 projects, each lasting between one and two years. Funded projects span 10 MIT departments, laboratories, centers, and institutes. Funding for the new grants comes chiefly from MITEI's founding and sustaining members, supplemented by funds from the Chesonis Family Foundation, an anonymous donor, and MITEI. The program supports innovative early-stage research projects addressing energy and related environmental issues. New grants are awarded twice annually.

Eni-MITEI Solar Frontiers Center

In spring 2010, the Italian energy company Eni and MIT officially opened new headquarters for their major energy partnership, the MITEI Solar Frontiers Center. The laboratories in the center focus on the development of advanced solar technologies, from novel photovoltaic materials to the design of solar power plants. Eni's founding-member commitment of \$50 million over five years will include \$25 million for the center.

The Eni-MITEI Solar Frontiers Center includes the following focus areas:

- Nanostructured thin-film photovoltaics

- Self-assembling photovoltaic materials
- Artificial leaves
- Materials genome
- Maximizing the return on investment for solar thermal plants
- Paper-thin solar cells

Professors Daniel Nocera (Chemistry) and Vladimir Bulovic (EECS) have been named the first science codirectors of the program, while professor Clifton Fonstad (EECS) has been named the program's executive director.

Another element of Eni's founding-member research portfolio is the investigation of evaluation methodologies for the commercial potential of energy startups and novel energy technologies.

Solar Revolution Project

While not formally a part of MITEI, the Solar Revolution Project, initiated by a \$10 million gift from the Chesonis Family Foundation, is a key component of the growing solar research cluster at the Institute and will leverage MITEI-supported programs. The objective of the project is to transform solar power from a "boutique" option to an affordable, dependable, large-scale energy solution through research into innovative materials and systems. In 2010, the Solar Revolution Project was further bolstered by a \$1.5 million gift from Doug and Barbara Spreng, designated to fund additional work in solar conversion and energy storage technologies.

Federally Funded Energy Research Programs

MITEI actively supports the development of federally sponsored energy research programs at the Institute through information dissemination, consortium building, strategy support, and proposal development. Building on the Institute's success in 2009 in launching two Energy Frontier Research Centers supported by the DOE, MIT has received multiple awards from two new DOE programs: ARPA-E and Hubs.

ARPA-E focuses on creative out-of-the-box transformational energy research to mitigate the environmental impact of energy production and consumption, improve energy security, and improve national technological competitiveness. MIT won a staggering six awards in the inaugural three rounds of ARPA-E funding, two of which MITEI submitted. These were:

Electrochemically Mediated Separation for Carbon Capture and Mitigation (T. Alan Hatton, Howard Herzog): An MIT-led team including Siemens will develop an electrochemically mediated separation processes for post-combustion CO₂ capture at coal-fired power plants. Electrochemical separation offers a nonthermal approach to carbon capture with anticipated benefits including greatly increased energy efficiency for carbon dioxide capture, easier retrofitting of existing coal-fired power plants, and simpler integration with new facilities. The project will involve molecular modeling and experimental optimization of carrier structure, fabrication and evaluation of prototype separation units.

Engineering Ralstonia eutropha for Production of Isobutanol Motor Fuel from CO₂, H₂, O₂ (Anthony Sinskey): This project relies on microbes that use hydrogen to convert carbon dioxide into liquid transportation fuels. The project will develop a system using *Ralstonia eutropha* to redirect carbon flux to butanol production in a novel bioreactor system with increased performance.

The remaining four MIT projects granted ARPA-E awards were:

- Electroville: High-Amperage Energy Storage Device-Energy Storage for the Neighborhood
- Semi-Solid Rechargeable Power Sources–Flexible, High Performance Storage for Vehicles at Ultra-Low Cost
- Bioprocess and Microbe Engineering for Total Carbon Utilization in Biofuel Production
- Advanced Technologies for Integrated Power Electronics

For the DOE Energy Innovation Hubs, MIT participated in proposals for all three of the inaugural Hubs: *Modeling and Simulation for Nuclear Reactors* (partner on Oak Ridge National Laboratory–led proposal), *Fuels from Sunlight* (partner on National Renewable Energy Laboratory–led proposal), and *Energy Efficient Building Systems* (lead applicant). These large centers (\$22 million per year) are designed to bring together a variety of disciplines to advance highly promising areas of energy science and engineering from basic science through to demonstration and transition to industry.

By the end of the fiscal year, only the Hub for Modeling and Simulation for Nuclear Reactors had been awarded and was given to the Oak Ridge National Laboratory–led proposal in which MIT is a core partner. This Hub will allow engineers to create a simulation of a currently operating reactor that will act as a “virtual model” of that reactor. They will then use the virtual model to address important questions about reactor operations and safety. This will be used to address issues such as reactor power production increases and reactor life and license extensions. The combination of data gained from the virtual model and the physical reactor will be used to resolve technology issues confronting nuclear energy development in the near, mid, and long terms.

International Initiatives

MITEI has made a significant effort this year to foster research and educational ties between MIT and international universities, especially those in countries with developing and rapidly emerging economies. Our objective is to foster funded research by MIT faculty in areas of high global concern related to energy and the environment such as carbon capture and sequestration, and grid scale renewable power generation. We hope to encourage research on topics that get relatively little attention in the United States and other wealthy countries with their established infrastructure and markets—for example, efficient small-scale power grids, biofuel production from waste biomass, and low cost water treatment—but are of serious concern in poorer countries with more limited capital and natural resources, higher population densities, and accelerating demand for modern energy services.

In November 2009, the Institute launched a three-way collaborative research agreement with Cambridge University and Tsinghua University under the banner of LCEUA. The alliance will fund research at all three institutions in areas of significant global concern, many of which have special urgency for China with its rapidly expanding cities, world-leading greenhouse gas emissions, burgeoning automotive fleet, and dependence on heavy industry. LCEUA's six research focus areas will be clean coal technology (including carbon capture and sequestration), biofuels, energy efficient buildings and cities (including transportation systems), nuclear energy, waste heat recovery, and low carbon energy and economic scenarios.

More recently, MITEI has begun to formulate similar programs with universities and research institutes in other parts of the world, including India, Africa, Central and South America, and Southeast Asia. The approach in each case has been to build programs around competitively awarded research grants available to teams that must include faculty from both MIT and partner country institutions. The intent is to foster world-class research while providing important training opportunities for talented students and postdoctoral fellows from MIT and from around the developing and developed world.

Low Carbon Energy University Alliance—China

Just six months into its first year of operation, LCEUA has already carried out its first research competition, having made three-year awards to three groups including MIT faculty. The MIT projects will focus on novel carbon capture technology, urban scale geothermal energy extraction, and biofuels production from sorghum. The alliance partners expect to conduct further competitions at least annually, making approximately a dozen new awards each year.

