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 two years of operation, MITEI has attracted more than $250 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 2009 was another year of institutional growth for MITEI. Key achievements included:

- Building robust research partnerships and networks with 37 industry and public MITEI members, 14 of which signed this year
- Attracting sponsored-research and other research support totaling approximately $250 million in commitments over five years
- Funding 29 novel or early-stage research projects and two planning grants submitted by faculty and senior researchers from across the campus
- Enlarging the Society of Energy Fellows, which was established in MITEI's first year and includes 40 graduate students in its second class
- Supporting curriculum development for 10 new and revised undergraduate energy classes
- Developing the first energy minor at MIT, enhancing the energy educational opportunities for MIT students
- Coordinating MIT's efforts for the Energy Frontier Research Center (EFRC) program of the Department of Energy (DOE), with MIT receiving two large, high-impact EFRC awards
- Building the Sustainable Energy Revolutions Program, a multifaceted program within MITEI that supports renewable low-carbon energy research and related integrated policy studies
- Establishing the Eni-MITEI Solar Frontiers Research Center
- Sponsoring numerous energy seminars and colloquia
- Progressing on three integrated, multidisciplinary energy studies on the future of solar energy, the future of natural gas, and advanced nuclear fuel cycles
- Publishing an update of the MIT 2003 *Future of Nuclear Power* interdisciplinary study
- Publishing a report of the "Retrofitting of Coal-Fired Power Plants for CO_2 Emissions Reductions" symposium, organized by MITEI
- Supporting a range of student projects to improve energy and environmental management of the MIT campus

MITEI seeks support from partners in industry, from private donors, and from 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 and other universities have been very concerned that the government is underfunding energy research and development, which is crucial to our energy future. Many independent studies have already called attention to this problem. 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 US. 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, and the impacts will be enhanced if the pool of energy research dollars grows.

MITEI's leadership team includes its director, professor Ernest Moniz (Physics and Engineering Systems); deputy director, professor Robert Armstrong (Chemical Engineering); and associate director for strategic planning, Melanie Kenderdine. The directors are members of the Energy Council, which 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 second time in October 2008.

Mission

MITEI is designed to mobilize the Institute's research 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, MITEI has welcomed:

Founding Public Member: Masdar Institute of Science and Technology

Sustaining Members: Lockheed Martin, Siemens, and Total

Associate Member: Electricité de France Development Inc.

In addition, nine new affiliate members have joined.

In April 2009, MITEI selected the third group of projects, submitted by MIT faculty and senior researchers, to receive Seed Fund Program research grants. Total funding in this round of seed grants exceeded $1.5 million. Twelve one- to two-year projects received grants ranging from $60,000 to $150,000, while two additional projects were awarded smaller, shorter term "planning grants." The program supports innovative early-stage research projects addressing energy and related environmental issues and is supported by pooled funds from MITEI members as well as by private donors such as the Chesonis Family Foundation. New grants are awarded twice annually.

Eni-MITEI Solar Frontiers Center

In March 2008, the Italian energy company Eni officially became a MITEI founding member. The centerpiece of this major energy partnership is the Eni-MITEI Solar Frontiers Center, which focuses 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

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

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.

Solar Revolution Project

While not formally a part of MITEI, the Solar Revolution Project, funded by a $10 million gift from the Chesonis Family Foundation, is an important part of a growing solar research cluster at the Institute and will help 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. The Chesonis Foundation gift currently supports 24 student fellowships and three postdoctoral fellows in a wide range of solar-related studies. The gift also supports the interdisciplinary Future of Solar Energy study, chaired by Professor John Deutch, which will be completed under MITEI's auspices. In addition, the Chesonis Family Foundation is contributing $200,000 annually to the MITEI Energy Seed Fund Program.

Researchers in the Eni and Chesonis solar initiatives will also interact with two other programs—the proposed Fraunhofer Center for Sustainable Energy Systems and Masdar Institute-supported solar research projects—as well other solar research activities at MIT.

The Sustainable Energy Revolutions Program was initiated by MITEI in the fall of 2008 with the intent of replicating the Solar Revolution Project model of philanthropic support of energy research across other renewable energy technologies. The program will focus on bioenergy and solar, wind, geothermal, wave, and tidal energy; it will also establish technologies relating to energy storage, the grid, and materials.

Energy Research Opportunities

MITEI is actively engaged in identifying opportunities for energy research at MIT in response to possible American Recovery and Reinvestment Act (ARRA) funding. MITEI disseminates information on funding opportunities to faculty and research staff and also provides support for proposal development and consortium formation as needed. Proposals for ARRA funding thus far have spanned a spectrum of technologies, including solar, wind, bioenergy, building technologies, carbon capture and storage, and nuclear.

Future of Solar Energy Study

The MIT Future of Solar Energy study continues the 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 sharpen 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 and other developed and developing countries. In addition, the study analyzes past and potential policies supporting basic research, demonstration, and adoption of solar technologies.

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 chaired by Institute Professor John M. Deutch and executive director Joshua Linn, visiting research scientist at MITEI. Numerous undergraduate and graduate students are participating throughout the study. Experts from industry and government have been invited to MIT to provide input, and study 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 Natural Gas Study

A study of the future of natural gas 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 chairmen, and senior research scientist Daniel Cohn is the executive director. The study began in the summer of 2008 and will be completed in June 2010.

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 will be the effects 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.

This study will provide an independent assessment of potential natural gas supply, which will involve 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 will consider the longer future natural gas demand, 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 will be evaluated in some 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, will also be considered. The overall systems interaction among supply, demand, and policy will be studied using the MIT Emissions Predictions and Policy Analysis (EPPA) 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.

