MIT Energy Initiative

The MIT Energy Initiative (MITEI) is MIT's energy hub, pairing world-class research teams from across the Institute with government and industry to respond to global energy challenges through research, education, and outreach. MITEI supports energy research, leads Institute energy education efforts, and produces comprehensive analyses for policymakers. Through its member companies, government funding, and philanthropic donations, MITEI has raised more than $550 million to date to support MIT and MITEI research, education, and outreach programs.

MITEI is an Institute-wide initiative that, in its depth and breadth, is without peer at US academic institutions. MITEI-sponsored researchers are developing cutting-edge solutions and bringing new technologies to the marketplace. Nearly 30% of the MIT faculty is engaged with MITEI's programs.

MITEI has more than 71 industry and public partners that have collectively funded nearly 130 innovative seed research projects proposed by faculty from across MIT. Researchers in all five schools and in 22 departments have received support through the Seed Fund Program. Seed projects have led to the formation of numerous start-up companies, and others have received major government funding or have grown into member-supported sponsored research programs. Overall, in addition to the Seed Fund Program, MITEI members have sponsored more than 800 projects, many taking the form of collaborations with their researchers. MITEI has also helped individual faculty and faculty teams secure competitive government funding for the Department of Energy (DOE) Innovation Hub led by the Oak Ridge National Laboratory, in which MIT is a core university partner; two highly competitive DOE Energy Frontier Research Centers, both of which were renewed this June; and five prestigious Advanced Research Projects Agency-Energy (ARPA-E) awards.

More than two-thirds of MITEI's research portfolio reflects the initiative's core mission of enabling the low-carbon economy of the future through the adoption of renewable energy, energy efficiency, and carbon management technologies. The largest single area of funded research is solar energy technology and policy. Much of the remainder of the portfolio is concerned with meeting contemporary energy needs through the efficient use of conventional energy sources.

MITEI offers a "commons" approach that multiplies benefits to its member participants. All of the members benefit from opportunities to pool resources that increase their overall understanding of MITEI's research and analyses. Member shared value is created through consortia, seed fund research, and the sponsorship of fellows.

MITEI's educational offerings combine single-discipline depth with multidiscipline breadth, transforming the MIT campus into an energy learning laboratory. This year, the number of visits to energy classes on OpenCourseWare (OCW) passed 1 million. Energy classes are also taught on *MITx* and edX.

The initiative has awarded 300 graduate fellowships in energy and supported 185 undergraduate research opportunities. This year the energy studies minor, the third largest minor at MIT, graduated 35 students. Faculty associated with MITEI help shape energy education at both the undergraduate and graduate levels by teaching, advising, and developing new curricula.

MITEI's outreach program promotes and disseminates energy research findings to the MIT community as well as to policymakers, industry leaders, and other stakeholders. Through colloquia, symposia, and seminars, MITEI introduces energy thought leaders from across the energy value chain to the local audience, including the MIT community, students and faculty at nearby colleges and universities, Boston- and Cambridge-area politicians, energy industry personnel, and interested residents.

Through research, education, and outreach, MITEI's interdisciplinary approach covers all parts of the energy spectrum, from supply and demand to security and environmental impact.

Organization

This year director Robert Armstrong introduced MITEI's new leadership team, which includes Robert Stoner, deputy director for science and technology; Martha Broad, executive director; Louis Carranza, associate director; Amanda Graham, director of education; and Francis O'Sullivan, director of research and analysis. The team is building on MITEI's strong foundation and bold, interdisciplinary approach to deliver global energy solutions. In addition, the team is broadening MITEI's membership base, increasing opportunities for faculty research, strengthening operations, and playing a leading role in energy education at MIT.

Energy Council

Armstrong, Stoner, and Broad are members of the Energy Council, which helps shape MITEI's research, education, and outreach directions. This past year, the council also included professors Angela Belcher (Materials Science and Engineering and Biological Engineering), Vladimir Bulović (MIT Innovation Initiative and Electrical Engineering and Computer Science), John Deutch (Chemistry), Leon Glicksman (Architecture and Mechanical Engineering), Richard Schmalensee (Sloan School of Management), and Michael Greenstone and Nancy Lin Rose (Economics). A new representative from the Department of Economics will be announced in 2015, replacing Greenstone and Rose.