Developing Countries

Benefitting from MIT's well-established ties to the World Bank through our alumni and faculty, MITEI is working to build further alliances in some of the world's poorest countries. Our objective is to formulate an informed partnership program emphasizing collaborative research and university-level science education that complements national development strategies and ongoing World Bank programs. To help identify areas of common interest and complementary strength, MITEI led a joint meeting introducing faculty and their work to World Bank staff this spring in Washington, DC. The meeting was jointly opened by President Hockfield and World Bank president Robert Zoellick. MITEI external advisory board member and World Bank managing director Ngozi Okonjo-Iweala PhD '81 played a key role in organizing the meeting. MITEI is now working with senior World Bank staff to formulate an integrated partnership program which we hope to pilot in one or more of the bank's client countries.

Earlier this year, MITEI provided a grant to establish SP.775 D-Lab: Energy, a new D-Lab subject designed to teach undergraduate students about the energy challenges faced by developing countries. The class, which was over-subscribed, was offered for the first time in the spring term in parallel with a similar class for graduate students at the Masdar Institute. As part of the class, MIT students traveled to Nicaragua during spring break to work with local nongovernmental organizations on a variety of energy projects

and Masdar students traveled to Borneo. MITEI is seeking to raise donor contributions to significantly expand D-Lab: Energy in future years.

India

At the invitation of MIT alumni and Energy Advisory Board member Baba Kalyani, MITEI representatives paid a weeklong visit to India in February, during which they met with representatives from several universities, members of the Confederation of Indian Industry, and government ministers. MITEI is now working with a group of leading Indian entrepreneurs to create the India-MIT Clean Energy Initiative, which will seek to catalyze world-class renewable energy research in India. This initiative is expected to benefit Indian industry directly, by enabling the development of intellectual property of high practical and commercial value, as well as indirectly, by helping to create a pool of highly trained indigenous scientific and engineering talent from which industry can draw.

The Indian initiative will address a broad range of topics related to energy and its impact on the environment, and particularly the energy challenges faced by India's rural population. Research programs will be established in four topic areas: solar energy, bioenergy, energy in the built environment, and the IT-energy nexus. Drawing on the LCEUA model, the initiative will make competitive research seed grants to combine teams of MIT and Indian researchers, and award postdoctoral fellowships to Indian graduates for study in India and at MIT. Projects will be conducted jointly by MIT and Indian researchers.

Interdisciplinary Studies

An important MITEI activity spanning research and outreach is the formation of projects in which groups of MIT faculty, research staff, and graduate students with input from public and private experts devote two years of study to the prospects of alternative energy sources to meet future demand in a marketplace conditioned by CO₂ prices. Each project also integrates an educational component, as leaders in each area are invited to give seminars on aspects of the energy source under study. The final product of each study is a report examining the conditions under which the energy source may be competitive in a carbon-constrained world. The audiences for the studies include the US government, industry and academic leaders, and other decision makers.

The composition, implementation, and objectives of these studies demonstrate MITEI's capacity to seamlessly marshal academic research, public and private resources, education, and outreach to inform national-scale decision making for the energy future.

MITEI's first two reports dealt with nuclear energy (2003, updated 2008) and coal (2007). In June of this year, participants in the study of the future of natural gas released an interim report of their investigation. A comparable study of the future of solar energy is scheduled for release in fall 2010. Studies of the nuclear fuel cycle and of the "smart grid" are also under way.

Future of Natural Gas

In spring 2010, the group of faculty and researchers investigating the future of natural gas completed the research phase of their study. An interim report of their findings was released in Washington, DC, on June 25, 2010 to an audience of high-level policy makers and press representatives. The full study, *Future of Natural Gas*, will be released in September 2010 and will be available on the MITEI website.

The study is being carried out by an interdisciplinary team with funding from the Clean Skies Foundation. Visiting scientist Anthony Meggs and professors Henry Jacoby (Sloan School of Management) and Ernest Moniz are co-chairs, and senior research scientist Daniel Cohn is the executive director. The study began in the summer of 2008.

The purpose of the study is to assess the future prospects for natural gas both in the United States and across the world over a time period that extends to 2050. A major theme of the study is the effect of carbon constraints. Another key aspect is the assessment of new sources of natural gas, particularly shale gas. Recent developments in shale gas production have led to the possibility that natural gas could play a substantially greater role than previously anticipated.

The study provides an independent assessment of potential natural gas supply, which involves the development of cost curves that provide estimates of the amount of gas available at a given price. In addition to shale gas and conventional gas, the study discusses the longer-term future demand for natural gas, including demand for electrical power generation, nonelectrical industrial use, and transportation. Electrical power demand for electricity, including the connection between the growth of renewable-energy-generated electricity and the demand for natural gas, will very likely play a particularly important role and is being evaluated in detail.

The potential use of natural gas for transportation will be evaluated for both light- and heavy-duty vehicles. This assessment will involve a study of the conditions in which there has been significant market penetration of natural gas vehicles worldwide. The effects of increased efficiency, particularly in buildings, are being considered. The overall systems interaction among supply, demand, and policy will be studied using the MIT Emissions Predictions and Policy Analysis model. In addition to these areas, the natural gas study will involve an evaluation of research, development, and demonstration needs; natural gas infrastructure; and geopolitical issues.

The study received support from the American Clean Skies Foundation, Hess Corporation, Agencia Nacional de Hidrocarburos of Colombia, and the Energy Futures Coalition, as well as from MITEI.

Future of Solar Energy

MIT's *Future of Solar Energy* study is one of a series of interdisciplinary studies within MITEI that investigate the contribution of specific energy technologies to meeting future energy needs while reducing greenhouse gas emissions. The purpose of the study is to increase the understanding of the problems and prospects associated with solar energy playing a large role in the energy economy. The study will analyze the technical

performance and economic costs and benefits of solar in particular applications relative to other technologies. Following the two-year study, a final report will be made available that will include key findings, identify the barriers to expanded utilization of solar energy, and recommend policies and actions that governments should or should not take to encourage deployment in an efficient manner that takes account of externalities.

The study examines the technical performance, resource needs, and costs of solar photovoltaics, solar thermal electric systems, and solar water heating, as well as the use of solar energy to create fuels. The economic competitiveness and large-scale integration of these technologies are considered in the context of the United States. In addition, the study analyzes past and potential policies supporting basic research, demonstration, and adoption of solar technologies. The report of the study group is expected in fall 2010.

The nine MIT faculty members involved in the study specialize in chemistry, mechanical engineering, electrical engineering and computer science, chemical engineering, materials science and engineering, physics, economics, and management. The study is co-chaired by Institute Professor John M. Deutch and executive director Joshua Linn, a visiting research scientist at MITEI. Undergraduate and graduate students will participate throughout the study. Experts from industry and government have been invited to MIT to provide input, and team members have visited and plan to visit leading companies. The study is financed by the Chesonis Family Foundation and the Sloan Foundation.