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 campus energy management activities discussed below.

Major energy education accomplishments in 2008–2009 included the approval to launch an Institute-wide undergraduate energy studies minor and significant growth in the undergraduate energy curriculum, sponsorship of energy-focused summer Undergraduate Research Opportunities Program (UROP) projects, and the formation of the MIT Society of Energy Fellows program and ongoing support of the program and its graduate student participants.

The energy studies minor, which will be launched in September 2009, consists of five subjects (three core subjects plus 24 units) and is designed to complement any undergraduate major at MIT. To earn the minor, students are required to take at least one fundamental subject within each of three domains:

- Energy Science Foundations
- Social Science Foundations of Energy
- Energy Technology/Engineering in Context

Subject 14.01 Principles of Microeconomics, or its equivalent, is a prerequisite for the Social Science Foundations of Energy domain. The additional 24 units can include other fundamental subjects or approved energy electives from an expansive subject list. Students who complete the minor will have an understanding of the broader contexts, tradeoffs, and realms of action required to create, evaluate, and advocate meaningful solutions to energy and associated environmental challenges. An experimental governance structure for the minor that includes one associate dean from each school was approved unanimously at the faculty meeting held on May 20, 2009.

En route to finalizing the energy studies minor proposal, the Energy Education Task Force (EETF) held workshops open to all MIT faculty members to solicit energy curriculum development ideas in science, social science, and engineering/technology. With the generous support of the Dirk and Charlene Kabcenell Foundation, EETF was able to fund the development of six new undergraduate classes (12.021 Earth Science, Energy, and the Environment; 15.031J Energy Decisions, Markets, and Policies; 11.162 Politics of Energy and the Environment; STS.032 Energy, Environment, and Society; and

two architecture subjects) as well as the substantial revision of the curricula for four additional subjects. Another workshop brought together faculty, students, and staff to build strong "on-ramps" to and "off-ramps" from the minor in the form of robust menus of first-year/entry-level and capstone options for energy education.

Two postdoctoral fellowships for women in energy supported by the Clare Boothe Luce Foundation were first offered in 2008–2009. Dr. Bonna Newman earned her PhD in physics at MIT and is working with professor Tonio Buonassisi (ME) on materials for solar energy applications. Dr. Carolyn Seto holds a PhD in petroleum engineering from Stanford University; she works in professor Greg McRae's (Chemical Engineering) group on monitoring carbon dioxide sequestration and studying the future of natural gas. Newman and Seto both reported that the first year of their Luce Fellowship was of tremendous value in extending their energy scholarship across disciplinary boundaries and exploring the academic work environment.

MITEI's UROP grew to 15 students working on 12 projects during summer 2009. Projects range from improving the efficiency of organic materials for photovoltaics to developing new ways to model travel and investigating better methods to cool data centers. The program is supported by four MITEI affiliate members and one alumni donor.

The Society of Energy Fellows at MIT has grown to 80 members with the designation of the 2009–2010 cohort of graduate students representing 20 departments and all five schools. The fellowships are supported by MITEI's two founding, nine sustaining, and one associate member. 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 throughout the 2008–2009 academic year exposed members to a broad range of topics, ideas, and points of view. Fellows events included a full-day symposium in September highlighting the range of MIT energy research, meetings and discussions hosted by sponsors for their groups of fellows, a range of informal gatherings, and an end-of-year celebration featuring remarks from Institute Professor, MITEI Energy Council member, and MIT graduate John Deutch ('61).

MITEI's EETF guides the development of energy education at MIT. The task force, cochaired by professor Vladimir Bulovic and professor Donald R. Lessard (Sloan School of Management), includes 16 faculty members from 14 different departments and three students. EETF meets regularly during the academic year. Professional staff in MITEI's Education Office support MITEI and EETF in implementing energy education programs.

Campus Energy Management

The Campus Energy Task Force has advanced a host of campus energy projects that complement MITEI research and education activities and engage the entire MIT community. The task force is the catalyst for an unprecedented partnership among Institute students, faculty, and staff to develop a robust campus energy program focused on discovering and adopting the best practices and technologies to address MIT's own campus energy challenges. Task force members include faculty from the five academic schools, representatives from key administrative offices and support staff, and both

undergraduate and graduate students. A number of strategies to advance sustainable energy practices and reduce MIT's energy use have been the result of research and collaborative projects involving students and faculty from many different schools at MIT and staff from administrative units such as Facilities, Information Services and Technology, Housing, Travel, and Environment, Health, and Safety.

This year, the Campus Energy Program has advanced President Hockfield's vision of engaging the entire MIT community in MITEI activities. The program provides a focus and platform for engaging students, staff, administrators, alumni, and local community members, including community members who may not be engaged in formal research or educational endeavors. The task force has supported a wide community of people—custodians, department heads, administrative assistants, research scientists, faculty members, undergraduates, department staff, and others—in helping MIT "walk the talk" on energy and sustainability. In addition, the program has provided a rich opportunity to build awareness of MITEI in general across campus and has allowed many more people to engage with, learn from, and enrich MITEI in different capacities.