External Advisory Board

MITEI is overseen by an external advisory board composed of industry, academic, nonprofit, and public sector leaders, and is chaired by George Shultz. The views and guidance of the committee greatly assist MITEI to maximize its impact on helping meet the world's energy needs, reducing the environmental effects of energy production and consumption, and influencing public discourse on energy and the environment. The committee meets annually each fall.

Task Forces

Task forces comprising faculty members and students from all five of MIT's schools oversee the initiative's education and campus energy programs. They develop new directions and support activities in those two realms of opportunity at MIT.

MITEI Members

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 energy-focused labs, programs, and centers at MIT; fund critical energy fellowships; support innovative energy concepts from proposals solicited across the campus; and participate in MITEI's seminars, lectures, and colloquia.

In the past year, BP renewed its founding membership; Statoil joined MITEI as a sustaining member; Lockheed Martin, Schlumberger, and Total renewed their sustaining memberships; Entergy and Enel S.p.A. renewed their associate memberships; and 10 new affiliate members joined MITEI.

Research and Analysis

MITEI is committed to working on key elements of the complex energy challenge through multidisciplinary research activities designed to address supply and demand, security, and environmental challenges. MITEI mobilizes the Institute's research and educational capabilities to help meet the world's most pressing energy challenges.

Facilitation of basic research is needed to bolster critical breakthroughs that can fundamentally alter large-scale energy systems several decades into the future, as well as accelerate the implied transformations. Such precompetitive research has a time scale well suited to the university environment, both because its impact is often beyond the time horizon for funding by individual firms and because it educates the energy sector's future leaders.

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

Each of these concentrations includes several subgroups of disciplinary and interdisciplinary interest.

MIT Faculty Research Highlights

Solar Energy

Boosting Solar Cell Efficiency: MIT chemist Troy Van Voorhis and electrical engineer Marc Baldo created the first solar cell that produces two electrons for every incoming photon of sunlight, thereby wasting less heat while generating twice the amount of energy relative to conventional solar cells. The technology, when applied as an inexpensive coating, could increase the amount of solar energy converted to electricity in silicon cells by as much as 25%.

Low-Cost, Flexible Solar Cells: A team of researchers from four MIT departments (Materials Science and Engineering, Electrical Engineering and Computer Science, Chemistry, and Physics), led by Materials Science and Engineering's Silvija Gradecak, developed flexible, transparent solar cells that combine highly conductive microscopic fibers with robust electrodes made of a one-atom-thick form of everyday carbon. Tests with assembled solar cells showed that incorporating the nanowires increased device efficiency and that replacing a conventional high-cost, brittle electrode with their version, made of abundant, inexpensive carbon, did not result in any performance penalty.

Paper-Thin Solar Cells: Chemical engineer Karen Gleason and electrical engineer Vladimir Bulović developed a method for depositing photovoltaic (PV) cells on sheets of ordinary paper and other inexpensive, lightweight, flexible materials. In one lab, they use a novel process to "vapor print" anodes that are integrally linked to the surface of the paper. In another lab, they use evaporative methods to deposit the remaining layers of the PV cells, producing solar arrays that can power small electronic devices.

3D Solar Cells: Led by Jeff Grossman, a team of MIT researchers from the Departments of Architecture, Mathematics, and Materials Science and Engineering built solar cells in the form of cubes or towers that extend cells upward in three-dimensional configurations. The new design can more than double the solar power generated from a given area. The biggest boost in power was seen in situations in which improvements are most needed—in locations far from the equator, in winter months, and on cloudy days.

Energy Storage

Lithium-Air Battery Performance: Lithium-air batteries hold the promise of drastically increasing power per battery weight. This increased power could lead, for example, to electric cars with a much more far-reaching driving range. But there are challenges

to bringing this promise to reality, including the need to develop better, more durable materials for the batteries' electrodes and to improve the number of charging-discharging cycles the batteries can withstand. MIT materials scientist and biological engineer Angela Belcher and mechanical engineer Yang Shao-Horn found that adding genetically modified viruses to the production of nanowires—wires about the width of a red blood cell that can serve as one of a battery's electrodes—could help solve some of these problems. The key to their work was to increase the surface area of the wire, thus increasing the area at which electrochemical activity occurs during charging or discharging of the battery. Altogether, these modifications have the potential to produce a battery that could provide energy density two to three times greater than that of today's best lithium-ion batteries.