Future of the Nuclear Fuel Cycle

The *Future of the Nuclear Fuel Cycle* study is being coordinated through the Center for Advanced Nuclear Energy Systems (CANES). The study was initiated in 2008 to compare various fuel cycle options that might make nuclear power a significant producer of energy. The publication of the full study is scheduled for September 2010. For more information see the CANES report below.

Future of the Electric Grid

In September 2009, the MIT Energy Initiative began a multi-client-sponsored, interdisciplinary study to examine critical issues surrounding the national initiative to enhance the functionality and reliability of the electric grid. This project will explore the contribution of an enhanced electric grid on meeting the growing and changing energy needs of the nation in an efficient and environmentally responsible manner. The study will investigate the technical, economic, and policy factors that will shape the future of the grid, and make recommendations about research, development and demonstration strategies, government policies, and industry actions. Co-directors of this study are professors Richard Schmalensee and John G. Kassakian. A final report will be published in 2011.

Education

Catalyzing student knowledge and enthusiasm to solve technologically, socially, and politically challenging problems is a central component of the MITEI program. Education is closely integrated with MIT's energy research and with campus energy management activities discussed below.

Major energy education accomplishments in AY2010 included the official launch of the Institute-wide undergraduate Energy Studies minor, two major gifts for undergraduate energy education, and continued growth in the undergraduate energy curriculum, energy-focused summer Undergraduate Research Opportunities Program (UROP) projects, and the MIT Society of Energy Fellows program.

MITEI's Energy Education Task Force (EETF) guides the development of energy education at MIT. The task force, cochaired by professors Vladimir Bulović (EECS) and Donald R. Lessard (Sloan School of Management), includes 16 faculty members from 14 different departments and three graduate and two undergraduate student representatives. EETF meets regularly during the academic year. Professional staff members in MITEI's Education Office support MITEI and EETF in implementing energy education programs.

Energy Studies Minor

The Energy Studies minor was officially launched in September 2009. The minor's multidisciplinary curriculum integrates energy science, social science, and technology and engineering, and is open to students from all majors. More than a dozen students applied for the minor by the end of AY2010, with three seniors completing the minor before Commencement in June 2010.

The Energy Minor Oversight Committee (EMOC), a subset of EETF with members from all five Schools, is responsible for the intellectual content of the minor. In AY2010, EMOC met monthly to review and refine the Energy Science Foundations requirement, develop a process for reviewing petitions for subject substitution within the minor, and make recommendations regarding funding priorities for continued curriculum development in the minor program.

EMOC reports to the Inter-School Educational Council (ISEC), a new body consisting of one associate dean from each School, the dean of undergraduate education, and one associate provost. ISEC was established as a three-year experimental governance model for interdisciplinary academic programs at MIT, of which the Energy minor is the first. In AY2010, ISEC convened once per term to review progress updates from EMOC and discuss resource and administrative coordination issues particular to the multidisciplinary character of the Energy Studies minor.

Major Gifts for Energy Education

Two major gifts totaling nearly \$8 million were made to the Energy Studies minor program in fall 2009. These gifts will support curriculum development, project-based classes and teaching space, dissemination of educational materials via OpenCourseWare (and other means), and other activities.

Energy UROPs

MITEI's summer UROP grew to 23 students (50% female) from 12 departments working on energy projects during summer 2010. Projects ranged from concentrated solar power technology, biofuels, enhanced geothermal systems, to carbon nanotubes as thermal

conduits. In summer 2010, MITEI UROPs were supported by three MITEI affiliate members, four alumni donors, and MITEI founding member BP.

Graduate Energy Fellows

The Society of Energy Fellows at MIT has grown to more than 120 members, with the designation of the AY2011 cohort of graduate students representing 19 departments and all five Schools. The fellowships are supported by a group of MITEI's founding, sustaining, and associate members. The Society of Energy Fellows at MIT plays a key role in MITEI's intellectual and educational mission by cultivating a community of doctoral students with a wide range of disciplinary perspectives and talents focused on a common set of energy challenges. Society-sponsored activities in AY2010 included an afternoon symposium and poster reception on the eve of MITEI's fall research conference in September, meetings and discussions hosted by sponsors for their groups of fellows, a dinner seminar featuring Building Technology faculty, and a range of informal gatherings.

Clare Boothe Luce Postdoctoral Fellowships for Women in Energy

As the Clare Boothe Luce Postdoctoral Fellowship Program for Women in Energy approached its final months, the MITEI Education Office assisted vice president for research and associate provost Claude Canizares in hosting a luncheon to gather feedback about the postdoctoral experience at MIT for women and factors influencing their career path decisions. Doctors Bonna Newman and Carolyn Seto will complete their fellowships in August and October, respectively.

Campus Energy Activities

The Campus Energy Task Force has continued to build on earlier progress making MIT's campus a model living laboratory to test and implement leading approaches to advance sustainable practices in a large, energy-intensive institution. A hallmark of this past year's progress has been the movement of pilot-level projects to Institute-wide programs for significant impact and the establishment of a stronger, more informed, diverse, and engaged sustainability community. A summary of highlights include:

- The establishment of *MIT Efficiency Forward*, an industry-leading energy conservation and efficiency program to save 34 million kWh over three years and \$50 million over the lifetime of projects.
- Achievement of campus energy cost savings to date totaling \$2.2 million annually, paired with an innovative, revolving investment fund mechanism.
- Receipt of a "gold" rating for the sustainable design of the New Ashdown dorm.
- Recruitment of more than 185 faculty, staff, and student Green Ambassadors to drive sustainable practices in offices, labs, and dorms.
- Recognition of MIT's campus transportation program for its efforts in reducing the rate of people driving to work alone from 26% to 22%, thus increasing alternative modes of transportation.

- The providing of rich research and learning opportunities for students and faculty, including campus-focused UROPs, class practicums, theses, and student projects.
- President Hockfield's signing in early 2010 of the Global University Leaders Forum's sustainable Campus Charter, which reinforced MIT's commitment to sustainable campus development.
- Joining (as the only university invited to do so) the US Department of Energy's new Global Superior Energy Performance (GSEP) Partnership to pilot the program's new building energy management certification program.

Energy Conservation, Efficiency, and Sustainable Design

Energy Conservation and Efficiency

A priority for the Campus Energy Task Force has been developing a robust, fiscally disciplined program targeting energy conservation investments across campus. Emphasis has been placed on measures that have a substantial impact on energy consumption and greenhouse gas emissions and at the same time offer positive economic return. Each project is being monitored to establish the best available data concerning actual energy savings as well as capital costs.

From 2005–2009, MIT has committed \$3 million in new energy conservation measures focused on lighting retrofits, steam strap system renewal, and heating/ventilation/air conditioning (HVAC) optimization. These investments alone are estimated to save MIT over \$2.2 million annually in energy savings, providing additional strategic capital to reinvest in additional projects while also reducing greenhouse gas emissions by over 22 million pounds annually.