The MIT Campus Energy Program has three goals:

- Reduce MIT's energy consumption and associated greenhouse gas emissions economically
- Enhance student learning by using campus operations as a living laboratory for discovery and innovation
- Serve as a model of intelligent, effective actions to reduce energy consumption and greenhouse gas emissions, a model that can be used by others in the US and worldwide

The program is guided by the following principles:

- Comprehensive: utilities, transportation, computing, sustainable design, and education, including both engineered and behavioral solutions
- Inclusive: students, staff, and faculty, with a focus on multidisciplinary and collaborative problem solving
- Disciplined: sound return on investment and use of a portfolio approach, with a focus on modeling best practices for global impact

This past year, the Campus Energy Task Force advanced progress in several areas. Areas of focus include:

- Facilities energy conservation and conservation funding
- Sustainable design
- Commuting
- Efficient computing
- Community participation
- Student learning

Energy Conservation Investment Fund

MIT has advanced the pilot phase of the MIT Energy Conservation Investment Fund with $500,000 of seed capital provided by the MIT treasurer to fund investments in energy efficiency across campus. The projects funded with this initial investment included steam trap monitoring and renewing, lighting upgrades, continuous commissioning, and coil cleaning. The estimated annual cost saving from these projects approaches $1 million. The treasurer committed to reinvesting the savings achieved in the next round of projects that are under way.

An alumnus has recently added $500,000 to this fund. We have a gift from another donor for $1 million that will create an expendable fund for an agreed-upon list of on-campus energy conservation and efficiency projects using proven technologies with rapid payback. The fund is intended to demonstrate that significant savings can be realized by effectively using proven technologies to save energy. The savings will be measured and validated using generally accepted engineering standards for the technologies implemented. MIT will use the savings from these projects to fund a second list of projects to further advance the Institute's energy savings program.

Facilities Energy Conservation, Efficiency, and Sustainable Design

The Department of Facilities has made substantial progress in designing and carrying out a series of measures to conserve energy and promote sustainable design. A few recent highlights are described below.

A continuous commissioning program (a program that monitors hundreds of key operating parameters to identify systems that are not operating properly) was carried out in the Dreyfus Chemistry Building (Building 18) and the Zesiger Sports and Fitness Center (Building W35). To date, measures with annual savings of $500,000 have been identified. Similar continuous commissioning programs are also being implementing in Buildings E25, 68, 16, and 56. In Building 68 alone, recent work has identified approximately $300,000 in annual savings due to pinpointing and correcting inefficiently operating heating, ventilation, and air conditioning (HVAC) system components from a one-time capital cost of approximately $100,000.

Various lighting projects have been initiated. These include the replacement of lamps and ballasts with more efficient versions, the addition or improvement of lighting controls, and fixture upgrades. Recent lighting measures in Dupont W32 (including fencing, wrestling, and squash facilities), the W8 boathouse, and the Building 34 elevator lobbies cost $80,000 and are estimated to return an annual savings of $45,000. A Stata Center lighting program is expected to cost $520,000 and save approximately $160,000 annually. A new policy encourages custodians to turn off lights in offices and classrooms at the end of their shifts, resulting in fewer lights being left on around campus at the end of the day. A program to encourage turning off lights in labs is currently being developed.

In the recently completed PDSI project (named for the Department of Physics, Department of Materials Science and Engineering, Spectroscopy Laboratory, and Infrastructure), an innovative and more energy-efficient cooling system known as "chilled beams" has been successfully completed and commissioned and will set the

standard for future renovations of other Main Group spaces. An estimated 300-ton reduction in chilled water demand has been achieved as well as a 110-hp reduction in necessary fan horsepower.

New Ashdown House (NW35) is on track for Leadership in Energy and Environmental Design (LEED) Silver certification with the possibility for Gold. This is the first MIT dorm to employ heat recovery from kitchen and bath exhaust systems as well as a highly efficient curtain wall system allowing the use of smaller than typical size HVAC equipment. The Department of Facilities continues to fine tune the new systems to achieve even higher efficiencies. Similar to the Sloan School 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 lab energy use head on and challenges current rules of thumb for HVAC needs to improve system efficiencies.

The Housing Office partnered with the winners of the annual Dorm Electricity Competition, in which the contest-winning dorm receives a prize of $10,000, to develop energy-efficient renovations within their residence halls. Housing staff and students worked collaboratively to identify efficiency opportunities. As a result of this work, lighting in dormitories has been improved and dorms have been provided with motion and heat sensors, helping students gain a better understanding of their effects on overall energy costs. The 2009 competition saved MIT approximately 167.28 MWh of electricity, enough electricity to power 14 homes for an entire year.

Students and the Housing Office are collaborating with MITEI and other departments to install electrical meters in specific apartments to showcase the effects of behavior on energy use and cost.

Campus Dining has initiated and deepened several programs to advance more sustainable dining practices and options, including working with its food service providers to offer and celebrate more locally sourced and organic foods, promoting the use of nondisposable serviceware, supporting Biodiesel@MIT to convert waste vegetable oil to biodiesel fuel, adopting more environmentally friendly dishwashing technologies, composting food preparation waste, recycling wherever possible, and employing batch cooking and made-to-order food to reduce food waste.

Transportation and Commuting Enhancements

Since transportation needs for the Institute represent a significant source of energy use and greenhouse gas emissions, the Campus Energy Task Force considers measures that can have favorable impacts on our campus fleet and commuting options and patterns. MIT has a wide range of flexible, environmentally friendly, and cost-effective options available to Institute commuters, details of which are available at http://web.mit.edu/facilities/transportation/. These options help the MIT community lower its carbon footprint, as evidenced by the choices people make on how they commute to campus. The Parking and Transportation Office has focused recent efforts on programs that help those with the longest commute (commuter rail users) and those who drive full time. The following are some highlights of recent enhancements.

Encouraging drivers to try public transportation, MIT offered free transit passes for the month of September 2008 to employees who currently park at MIT five days per week. The community enthusiastically responded to this offer, as evidenced by the fact that 708 drivers opted to participate. In October 2008, 79 people switched to transit.