Low-Cost, High-Capacity Battery: MIT chemical engineer and mathematician Martin Bazant joined mechanical engineer Cullen Buie to develop a low-cost, high-capacity rechargeable battery that could one day enable widespread adoption of intermittent renewable energy sources such as solar and wind. The battery uses bromine—an inexpensive, abundant element—combined with hydrogen. Inside the battery, the reactants are kept apart, not by the usual expensive membrane but by natural flow processes. This system generates up to three times more power per square centimeter than other "membrane-less" systems. Redesigns currently under way promise even higher performance.

Other Low-Carbon Energy Improvements

New Insights to Prevent Corrosion Cracking: Corrosion cracking can be a major problem for nuclear power plants. Nuclear scientist Bilge Yildiz teamed with materials scientist William Hebert to discover that nanoscale disruptions in the structure of metals affect those materials' vulnerability to stress cracking. They hope to define nanostructures that can help prevent this degradation.

Yeast-to-Biofuel Production: In the search for renewable alternatives to gasoline, heavy alcohols such as isobutanol are promising candidates. Not only do they contain more energy per unit volume than ethanol, but they are also more compatible with the existing gasoline-based infrastructure. For this alternative to become practical, however, scientists need a way to reliably produce huge quantities of isobutanol from renewable sources. MIT chemical engineer Gregory Stephanopoulos and biologist Gerald Fink devised a way to dramatically boost isobutanol production in yeast, which naturally makes it in small amounts.

Energy Economics and Policy

E2e Project: The University of California, Berkeley, and MIT are working together to conduct research on energy efficiency. The E2e project, created by professor Chris Knittel and former professor Michael Greenstone, unites top researchers in economics, engineering, and other fields to close the energy efficiency gap by using transparent and state-of-the-art analytical techniques. In addition to conducting research, E2e communicates results to policymakers and the public to maximize impact. Infusing the creation of knowledge with a commitment to nonpartisan outreach, E2e aims to create a cheaper and greener future.

Reactions to Changes in Energy Prices and Regulations: A recent paper by professor Chris Knittel showed that alternatives to carbon pricing are more costly than cap-and-trade and carbon taxes in reducing greenhouse gas emissions. The paper delved into the reasons the United States might rely on these more costly alternatives and revealed that one feature of such alternatives is that they create huge winners. In addition, the paper showed that the existence of these winners explains voting patterns in the House of Representatives.

Seed Fund Program

In the past year, MITEI selected the ninth group of projects submitted by MIT faculty and senior researchers to receive Seed Fund Program research grants. MITEI awarded more than $1.5 million to 11 new projects, each lasting one to two years. The funded projects span seven MIT departments, laboratories, and centers and four of the five schools. Funding for these grants comes chiefly from MITEI's founding and sustaining members, supplemented by funds from John M. Bradley '47, SM '49 (Bradley MITEI Innovation Seed Fund); an anonymous donor; and gifts from other MIT alumni. The program supports innovative early-stage research projects addressing energy and related environmental issues.

This year's call for proposals welcomed submissions on topics across the spectrum of energy and related environmental research, with interdisciplinary research strongly encouraged. In addition, the call sought to promote submissions on two particular themes: natural gas monetization and materials for energy. Past themes have included topics as diverse as the role of big data and the energy-water nexus.

Consortium Research

MITEI has a long history of identifying research topics that lend themselves to a consortium approach. Such topics benefit from aggregating a diverse set of perspectives on a set of critical issues facing the industry at large. Two projects taking this "commons" approach are under way between MITEI and IIT-Comillas: the Comillas University Massachusetts Institute of Technology Electricity Systems Program (COMITES) and Utility of the Future.