A major accomplishment this year was the establishment of MIT Efficiency Forward, a three-year, \$13 million collaborative energy conservation and efficiency program with our electric and gas utility company NSTAR. The program is a first-ever-of-its-kind with a utility company and is the single largest energy efficiency project NSTAR has developed with a customer. The program will invest over \$13 million over three years, with a mix of funds from MIT, NSTAR incentive payments, and reinvestment of energy savings. MIT has committed to a goal of reducing electrical use on campus by 34 million kilowatt hours over three years, equivalent to 15% of MIT's current electrical use. The total estimated savings over the lifetime of the investments is estimated in excess of \$50 million. MIT Efficiency Forward allows NSTAR and MIT to create a new model for enhanced utility efficiency programs to support the Massachusetts Green Communities Act and the state's desire to make efficiency competitive with new source generation.

Sustainable Design

In 2009, the new Ashdown House was awarded the US Green Building Council's Leadership in Energy and Environmental Design Gold certification for its high degree of sustainable design. Similar to the Sloan School of Management project, the Koch Institute for Integrative Cancer Research design team has been using a version of the integrated design process to achieve a greener building that tackles energy use head

on and challenges current conventional rules for HVAC needs to improve system efficiencies.

Engaging the Entire Community

In 2009, the Task Force launched the “greeningMIT” campaign to further integrate campus energy activities with the entire MIT community. Greening MIT is an initiative to engage all students, staff, and faculty in taking action to make the MIT campus more sustainable and energy efficient. Education and awareness campaigns were launched across campus that encouraged the MIT community to consider the energy impacts of everyday choices and activities. The president’s community-wide fall break event adopted a greeningMIT theme to showcase the breadth and depth of activities and resources available on campus to help MIT “walk the talk” on energy and sustainability. The event was attended by over 2,000 people and launched MIT’s first institute-wide zero-waste event where everything served was compostable.

Network of Change Agents

The Green Ambassadors Program was established in 2009 to create and empower a network of individuals interested in taking action in their own lab, office, or dormitory to promote more sustainable practices at MIT. Areas of focus include energy conservation, resource efficiency, green purchasing, alternative transportation, awareness, and outreach. To date, the Green Ambassador Program has grown to include 185 staff, faculty, and student volunteers to model and promote the Institute’s energy and environmental stewardship objectives. The Campus Energy Task Force members have supported this popular initiative by providing information resources, outreach material, and networking support to share best practices and by hosting workshops. A survey designed to assess progress indicates the vast majority of Green Ambassadors are showing and leading the way for sustainable practices across campus.

Improving Transportation Options

Recognized as a national Best Workplace for Commuters by the Environmental Protection Agency, a MassRides Gold Partner, and a 2010 GoGreen winner by the City of Cambridge, MIT deepened its leading programs to promote more sustainable travel options for its 20,000 faculty, staff, and students. MIT’s transportation programs are designed to reduce the environmental impacts associated with our community travel while simultaneously enhancing users’ experience of taking alternative forms of transportation. Key metrics for measuring transportation program success have shown strong improvements this past year:

- MIT’s proportion of single occupant vehicle trips declined by 15% from 26 to 22
- Full-time parkers decreased 7% from 2,917 to 2,709
- Occasional parkers increased 8% from 1,839 to 1,987
- Student commuters decreased 37% from 78 to 49
- MBTA Pass Program participants increased 17% from 4,640 to 5,556

Making Biking Better

This past year marked a watershed for improvements to one of MIT's and the city of Cambridge's transportation priorities: enhancing biking programs and facilities. MIT has seen a significant rise in both the number of bike commuters and resident students using bikes on campus, and with it has come the need to accommodate more bike parking. Respondents to the 2008 MIT Transportation Survey indicated that providing cyclists with additional outdoor covered bike racks or indoor storage rooms would be the most effective way to improve bike storage on campus.

Welcoming Bikers onto Campus

To assist cyclists with minor repairs and adjustments, five bicycle repair stations with tools and air pumps have been installed at the following buildings: Stata Center (Building 32), Student Center (Building W20), Media Lab (Building E15), Tang Center (Building E51), and Building 9. The repair stations are located in covered areas evenly distributed throughout the campus.

MIT has launched a number of transportation demand management strategies over the past year specifically targeted at bicyclists. Full-time employees are now eligible to participate in the MIT Bicycle Commuter Benefit Program, which provides reimbursement of \$20/month (\$240/year) for the purchase, improvements, repair, or storage of a bicycle used for commuting to MIT. This commuter benefit may also be used to purchase a Bike Commuter Membership with MIT Recreational Sports, which allows cyclists access to shower and locker room facilities. In 2009, two shower facilities on campus were renovated to provide additional access to clean, secure accommodations.

Student Learning, Research, and Engagement

Using our Campus as a Living Laboratory

MIT's campus operations are being used as a living laboratory through UROPs, special classes, internships, and research projects designed to foster students' emerging technical and leadership skills to help define and solve our own energy challenges. In the past two years, over 21 UROPs and internships focusing on campus energy issues were supported by Task Force members in partnership with academic and administrative units. For example, one UROP is working with the Environmental Health and Safety Office (EHS) and Building Technology Program (BTP) to test alternative, more climate-friendly tracer gases for use in testing fume hood performance.

Through the MITEI Student Campus Energy Project Fund, MIT has supported over 35 student projects on campus that engage our students and advance our campus energy objectives while simultaneously providing rich learning opportunities. Recent supported student campus projects include a program to bring a wind turbine to campus, development of a real-time dorm energy-use monitoring system, and the development of outreach and awareness material for promoting more sustainable on-campus catering. Administrative units, including the Department of Facilities and EHS, continue to support curricular, project-based learning activities by developing and advising campus energy-related projects, including ones for the new 5.92 Projects in Energy course, the Sloan School of Management's Executive Education program, and the Freshman Pre-

Orientation Program. Student-led campus energy projects continued to bloom across campus offering new learning and leadership opportunities.

Our Campus Energy Task Force faculty members have integrated coursework to address important issues confronting our campus. For example, a Sloan School of Management team in the System Dynamics Group has been researching the impact of deferred maintenance cycles on energy efficiency within MIT's campus. Using custom simulation modeling software, the team is working to identify new policies and novel maintenance approaches that optimize campus operations and minimize energy waste. Preliminary research indicates that increased investments in preventative maintenance can lead to decreases in overall repair costs and energy waste.

Two BTP design courses in building energy and HVAC (4.427 and 4.464) had a joint final project that teamed up architects and engineers to design a near-zero-energy building. The design project is considering a possible new MIT building on Massachusetts Avenue. Students were asked to propose and assess an innovative, overall building design along with technologies and operating schemes that will yield a high-performance, sustainable building in terms of energy consumption, comfort, and use of materials. The goal is a practical near-zero-energy building.

A BTP and Mechanical Engineering PhD thesis project developed a software system for MIT that can utilize data from the existing campus building control system to automatically identify certain types of energy inefficient equipment behavior. The researchers' long-term vision is that such a system may one day provide MIT facilities managers with a practical tool for identifying, tracking, and managing costly and unhealthy equipment pathologies across a portfolio of buildings.