Helping many who have some of the longest commutes and were not using commuter rail, MIT increased its subsidy of MBTA commuter rail passes for the month of October 2008 onward, up to 50% in all zones. This resulted in savings for nearly 600 members of the MIT community. Commuter rail pass sales showed a year-over-year increase of more than 13% in the first nine months of AY2009.

MIT expanded parking options at five satellite off-campus sites. In combination with existing shuttle services, we added 22 spaces at Lincoln Laboratory and 10 spaces at Wellesley College for commuters who drive in from the western suburbs. Since parking can be a barrier to the formation of car and van pools, we added rideshare parking at Haystack, Endicott House, and Bates.

To reduce the environmental impact for commuters who need to drive to MIT and to encourage MIT drivers to choose an environmentally friendly vehicle the next time they purchase a vehicle, a 20% parking discount was introduced for eco-friendly vehicles.

A private transit reimbursement has been added for people who do not live within a transit area serviced by MBTA. Eligible providers include Amtrak, Peter Pan, and P&B. The reimbursement provides a monthly $75 "commuter check" to participants, up to a monthly maximum of $120 when combined with an MBTA pass.

A recent survey showed that the percentage of MIT commuters driving alone the entire way to campus (a key metric of commuter programs) has decreased from 26% to 22%.

Community Engagement and Behavior Change for Energy Conservation

The Campus Energy Task Force has launched the GreeningMIT campaign to further integrate MITEI activities with the entire MIT community. GreeningMIT is a new initiative to engage all students, staff, and faculty in taking action to make the MIT campus more sustainable and advance priority actions of the task force. Through awareness campaigns, information resources, planning tools, and a supportive network of green ambassadors, the task force is making it easy for everyone to make a difference in their "place" at MIT. The Green Ambassadors program is an initiative that creates and empowers 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 task force has recruited more than 90 individual green ambassadors to support the Institute's energy and environmental stewardship objectives.

MITEI's Energy Futures Week, held during Independent Activities Period (IAP) 2009, featured several activities to showcase the work of the Campus Energy Task Force to "walk the talk" and kick off the community engagement activities of the GreeningMIT campaign. With a community rally, panel discussions, a "greening" workshop, and the

launch of the new GreeningMIT logo, we were able to engage hundreds of members of the MIT community and raise awareness of ways we all can promote sound energy and environmental practices in our daily lives.

Efficient Computing

The energy impacts from the use of information services and technology on campus are substantial. To identify measures that can reduce those impacts and advance more sustainable information technology (IT) practices, the Campus Energy Task Force has supported the energy program efforts of the Information Services and Technology Department (IS&T). Some recent highlights include the following.

IS&T has licensed server virtualization software for use at MIT from VMware Inc. Use of virtualization software will enable the consolidation of underutilized physical servers through the creation of multiple virtual machines (VMs) on a single physical server. An added benefit is the ability to run multiple operating systems on a single server, eliminating the need to purchase two separate servers. The reduction in physical servers results in a reduction in power and cooling energy.

Potential recent savings from reduced power use and cooling requirements as a result of using virtualization include a savings of 1,885,465 kWh of electricity, reducing 848 tons of CO_2 emissions. Top users of VM licenses include Lincoln Laboratory (46%) and IS&T (38%). Application types include web servers, infrastructure support, development, and testing. Additional IS&T energy projects are detailed at http://web.mit.edu/ist/initiatives/it-energy/.

Student Learning and Engagement

The Campus Energy Task Force provides opportunities to engage students in work of the Campus Energy Program that provides rich learning and educational experiences while contributing valuable research, analysis, and project implementation. These opportunities are found within and outside MIT's curricula and allow students, faculty, and staff to engage in hands-on research and exploration using the operations and management of the campus infrastructure as a test bed of ideas and approaches. MIT's campus operations are being used as a learning laboratory—through UROP projects, special classes, internships, and research projects—to foster students' emerging technical and leadership skills, which will help define and solve our own energy challenges. This past year, 13 UROP projects and internships focusing on campus energy issues were supported by task force members in partnerships with academic and administrative units. Through the MITEI Student Campus Energy Project Fund, we have been able to support over 30 student projects on campus that engage our students and advance our campus energy objectives while simultaneously providing rich learning opportunities.

The task force facilitates and supports MIT research activities that use our campus for real-world testing. For example, a yearlong monitoring program in IS&T's main building (N42) conducted by a Building Technology Program PhD student was recently completed. The purpose of the project was to identify potential avenues for efficiency savings at N42. After installation of several devices for measuring daylighting and

temperature in the building, the project identified simple lighting and HVAC efficiency opportunities that might save over 20 percent of IS&T's electricity bill at its headquarters.

IS&T is also participating in a recently funded MITEI seed grant proposal titled "The MIT Enernet." Submitted by professors Neil Gershenfeld, Carlo Rati, and Harvey Michaels, the multidisciplinary MIT Enernet project combines network activity data from IS&T with energy data from MIT Facilities in an analytical framework that will allow MIT Facilities to quickly identify energy efficiency opportunities in every building at the Institute.

Fundraising

The Campus Energy Task Force has identified two major areas for fundraising related to the campus energy effort: educational opportunities tied to campus energy activities and an investment fund for energy efficiency improvements in the campus infrastructure. This past year, it has secured two significant alumni gifts totaling $1.5 million to support priority initiatives and advance campus energy objectives. Both gifts reflect the compelling and innovative features of the MIT Campus Energy Program that allow for community engagement in shaping the Institute's future while also providing robust financial returns through energy cost savings. The task force will continue to develop and build awareness of these opportunities. Using widely accepted methods for measuring and verifying savings from donor-supported energy conservation projects, it will be in a strong position to demonstrate to the donor community the real impact of these gifts to MIT.