The Road Ahead for our Sustainable Campus

Looking forward, MIT is very well positioned to continue to build on priorities of the campus energy program, including demonstrating sound and meaningful energy conservation and efficiency strategies, designing programs to engage the broader community in better energy practices, and opening our campus operations as a living laboratory for student learning and education.

In January 2010, President Hockfield joined 25 of her national and international counterparts in signing the World Economic Forum's Global University Leaders Forum (GULF) Sustainable Campus Charter. The charter commits MIT to embracing a series of sustainable development principles that will guide campus operations towards a more energy efficient and sustainable future. This commitment will be a feature in many aspects of our campus development, and the Campus Energy Task Force will be coordinating our engagement and seeking the broad participation of the MIT community in shaping our progress. Campus Energy Task Force members have been working collaboratively with the GULF Sustainable Campus Charter Secretariat to design and develop the implementation and reporting guidelines to transition the charter from a program of commitment to a program of action.

MIT has recently accepted an invitation by DOE secretary Stephen Chu to be the only university to pilot the Global Superior Energy Performance partnership, a new DOE-supported, public-private partnership designed to accelerate energy efficiency improvements in commercial buildings and industrial facilities. Recognizing MIT's leadership in campus energy management, DOE chose MIT to pilot GSEP's international certification program to affirm facilities that adopt approved energy management systems and achieve significant and independently validated efficiency improvements over time. To start, seven companies representing over \$600 billion in annual sales and MIT will pilot the program. This new partnership will allow MIT to learn from and to share its experience and knowledge with other leading national and international organizations.

A more detailed Campus Energy Update report is available at <http://mit.edu/mitei/docs/campus/update-4-21.pdf> and at <http://mit.edu/mitei/campus/projects.html>.

Outreach

MITEI hosted a number of outreach events throughout the year, including two energy colloquia, ten seminars in the second year of its seminar series, a second year of seminar speakers in support of the natural gas study, the first year of co-sponsorship of a series of topics in microbiology, and ten additional special events.

In October 2009, MITEI helped organize a visit to MIT by Barack Obama, who gave an address on US leadership in clean energy. President Hockfield and MITEI director Ernest Moniz escorted President Obama through a MITEI lab tour showcasing energy innovations, featuring the work of professors Marc Baldo, Vladimir Bulovic, Paula Hammond, Angela Belcher, and Alex Slocum.

In June 2010, MITEI leadership hosted a press briefing and release of the interim report of the *Future of Natural Gas* study in Washington, DC. Aimed at senior policy makers in government and industry, the results of the study were widely reported. MITEI also organized press events for the MIT Energy Club conference in March 2009 and the opening of the MITEI Solar Frontiers Center in May 2009.

In addition, MITEI and the Microbiology Graduate Program initiated co-sponsorship of the new monthly Microbiology Seminar Series. The often overflowing attendance at these events shows the high level of interest and demand for energy-related information across campus and throughout the MIT community as well as in the local community. Through these events, MITEI helped to bring the national energy policy conversation to campus.

MITEI Seminar Series

The MITEI Seminar Series was made possible by IHS Cambridge Energy Research Associates (CERA). The series included:

Materials Challenges in Polymer Electrolyte Fuel Cells, April 6, 2010, Frank DiSalvo, Cornell University

Bioenergy Production Using Microbial Fuel Cell Technologies, March 2, 2010, Bruce Logan, Penn State University

Why is Modernizing our Energy Technologies So Darn Hard, but Worth the Effort?, February 2, 2010, Susan Tierney, Analysis Group, Boston

All That Gas..., December 14, 2009, Leonardo Maugeri, Eni SpA

Emerald Cities: How Are Cities Advancing the Shift to a Green Economy?, December 1, 2009, Joan Fitzgerald, Northeastern University

Thermoelectric Energy Conversion: Recent Progress and Applications, November 3, 2009, Joseph Heremans, Ohio State University

Facing the Harsh Realities: Shaping the Energy Mix of the Future, Starting Today, October 29, 2009, Tony Hayward, CEO, BP plc

The Next Phase in Large-Scale Solar Thermal Power Generation, October 6, 2009, Jacob Karni, head, Weizmann Institute Energy Center

Colloquia

MITEI Colloquium: Can We Meet the Planet's Deadline?, October 7, 2009, Frances Beinecke, president, Natural Resources Defense Council

Earth Day Colloquium: Cradle to Cradle: A Strategy of Hope, April 22, 2010, William McDonough, principal, William McDonough + Partners

Special Events

Solar Thermal Technology—Present Usage, Future Possibilities, and Best Practices, October 19, 2009, Christian Holter, SOLID GmbH

American Leadership on Clean Energy, October 21, 2009, President Barack Obama

Engineering a Cooler Earth: Can We Do It? Should We Try?, October 30, 2009, symposium sponsored by the Earth Systems Initiative, MITEI, and the Center for Global Change Science

Status and Technological Challenges for Renewable and Sustainable Energy Options, November 20, 2009, Robert McGrath, Deputy Laboratory Director for Science and Technology, National Renewable Energy Laboratory

Energy Futures Week 2010, January 11–15, 2010. See the calendar of activities at <http://web.mit.edu/mitei/news/seminars/energy-futures-week-10.html>.

The Road from Copenhagen, February 5, 2010, Moderator: Ernest Moniz; Panelists: William Bonvillian, director, MIT Washington DC office; Michael Greenstone, Department of Economics, MIT; Henry Jacoby, MIT Joint Program on the Science and Policy of Global Change; Rob Stavins, Albert Pratt professor of business and government, Harvard University; Edward Steinfeld, Department of Political Science, MIT

China's Climate Change Policy, Technologies, and Investment in the Post-Copenhagen Era, February 18, 2010, Gang Chen; John Parsons; Kelly Sims Gallagher, Tufts and Harvard; Amy Smith, Barclays Capital

Electrification of the Transportation System, April 8, 2010, symposium by invitation

Antarctica 2009: A Continent in a State of Alert, April 13, 2010, HSH Prince Albert II of Monaco

SMARTpower: Climate Change, the Smart Grid, and the Future of Electric Utilities, April 14, 2010, Peter Fox-Penner

Press Briefings

Future of Natural Gas, June 25, 2010, Ernest Moniz, Melanie Kenderdine, Henry Jacoby, Tony Meigs

Eni-MIT Solar Frontiers Center, May 16, 2010), MIT president Susan Hockfield; Paolo Scaroni, CEO, Eni; Ernest Moniz

Advances in Energy Research at MIT, March 5, 2010, Ernest Moniz, Marc Baldo, Dan Nocera, Paula Hammond, Gang Chen, Michael Strano, John Sterman, Luis Ortiz, Michael Greenstone

Clare Boothe Luce Postdoctoral Fellowship Seminars

Reducing Risk in Basin Scale CO₂ Injection through Monitoring and Verification, April 27, 2010, Carolyn Seto, Clare Boothe Luce Postdoctoral Fellow

Defect Engineering for High-Efficiency Lower-Cost Photovoltaics, May 11, 2010, Bonna Newman, Clare Boothe Luce Postdoctoral Fellow

Future of Natural Gas Seminar Series

The Seminar Series associated with the two-year study on the future of natural gas continued in AY2010.

USGS Circum-Arctic Resource Appraisal: Estimating Undiscovered Oil and Gas in the Highest Northern Latitudes, July 22, 2009, Donald Gautier

A Cost Appraisal of Arctic Oil and Gas Resources, July 22, 2009, Loring White

Aggregation Methodology for the Circum-Arctic Petroleum Assessment, July 22, 2009, Jack Schuenemeyer

US Natural Gas Market Outlook: Boom and Bust, or New Beginning?, September 24, 2009, Porter Bennett

The History of GE Gas-Fired Power Plants, October 19, 2009, Eric Gebhardt

Microbiology Seminar Series

Beginning this year, MITEI and the Microbiology Graduate Program initiated co-sponsorship of the new, monthly Microbiology Seminar Series.

Engineering Microbial Gene Networks: Integrating Synthetic Biology and Systems Biology, May 20, 2010, James Collins, Boston University

Microbial Structuring on Ocean Biogeochemistry: Implications for Ecosystems and Global Habitability, April 15, 2010, Farooq Azam, Scripps Institute of Oceanography, University of California San Diego

Engineered Microbial Gene Networks: Integration Synthetic Biology and Systems Biology, March 18, 2010, Bruce Walker, Ragon Institute of Massachusetts General Hospital, MIT, and Harvard University

Peering into the Lives of those Gassy, Electrifying Microbes, February 18, 2010, Peter Girguis, Harvard University

The Microbe Electric: Combining Systems Biology and Physics to Understand and Optimize Microbe-Electrode Interactions and Their Applications, January 21, 2010, Derek Lovley, University of Massachusetts Amherst

A Darwinian View of the Hygiene Hypothesis, December 17, 2009, Graham Rook, University College London

Selective Pressures on Enzymes and Adaptation of Metabolic Systems, November 19, 2009, Chris Marx, Harvard University

Understanding the Biofilm Anode in Microbial Fuel/Electrolysis Cells, October 15, 2009, Bruce Rittman, Arizona State University

Designing Biological Systems for Programmed Interface with the Environment, September 17, 2009, Pamela Silver, Harvard University

Publications

MITEI's biannual magazine, *Energy Futures*, edited by Nancy Stauffer, was published in October 2009 and July 2010. MITEI also produced a volume of the 2009 research, education, and outreach spotlights featured on the MITEI website home page as well as an overview brochure and a brochure focusing on the MITEI education program.

This year the Outreach group instituted a new e-newsletter. The monthly bulletin updates readers on upcoming MITEI events, recent activities, and other news, all linked to the MITEI website. The e-newsletter's 5,000 subscribers include faculty, research staff, students, MITEI members, and many others in government, industry, and interest groups involved in the future of energy.

The Outreach group also produced the *Future of Natural Gas* interim report, and supplies materials as needed in support of MITEI activities. This year the group inaugurated a new, monthly e-newsletter linked to its website and delivered electronically to a growing, international list of readers following the progress of the initiative and active in its public colloquia, seminars, and research conferences.

Laboratory for Energy and the Environment

The Laboratory for Energy and the Environment (LFEE) is a key subunit within MITEI that deals with issues of energy, the environment, and sustainability. It includes both core component and affiliated programs; highlights of AY2010 achievements are detailed below.

Alliance for Global Sustainability

The 2009 Annual Meeting, held this year in Tokyo, inaugurated formal work in a new direction for AGS—the influence of demographic change, particularly the rapid aging of populations, in both the developed and developing world, on sustainability. All four AGS universities now include centers focused on the evolving work, life, medical, and other needs of older citizens. AGS’s long-standing interests in transportation and building stock are particularly closely linked to this area of interest.

Research and educational activities supported by the AGS connect scholars from four partner universities—MIT, the Swiss Federal Institute of Technology, the University of Tokyo, and Chalmers University of Technology, Sweden—with stakeholders from industry, nongovernmental organizations, government, and other leading academic institutions addressing complex environmental problems transcending geographical and disciplinary boundaries.

Building on past integrated, collaborative research activities, AGS 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, comprises a set of regional projects that focus on key energy sectors. In addition, work on the MIT-Portugal Program on Sustainable Energy Systems has focused on a major initiative on urban futures. A Green Island Program focused on the Azorean island of São Miguel will not only work on new research in the integration of sustainable energy technologies and management schemes but will also develop demonstrations to serve as a test bed for deployment in larger communities. These projects are looking in detail at how alternative portfolios of technologies and policies can affect the development of a region’s energy infrastructure.

AGS has already invested in sustainability focused energy research and can present a credible worldwide analysis while providing a neutral forum for the development of integrated scenarios that require political and regulatory action. To increase the profile of AGS and promote synergy among Near-Term Pathways research activities, the program will include cross-cutting communication, outreach, and learning initiatives. The 2009 annual meeting held in Zurich focused on urban futures, building on parallel and collaborative research at the four schools and their regional networks. Groundwork was laid for next year’s research and annual meeting focus, communications and partnership with other sectors, particularly industry. At present, AGS leaders are working closely with the World Business Council on Sustainable Development’s project on establishing goals for 2050 and what must be done by 2020 to achieve them.

Carbon Capture and Sequestration Technologies Program

The field of carbon capture and sequestration (CCS) continues to grow in visibility as a result of increasing concerns about global climate change. MITEI’s continuing work on carbon sequestration technologies focuses on three areas: assessment, education/outreach, and research. Howard Herzog leads this effort.

The core of the program is the Carbon Sequestration Initiative, an industrial consortium on carbon management. The 19 members are Alstom Power, American Electric Power,

American Petroleum Institute, Babcock & Wilcox, Chevron, ConocoPhillips, Electric Power Research Institute, Enel, Entergy, ExxonMobil, Marathon Oil, Peabody Energy, Sasol Technology, Schlumberger, Shell, Siemens Power Generation, Southern Company, Suncor, and Vattenfall. The initiative funds research and hosts an annual two-day Carbon Sequestration Forum to examine critical technical and policy issues related to CCS.