Campus Energy Task Force Members

Cochairs

Leon R. Glicksman, professor of building technology and mechanical engineering

Theresa M. Stone, MIT executive vice president and treasurer

Faculty

Vladimir Bulovic, associate professor of electrical engineering and computer science

Peter Fisher, professor of physics

Rae Langton, professor of philosophy

Leslie K. Norford, professor of architecture

John Sterman, Jay Forrester professor of management

Christopher P. Zegras, assistant professor of urban studies and planning

Administration and Research Staff

Richard Amster, director, facilities, campus planning, engineering, and construction

Peter L. Cooper, manager of sustainability engineering and utility planning, Department of Facilities

John Difava, director, facilities operations and security

Martin Schmidt, associate provost

Amanda Graham, director, MITEI Energy Education Office

Sherwin Greenblatt, director, Venture Mentoring Service, Office of the Provost

Walter E. Henry, director, Systems Engineering Group, Department of Facilities

Steven M. Lanou, deputy director, Sustainability Program, Environmental Programs Office

Karen Nilsson, senior associate dean for residential life

Laxmi J. Rao, IT energy coordinator, Information Services and Technology

Lauren Berning, administrative assistant, Department of Nuclear Science and Engineering

William Van Schalkwyk, managing director, Environment, Health, and Safety Programs

Students

Jason J. Jay, Sloan School of Management

Katherine Dykes, Engineering Systems Division and Energy Club

Vrajesh Modi, ME and Undergraduate Association Sustainability Committee

Outreach

MITEI hosted a number of outreach events throughout the year, including four high-level energy colloquia, eight seminars in the inaugural year of its seminar series, a natural gas speaker series, and eight additional "special" events that did not fall into series or programs. The 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 several of the events, MITEI has helped to bring the national energy policy conversation to campus. In October, MITEI and the MIT Energy Club hosted a debate on energy policy between senior advisors to the McCain and Obama campaigns. In April, MITEI hosted a symposium featuring Congressman Edward Markey, chair of the Select Committee on Global Warming; Carol Browner, assistant to the president for energy and climate change; and John Holdren, science advisor to the president. Forum speakers outlined the path to reaching domestic and international climate mitigation agreements. In the spring, with the MIT Museum, MITEI sponsored a Soapbox Series titled "What's the Latest in Solar Energy?" During the Cambridge Science Festival, MITEI participated in a panel discussion, "Meltdown: What You Need to Know and Do about Energy," at Cambridge City Hall; the discussion was moderated by Dr. Eric Lander. In May, MITEI hosted a panel of nuclear power experts to discuss how to address nuclear waste recycling or disposal. The meeting was convened by Senator Tom Carper (D-DE), chair of the Senate Subcommittee on Clean Air and Nuclear Safety.

In March, MITEI held a daylong, invitation-only symposium on the range of technology and policy issues associated with the retrofitting of coal-fired power plants for carbon capture. More than 50 technical and policy experts, representing the entire energy spectrum, participated. In June, MITEI produced a report from the symposium that reflected the views of the participants and detailed integrated policy and technology approaches for addressing this critical problem. The findings of the report were unveiled in a press briefing that featured Professor Moniz, Entergy CEO J. Wayne Leonard, and Congressman Ed Markey, as well as in House and Senate briefings in Washington, DC. Building on the success of this model, MITEI is engaging members in institutionalizing the model and will organize similar workshops on other timely topics on an annual basis.

List of Events

MITEI Energy Colloquia

Energy: The Past Must Not Be Prologue (October 15, 2008)
Speaker: George P. Shultz

Energy Supply and Demand, Economics, and Greenhouse Gas Management: Are They Related? (February 26, 2008)
Speaker: Carl Bauer, director of the Department of Energy's National Energy Technology Laboratory

The New Energy Reality (January 17, 2008)
Speaker: Clay Sell, deputy secretary and chief operating officer, US Department of Energy

Escaping from Our Energy Trap (January 14, 2008)
Speaker: Leonardo Maugeri, group senior vice president for strategies and development, Eni SpA, Italy

MITEI Seminar Series

Meeting US Energy and Climate Challenges with Rational Policy (May 5, 2009)
Speaker: Severin Borenstein

Using Science to Innovate in Efficient Energy Utilization (April 14, 2009)
Speaker: Arun Majumdar

Sunlight-Driven Hydrogen Formation by Membrane-Supported Photoelectrochemical Water Splitting (March 10, 2009)
Speaker: Nate Lewis

Recent Advances, New Trends, and Future Challenges within the Li-ion Battery Energy Storage System (February 10, 2009)
Speaker: Jean-Marie Tarascon

The Sustainable Energy Challenge (December 2, 2008)
Speaker: George Crabtree, Argonne National Laboratory

Zero Energy Buildings: Potentials and Realities (November 18, 2008)
Speaker: Stephen Selkowitz, Lawrence Berkeley National Laboratory

Energy Services for the Poor (October 7, 2008)
Speaker: H. Harish Hande

Profitably Reducing Greenhouse Gas Emissions (September 9, 2008)
Speaker: Thomas R. Casten, chairman, Recycled Energy Development

Natural Gas Speaker Series

Unconventional Gas: Resources and Technology Needs (February 20, 2009)
Speaker: Kent Perry

LNG: Expanding the Horizons of International Gas Trade (March 19, 2009)
Speaker: Jim Jensen

A New Energy Break Point: The Evolved Character of Natural Gas in North America (March 30, 2009)
Speaker: Peter Tertzakian

Perspectives of International National Gas Trade: Competition-Contracts-Cartel (April 29, 2009)
Speaker: Dr. Christian Von Hirschhausen

Principles and Methods of Gas Shale Production Enhancement (May 14, 2009)
Speaker: Dr. Robert Kleinberg

MIT Museum Soapbox Series: "What's the Latest in Solar Energy?"