Below is a listing of our current research project areas:

- [Strategies for Implementing CCS at Coal-Fired Power Plants](#)
- [Policies for Promoting Innovation in CCS](#)
- [Methodology for Uncertainty Analysis of Capacity Estimates and Leakage Potential for Geologic Storage in Saline Aquifers](#)
- [Modeling of Cost and Performance of CCS Plants in the Western Interconnect](#)
- [Costing CCS Technologies](#)
- [Comparison of Solvents for Postcombustion Capture of CO₂ by Chemical Absorption](#)
- [Stimulus-Responsive Structure Fluids for Dynamic Mediation of Carbon Dioxide Separation](#)
- [Representation of CCS Technology in Emissions Predictions and Policy Analysis](#)
- [The Feasibility of Air Capture](#)
- [Development of a Carbon Management Geographic Information System](#)
- [Survey of Public Attitudes about Carbon Dioxide Capture and Storage](#)
- [Regulatory and Legal Issues for Carbon Dioxide Capture and Storage](#)

A few highlights this past year include:

- In collaboration with professor Alan Hatton, the program won an ARPA-E award related to stimulus-responsive research area listed above.
- Ellie Ereira won an award for the best Technology and Policy Program thesis for “Assessing Early Investments in Low Carbon Technologies under Uncertainty: The Case of Carbon Capture and Storage.”
- The program was invited to testify before President Obama’s Interagency Carbon Capture and Storage Task Force.

Funding for the program comes from diverse sources, including DOE, private industry, and nongovernmental organizations. Additional information can be found on the program website at <http://sequestration.mit.edu/>.

Analysis Group for Regional Energy Alternatives

MITEI research in the area of regional planning for energy infrastructures and environmental performance is centered in the Analysis Group for Regional Energy Alternatives (AGREA), led by Stephen Connors. Through MITEI and AGREA, Connors coordinates the sustainable energy activities of AGS and the MIT-Portugal Program on Sustainable Energy Systems.

The scenario-based multi-attribute tradeoff-analysis approach developed in the early 1980s by MIT Energy Laboratory researchers is the primary tool used by AGREA. Ongoing and recent projects include the MIT-Portugal Program's Azores Green Island project and related studies, and AGS regional energy and environmental studies including Shandong Province in China and the Mexico City Air Quality Integrated Assessment Program. Recent US-related research has focused on calculating the avoided emissions from dynamic renewable resources such as offshore wind; localized wind, solar, and energy storage; and targeted energy efficiency based on the spatial and temporal dynamics of energy supply and demand, including fossil unit dispatch. AGREA routinely collaborates with partners in the United Kingdom, Norway, Sweden, Switzerland, Portugal, and Spain on topics related to high penetration rates of renewable energy and efficiency, smart grids, and electric transportation.

In addition to the projects and programs listed above, Connors co-supervises numerous graduate and undergraduate students in other projects and programs at MIT, looking at fuel consumption and emissions impacts among renewables and fossil fuels; electrification of transportation, energy storage, and smart grid technologies; the potential impacts of the widespread deployment of distributed generation to electrification in developing countries; and real options applications to energy investments involving climate change, economic growth, and energy security. Details are available at <http://web.mit.edu/agrea/>.

Affiliated Groups

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

Building Technology Program

Research in BTP has its principal focus on energy efficiency and sustainable design for buildings. In the US, buildings consume almost 40% of the total energy used and more than two thirds of the electricity used. Their long life 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 retrofitting buildings with new energy efficiency technologies 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.

All five faculty members of BTP have had strong input into LFEE's or MITEI's energy research and teaching: professors Marilynne Andersen, John Fernandez, Leon Glicksman, John Ocksendorf, and Les Norford from Architecture. Architecture professor Andrew Scott is also a member of the group and is active in many projects. Many activities involve substantial joint efforts with faculty members and students in EECS, Civil and Environmental Engineering, and ME as well as the Harvard School of Public Health; the city of Cambridge, England; Chalmers University of Technology; the Swiss Federal Institute of Technology; and Tsinghua University in China. Typically 20 to 25 graduate students are involved in building technology research at any given time. Some students receive degrees in the Department of Architecture and others in the School of Engineering. BTP faculty and students are working on major projects on natural ventilation of commercial buildings; design tools; fault detection, monitoring, and control; sustainable buildings for developing countries; daylighting; industrial ecology; and the application of option theory. They are also working with the MITEI Campus Energy Management and Education task forces. We have joint programs with researchers and academics in Portugal, Singapore, Abu Dhabi, and Japan. Professor Andersen will take a tenured position at the École Polytechnique Fédérale de Lausanne next year.

Center for Advanced Nuclear Energy Systems

MITEI is administering a large interdisciplinary study of the fuel cycle through CANES. Dr. Charles Forsberg is the executive director of the study, initiated in 2008 to examine the pros and cons of various fuel cycle options to enable nuclear power to play a significant role in future energy supplies. Professors Ernest Moniz and Mujid Kazimi cochair the study, which involves 10 other faculty members and approximately 12 graduate and undergraduate students. The study released an update of the 2003 *Future of Nuclear Power* study report that lays the foundation for the new fuel cycle investigation. The update showed that the cost of all electricity options was higher in 2008 than it was in 2003 and that nuclear energy can be competitive with coal if it can be financed on the same basis as coal or if modest carbon release costs are imposed on power plants. The full study, *Future of the Nuclear Fuel Cycle*, will be released in September 2010.

CANES develops research concepts for nuclear energy systems promising 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 Kazimi is the founding and present director of CANES. Information on the center's extensive research and outreach activities is available at <http://web.mit.edu/canes/>.

Sloan Automotive Laboratory

A significant amount of MITEI's research volume supports work at the Sloan Automotive Laboratory (SAL). Many of the lab's projects involve quantitative and cross-disciplinary study of the complex energy and environmental issues created by use of our transportation propulsion and vehicle technologies and fuels. SAL is directed by professor John Heywood (ME), with participation from professor Wai Cheng, Dr. Tian Tian, Dr. Victor Wong, and professor William Green. It continues to pursue promising

research to improve powertrain performance, efficiency, and fuel utilization in internal combustion engines and reduce adverse emissions.

Research at SAL is supported significantly by three consortia that offer long-term research programs. Funded by companies in the automotive and petroleum industries, the Engine and Fuels Research Consortium explores fuel economy opportunities and critical emission formation mechanisms in internal combustion engines. The Consortium on Lubrication in Internal Combustion Engines involves major engine component and lubricant manufacturers in addressing issues in oil consumption, wear, and engine friction reduction. The Consortium to Optimize Lubricant and Diesel Engines for Robust Emission After-treatment Systems has been established to develop low ash-producing lubricants to enable significantly improved diesel emissions control. Besides these consortia, there are substantial research projects with individual sponsorship from different companies and DOE. Examples are low temperature combustion and homogeneous-charge-compression-ignition concepts, diesel fuel detergency, and high speed lubrication for Formula One engines.

SAL researchers are also involved in multidisciplinary studies assessing new vehicle and propulsion system technologies for future road transportation use. A multisponsor study has examined the potential for more efficient engines, transmissions, vehicle weight reduction, and new fuel streams such as ethanol to reduce US and European fuel consumption and greenhouse gas emissions. It recently issued a major policy recommendation for cutting the transportation petroleum use and greenhouse gas emissions in US.