Next-Generation Solar Cells—Lowering Costs, Improving Performance and Scale (May 5, 2009)
Speaker: Professor Tonio Buonassisi (ME)

Nanoscale Engineering for High-Performance Solar Cells (May 12, 2009)
Speaker: Professor Vladimir Bulovic (EECS)

Luminescent Solar Concentrators Explained (May 19, 2009)
Speaker: Professor Marc Baldo (EECS)

Special Events

Recycling Nuclear Waste: Addressing Waste in the 21st Century (May 18, 2009)
Speakers: Senator Tom Carper, Charles Forsberg (Nuclear Science and Engineering), Matthew Bunn (Harvard), Ernest Moniz, Andrew Kadak (Nuclear Science and Engineering)

Meltdown: What You Need to Know and Do about Energy (April 23, 2009)
Speakers: Professor Eric Lander, moderator; Ron Prinn (TEPCO), Jake Jacoby, Ernest Moniz, Steve Morgan, Stephen Ansolabehere (Harvard), and Laurie Bent

Reflections on Our Planet and Its Life: Origins and Futures (MITEI Earth Day Colloquium; April 22, 2009)
Speaker: James McCarthy (Harvard)

A Symposium to Honor Institute Professor John Deutch (April 16, 2009)
Speakers: George Whitesides (Harvard), James Schlesinger (former secretary of defense), Linda Stuntz, Philip Deutch, Harold Brown (former secretary of defense), Brent Scowcroft (former US national security advisor), John Podesta (former White House chief of staff), and John Deutch

Clean Power: Building a New Clean Energy Economy (April 13, 2009)
Speakers: President Susan Hockfield, Congressman Edward J. Markey, John Holdren (director of the Office of Science and Technology Policy), Daniel Yergin (founder and chairman, Cambridge Energy Research Associates), Ernest Moniz, and Carol Browner (assistant to the president for energy and climate change)

Energy Futures Week (IAP 2009; January 12–15, 2009)
Several activities showcasing the work of the Campus Energy Task Force to "walk the talk" and kicking off the community engagement activities of the GreeningMIT campaign

Presidential Campaigns Debate Energy (October 6, 2008)
Speakers: Jason Grumet (executive director of the National Commission on Energy Policy) and R. James Woolsey (former director of the CIA)

Energy Policy and Technology (September 19, 2008)
Speaker: Joseph T. Kelliher, chairman, Federal Energy Regulatory Commission (FERC), with commentary by FERC commissioner Jon Wellinghoff

Publications

MITEI's biannual magazine was published in October 2008 and May 2009. MITEI also produced a book of research, education, and outreach spotlights for 2008, featured on the MITEI website home page, as well as an overview brochure and a brochure focusing on the MITEI education program.

Studies

In May, a group of MIT faculty completed an update of the 2003 Future of Nuclear Power study. The 2003 study addressed the steps needed in the near term in order to enable nuclear power to become a viable marketplace option at a time and scale that could materially mitigate climate change risks. The update showed that, compared to 2003, the motivation to make more use of nuclear power is greater, and more rapid progress is needed in enabling the option of nuclear power expansion if it is to play a role in meeting the global warming challenge.

A second purpose of the update is to provide a context for a new MIT study, currently under way, on the future of the nuclear fuel cycle; this study will examine the pros and cons of alternative fuel cycle strategies, the readiness of the technologies needed for them, and the implications for near-term policies.

Federal Government

In addition to hosting a forum with Congressman Edward Markey on clean power, a roundtable with Senator Tom Carper on nuclear waste recycling, and a reception with Secretary of Energy Steven Chu following his Compton lecture, MITEI has coordinated MIT's response to solicitations from the federal government.

MITEI was instrumental in coordinating MIT's response to DOE's call for proposals for the establishment of Energy Frontier Research Centers (EFRCs). MIT will lead two of 46 new multimillion-dollar EFRCs—the Center for Excitonics, funded at $19 million, and the Solid-State Solar-Thermal Energy Conversion Center, funded at $17.5 million—and will be engaged in four others.

Leadership

Solid-State Solar-Thermal Energy Conversion Center
Gang Chen, Director
Massachusetts Institute of Technology
Objective: To create novel, solid-state materials for the conversion of sunlight and heat into electricity.
This EFRC aims to advance our fundamental scientific understanding of thermoelectric and thermophotovoltaic materials and to develop novel materials and devices to harvest energy from the sun and terrestrial heat sources. The multidisciplinary effort integrates theory and experiment to study the fundamentals of photon, phonon, and charge carrier interactions in thermoelectric materials and will also utilize photonic crystals and metamaterials to convert the solar energy spectrum in an attempt to provide an ideal match to the bandgap of photovoltaic materials. This EFRC includes planned collaborations with scientists at Boston College and Oak Ridge National Laboratory, and will encompass novel materials synthesis, phonon and electron spectroscopies and multiscale modeling and simulation. Also, it will utilize scanning transmission electron microscopy imaging facilities as well as neutron spectrometers at the High-Flux Isotope Reactor and the Spallation Neutron Source of the Oak Ridge National Laboratory and ultraviolet photoelectron spectroscopy at Brookhaven National Laboratory's National Synchrotron Light Source.

Center for Excitonics
Marc A. Baldo, Director
Massachusetts Institute of Technology
Objective: To understand the transport of charge carriers in synthetic disordered systems, which hold promise as new materials for conversion of solar energy to electricity and electrical energy storage.
With photosynthesis as an inspiration and guide, this EFRC will achieve its objective through a combination of theory, modeling, materials synthesis, and characterization. The planned research has the following goals: understanding the effects of environment and coherence on exciton transport in complex nanostructures; exploring and characterizing novel excitonic states, including hybrid organic-inorganic excitons, strongly coupled exciton polaritons and exciton plasmon polaritons; and performing spectroscopic studies of exciton formation, dissociation, fission, and annihilation. This EFRC includes planned collaborations with scientists at Harvard University and Brookhaven National Laboratory, and some of the work will be done using the Center for Functional Nanomaterials at Brookhaven.

Collaborations

Center for Nanoscale Control of Geologic CO_2
Donald DePaolo, Director
Lawrence Berkeley National Laboratory
Objective: To establish the scientific foundations for the geological storage of carbon dioxide.
The objective this EFRC is to enhance the scientific foundation of how subsurface fluids and rocks interact as they are moved away, sometimes far away, from equilibrium by technological applications. The immediate application of interest is the problem of geological storage of carbon dioxide related to reducing greenhouse gases released to the atmosphere from stationary power sources, but long-term benefits are expected for predicting the performance of any subsurface storage application for long periods of time. This EFRC includes planned collaborations with scientists at Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, MIT, and the University of California, Davis. The EFRC will utilize the Advanced Light Source, Molecular Foundry, and National Energy Research Scientific Computing Center at Lawrence Berkeley National Laboratory and the Spallation Neutron Source at Oak Ridge National Laboratory.

Energy Frontier Research Center for Combustion Science
Chung K. Law, Director
Princeton University
Objective: To develop a suite of predictive combustion modeling capabilities for the chemical design and utilization of non-petroleum-based fuels in transportation.
This EFRC plans to construct accurate combustion models through the use of three-dimensional representations of the interacting chemistry functional groups, coupled with quantum chemical predictions of reaction rate coefficients, and to validate these models by comparisons with experimental data from a variety of measurements on gas-phase reactions. The EFRC will significantly impact the combustion community by developing a suite of predictive high-fidelity simulation and combustion modeling capabilities for designing novel non-petroleum-based fuels for advanced transportation engines, which will be characterized and validated by experiments at the molecular and macroscopic scales. This center includes planned collaborations with scientists at Case Western Reserve University, Cornell University, MIT, the University of Minnesota, the University of Southern California, the Combustion Research Facility at Sandia National Laboratory, and Stanford University. It will utilize the Advanced Light Source at Lawrence Berkeley National Laboratory.

Extreme Environment-Tolerant Materials via Atomic Scale Design of Interfaces
Michael Nastasi, Director
Los Alamos National Laboratory
Objective: To understand, at the atomic scale, the behavior of materials subject to extreme radiation doses and mechanical stress in order to synthesize new materials that can tolerate such conditions.
This EFRC recognizes that the challenge of developing materials with radically extended performance limits at irradiation and mechanical extremes will require designing and perfecting atom- and energy-efficient synthesis of revolutionary new materials that maintain their desired properties while being driven very far from equilibrium. To address these issues, the EFRC will develop a fundamental understanding of how

atomic structure and energetics of interfaces contribute to defect and damage evolution in materials and use this information to design nanostructured materials with tailored responses at irradiation and mechanical extremes. This EFRC includes planned collaborations with scientists at MIT, Lawrence Livermore National Laboratory, and the University of Illinois. The EFRC will utilize the Center for Integrated Nanotechnologies at Los Alamos and Sandia National Laboratories and the Electron Microscopy Center at Argonne National Laboratory.

Northeastern Chemical Energy Storage Center
Clare P. Grey, Director
State University of New York at Stony Brook
Objective: To understand how fundamental chemical reactions occur at electrodes and use that knowledge to design new chemical energy storage systems.
This EFRC seeks a fundamental understanding of how electrode reactions occur and how they can be tailored through appropriate electrode designs so that critical structural and physical properties vital to improving battery performance can be identified and used to design new battery systems. The EFRC will also develop advanced in situ diagnostic methods for chemical energy storage systems that combine multiple experimental approaches, such as spectroscopy and imaging. This center includes planned collaborations with scientists from Rutgers University, the State University of New York at Binghamton, MIT, Lawrence Berkeley National Laboratory, the University of Michigan, Argonne National Laboratory (including the Advanced Photon Source), Brookhaven National Laboratory (including the National Synchrotron Light Source and the Center for Functional Nanomaterials), and the University of Florida.

MITEI is now positioning MIT to respond to the Energy Innovation Hub program, for which there is proposed funding in the FY2010 budget. DOE proposes to fund eight multidisciplinary Energy Innovation Hubs at a total of $280 million. Modeled after the department's Bioenergy Research Centers, the work of the hubs will range from basic research to engineering development, commercialization, and a hand-off to industry. Each hub will be funded at $25 million per year, with one-time additional start-up funding of $10 million in the first year for renovation, equipment, and instrumentation.