Center for 21st Century Energy

The Center for 21st Century Energy is dedicated to developing technologies for a sustainable energy future. The center brings together existing and new energy research programs carried out in the Mechanical Engineering Department's laboratories and programs. These include the Electrochemical Energy Laboratory, the Energy in Buildings Program, the Reacting Gas Dynamics Laboratory, the Rohsenow Heat and Mass Transfer Laboratory, SAL, and the Laboratory for Manufacturing and Productivity. The center collaborates with energy researchers in other units and is one of the major participants in MITEI. Our research encompasses renewable energy, energy efficiency, carbon management, transportation, and environmental conditioning.

The center's research focuses on technologies for efficient and clean energy conversion and utilization, aiming to meet the challenges of rising energy demands and prices and the concomitant environmental impact. Our program encompasses existing and emerging technologies at the systems, engineering, and scientific levels, including engines and combustion, thermoelectricity, fuel cells and batteries, solar energy and wind power systems, energy-efficient buildings, carbon capture, hydrogen and alternative fuels, and water purification and desalination. The center director is professor Ahmed Ghoniem, and faculty participants include professors John Brisson, Ernie Cravalho, Wai Cheng, John Heywood, Alexander Mitsos, Eli Sachs, Yang Shao-Horn, Kripa Varanasi, and Evelyn Wang. Brief descriptions of the different research areas follow.

Solar Energy

New approaches to the design and manufacture of solar cells to reduce their cost are important focus areas in solar photovoltaics. We are developing novel approaches to engineering low-cost, naturally abundant manufacturable materials into defect-tolerant, high-efficiency devices. We work on nanostructured solar thermoelectric and thermophotovoltaic materials and devices, combined heat and power in concentrated solar thermal electrics, and optimal system design. Work on concentrated solar thermal systems includes addressing the storage challenges as well as engineering antifouling surfaces for mirrors and collectors and hybridizing solar with other renewable and fossil resources.

Wind Energy

Energy generated from floating offshore wind farms is the next frontier in wind energy. Innovative and economical wind turbine floaters are being developed for deployment in large-scale offshore wind farms in water depths up to several hundred meters.

Carbon Capture

More than 85% of our energy currently comes from fossil fuels, a percentage that is unlikely to change soon. Capture and storage of carbon dioxide from power plants and fuel production facilities is necessary for mitigating global warming. Our program's objective is to provide the necessary knowledge for enabling CO₂ capture, including research on gasification of solid fuels (including biomass), technologies related to the integrated gasification combined cycle, oxy-combustion technologies for solid and gaseous fuels, systems integration and optimization, syngas utilization, and novel gas separation technologies (including ion transport membranes). The program works on the production of hydrogen and its liquefaction and storage.

Transportation

In transportation, the major challenge is to increase vehicle fuel economy, reduce emissions, and initiate the transition to nonpetroleum fuels. Our program is working on improving combustion engines, developing viable fuel-cell and advanced battery systems, and exploring innovative approaches to using hydrogen in engines and fuel-cell-powered vehicles.

Modeling and Simulations

Advanced modeling and simulations are prerequisites for developing a control technology to optimize energy and propulsion system performance, including stability, emissions, efficiency, and power density. This group works on the development and application of advanced simulation methodologies for reactive flows focusing on dynamics, control-oriented models, and implementation of adaptive control algorithms including sensing and actuations.

Batteries and Storage

Energy storage is a significant enabler for expanding the use of renewable energy and for electrification of the transportation system. Faculty members are involved in developing fundamental knowledge of efficient and higher-energy-density lithium ion batteries. This program works on investigating mechanisms governing the performance of fuel cells for transportation and electricity generation. Research includes catalysis of small molecules such as oxygen reduction and water splitting, polymeric materials for ion transport, simulation of transport-electrochemistry interactions, and electrolytic and photoelectrochemical cells.

Building Technology

In terms of environmental conditioning, per capita energy use in the United States is among the highest in the world, in part because per capita space usage is also high. One important challenge is to apply environmental conditioning only to necessary regions within a space, rather than uniformly throughout the space. Our program's work on small cryogenic systems can provide precision cooling to small areas, and this work is being expanded to scales and temperatures suitable for cooling electronics, sensors, and personal spaces.

Microtechnology and Nanotechnology

Our faculty members are engaged in fundamental research on transport phenomena at the macroscale and microscale, including enhanced heat transfer, high heat flux heat transfer, and microscale and nanoscale heat and mass transport with applications to a range of issues such as advanced water purification and desalination through thermal and membrane-based processes. Today's clean water production technologies require orders of magnitude more energy than theoretically required; the objective is to significantly improve their efficiency and economies. This program is also exploring the opportunities for thermoelectric energy technologies. Work has been initiated on advanced materials wherein, by exploiting nanoscale phenomena and technology, new precision applications to energy conversion may be feasible.

Center for Energy and Environmental Policy Research

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

CEEPR research has a number of focuses that include the restructuring of electricity markets, evaluating the functioning and performance of markets created for environmental services, and evaluating the future of nuclear and coal energy and in developing markets for oil and natural gas and renewables. CEEPR also supports econometric work in the evaluation of environmental regulations and programs. Finally, research includes analyses of the financing of 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 Dr. John Reilly and professor Ronald Prinn, draws on MIT's traditional strengths in science and economics to conduct the interdisciplinary work needed to provide a basis for global climate policy. The now 19-year-old program is a world-leading center for integrated assessments of the climate threat and efforts to deal with its consequences. An MIT Integrated Global Systems Model developed by program researchers provides an avenue for research on the behavior of the climate system and assessment of policy proposals. An interdisciplinary team of faculty, professional staff, postdoctoral fellows, and graduate students carries out the work, and the program produces a continuing flow of reports, articles, student theses, and professional and public presentations on the science and policy of the climate issue and other aspects of global environmental change. Work is supported by five US government agencies; 40 corporations and industry organizations in North America, Europe, and Japan; and one foundation.

Martin Family Society of Fellows for Sustainability

Twenty advanced graduate students from nine departments were selected for the AY2011 Martin Fellows cohort. More than 240 doctoral students from all five schools and more than 25 departments have been supported by the Martin Family Society of Fellows for Sustainability (part of LFEE) since its formation in 1997. In September 2009, 14 current and past Martin Fellows participated in the annual Martin Fellows Retreat at Thompson Island in Boston Harbor. This year's retreat, which focused on salt-marsh ecology and restoration, was also attended by Casper Martin of the Martin Family Foundation, as well as leaders of several environment and sustainability student groups. Two lunch seminars featured young faculty involved in environmental/sustainability research: professors Heidi Nepf (Civil and Environmental Engineering) and Chris Zegras (Urban Studies and Planning). The Martin Family UROP program has supported 28 collaborations between undergraduate researchers and Martin Fellows since its inception in 2006.

Ernest J. Moniz

Director, MIT Energy Initiative

Cecil and Ida Green Professor of Physics and Engineering Systems

More information about the MIT Energy Initiative can be found at <http://web.mit.edu/miteil/>.