MITEI is also gathering and disseminating information on government solicitations, compiling a list of the current DOE solicitations for energy research and development for which universities are eligible to apply and sending a weekly notice to faculty. And while there continues to be very little detail available about the process DOE will use to allocate and distribute the funds it has received from the stimulus package to support energy research, development, and research infrastructure, MITEI is well positioned to respond. MITEI has collected and has readily available a number of short white papers that outline important areas of energy research MIT is seeking to undertake.

Laboratory for Energy and the Environment

The Laboratory for Energy and the Environment (LFEE) is a key subunit within the MIT Energy Initiative that deals with issues of energy, the environment, and sustainability. It includes both core component and affiliated programs; highlights of 2008–2009 achievements are detailed below.

Alliance for Global Sustainability

Research and educational activities supported by the Alliance for Global Sustainability (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 (NGOs), government, and other leading academic institutions addressing complex environmental problems transcending geographical and disciplinary boundaries.

Building on past integrated, collaborative research activities, 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, 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 Azorian island of São Miguel will work not only 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 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 AGS and promote synergy among Near-Term Pathways research activities, the program will also 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. The 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. LFEE'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 18 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, 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 CO_2 by Chemical Absorption
- Stimulus-Responsive Structure Fluids for Dynamic Mediation of Carbon Dioxide Separation
- Representation of CCS Technology in EPPA
- The Feasibility of Air Capture
- Development of a Carbon Management Geographic Information System (GIS)
- Survey of Public Attitudes about Carbon Dioxide Capture and Storage
- Regulatory and Legal Issues for Carbon Dioxide Capture and Storage

The CCS Technologies Program has been involved in many national and international efforts related to carbon capture and sequestration. This past year, the primary example is that MIT was the organizer of the Ninth International Conference on Greenhouse Gas Control Technologies (GHGT-9), held in Washington, DC, in November 2008. Howard Herzog chaired both the Organizing and Program committees. We attracted close to 1,500 delegates and over 600 technical papers. GHGT is the preeminent conference series for the CCS research community.

Funding for the program comes from diverse sources, including DOE, private industry, and NGOs. 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 the Analysis Group for Regional Energy Alternatives (AGREA), led by Stephen Connors. Through LFEE and AGREA, Connors coordinates the sustainable energy activities of AGS and the MIT-Portugal Program on Sustainable Energy Systems.

The scenario-based multiattribute 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, the TRANSES (Transition to Sustainable Energy Services in Northern Europe) project in collaboration with the Norwegian University of Science and Technology (NTNU), AGS regional energy and environmental studies, the China Energy Technology Program-Shandong Province case study, 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 localized wind, solar, and energy storage; offshore wind; 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.

In addition to the projects and programs listed above, Connors cosupervises 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 Africa and other developing regions; 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 the Building Technology Program (BTP) has its principal focus on energy efficiency and sustainable design for buildings. In the US, buildings consume almost 40% of the total energy and more than two thirds of the electricity. 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.

Four of the five faculty members of BTP have had strong input into LFEE's or MITEI's energy research and teaching: professors Marilyne Andersen, John Fernandez, Leon Glicksman, and Les Norford (Architecture). Professor Andrew Scott (Architecture) is also a member of the group and is active in many projects. Many of the activities involve substantial joint efforts with faculty members and students in EECS 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 (China). Typically there are 15 to 20 graduate students carrying out 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 the natural ventilation of commercial buildings; design tools; fault detection, monitoring, and control; sustainable buildings for developing countries; daylighting; and the application of option theory. They are also working with the MITEI Campus Energy Management and Education task forces. We currently have joint programs with researchers and academics in Portugal, Singapore, Abu Dhabi, and Japan.

Center for Advanced Nuclear Energy Systems

MITEI administered a large interdisciplinary study of the fuel cycle through the Center for Advanced Nuclear Energy Systems (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.

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 LFEE's and 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.

Focusing on new engine and fuel technologies, the Engine and Fuels Research Consortium explores critical fuel/air mixture preparation and emission formation mechanisms in gasoline and diesel engines and the development of new engine and fuel concepts. It is funded by companies in the automotive and petroleum industries and DOE. Complementing the engine and fuel 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 of these consortia also sponsor separate research projects on topics of specific interest to the individual sponsors related to engines and fuels. A consortium with 10 members focused on developing low ash-producing lubricants to enable significantly improved diesel emission control is now under way with strong support from the diesel engine industry.

SAL researchers are also involved in multidisciplinary studies assessing new vehicle and propulsion system technologies for future road transportation use. A multisponsor study is examining 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 report, On the Road in 2035, summarizing its findings.

An example of the group's efforts to develop new technology is a downsized boosted gasoline engine concept with fuel economy levels close to today's diesel engines at much lower cost, with the use of ethanol to enable knock-free boosted spark-ignition engine operation. This concept is being developed by Dr. Leslie Bromberg, Dr. Daniel Cohn, and professor John Heywood.

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 among the major participants in the MIT Energy Initiative. 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. A brief description of the different research areas follows.

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 engineer 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 CO_2 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 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 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 research 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_2 Allowance Trading Program and the Northeastern NO_x Budget Program. Recent work includes an 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 developing markets for oil and natural gas and renewables. 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 Professor Jacoby 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 17-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. The 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-three advanced graduate students from 11 departments were selected for the 2009–2010 Martin Fellows cohort. More than 220 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 November 2008, 15 current and past Martin Fellows participated in the annual Environmental Fellows Retreat at Woods Hole Oceanographic Institution. This year's retreat, which focused on long-term trends in global ecology, was also attended by leaders of nine environment

and sustainability student groups. The Martin Family UROP program has supported 21 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/mitei/.