COMITES is a major program focused on the electric power system of the future. It is designed to identify a range of technology and policy options and solutions to meet future power system challenges, develop new operations and planning methods for 21st-century electricity systems, and create new models to help integrate electricity and gas supply, distribution, and generation infrastructures, operations, and regulatory frameworks.

COMITES applies the capabilities of these two world-class research institutions to explore in depth the operation and capacity expansion of power systems under a range of new circumstances, with an eye toward reducing carbon and other harmful emissions, increasing energy security, integrating new technologies, lowering costs, informing investment options, ensuring reliability, and developing additional consumer choices. COMITES is led by Ignacio Perez Arriaga and Carlos Battle, who are both visiting professors from Comillas, and MITEI director Robert Armstrong.

Utility of the Future is a new study emerging from COMITES that focuses on the evolution of the electricity systems of the future. In particular, the study focuses on the identification of successful business models, regulatory trends, and transformative technologies in an increasingly decarbonized power sector. The approach combines MIT expertise and the knowledge of market participants in a neutral framework. The project builds on MITEI-sponsored research conducted over the past year by a team of faculty and students.

The study team from MIT and IIT-Comillas brings a breadth of skills in quantitative economics and engineering modeling, with a sophisticated understanding of the complex interactions in the electric power industry. The team includes faculty with decades of experience in advising governments, corporations, and institutions on regulation and market design. The study is led by professors Ignacio Perez Arriaga and Christopher Knittel and is being guided by a faculty committee that includes professors John Deutch, Richard Schmalensee, and Robert Armstrong. Participating companies include Shell, Saudi Aramco, Duke Energy, Entergy, NEC, Iberdrola, C3 Energy, GDF Suez, Northeast Utilities, and Siemens.

Reports and Studies

MIT faculty have, over the last several years, conducted in-depth multidisciplinary energy studies designed to inform future energy options, research, technology choices, and policy development.

The Future of Solar Energy Study is now being finalized for fall rollout, and additional studies are being framed. These studies, grounded in science, supported by objective analysis, and comprehensive in scope and input, underscore MITEI's role as an "honest broker" on energy issues. Other MITEI activities, such as symposia that gather experts from academia, industry, and government, also generate reports on topics of interest to policy leaders. These energy studies and reports provide both Congress and the executive branch with detailed recommendations to shape and influence energy policy debates, responses, and outcomes.

International Initiatives

The large projected increases in global population and energy demand, particularly in developing and emerging economies, underscore the defining need for new energy technology and policy. These issues serve as a reminder that an international perspective is central to framing the research agenda. Issues such as the functioning of oil markets and climate change are inherently global in nature. However, certain technology opportunities can be pursued most easily to good purpose in the least developed economies, where limited infrastructure may pose less complications for new energy architectures, if these solutions are advanced promptly. Demographic trends, such as significant urbanization, will also call for creative approaches to energy delivery.

MITEI maintains ongoing international relationships and has established significant programs with Tsinghua University, the University of Cambridge, Shanghai Jiao Tong University, the Norwegian University of Science and Technology, and the Skolkovo Institute of Science and Technology (Skoltech). In addition, MITEI has established

several initiatives with partners in China (including the Low-Carbon Energy University Alliance and the China Energy and Climate Project) and Portugal. Ongoing and new programs are under way in India (including the Solar Energy Research Institute for India in the United States), Spain, France, the United Kingdom, Chile, and Brazil.

Tata Center for Technology and Design

MITEI also hosts the Tata Center for Technology and Design, which was launched in the summer of 2012 thanks to the generosity of the Tata Trusts and their chairman Ratan N. Tata. The center's charter is to graduate students, guided by direct experience, who will apply deep technical knowledge to the many challenges faced by India and other developing countries in the fields of energy, water, housing, agriculture, and health care. Participating students, known as Tata Fellows, are nominated by faculty, who receive research and travel funds from the center for up to two years through a competitive research proposal process. The center is codirected by Sloan School professor Charles Fine and MITEI deputy director Robert Stoner.

In the past academic year, the center supported 49 Tata Fellows enrolled in master's (80%) and PhD (20%) programs across the Institute, notably in the Departments of Electrical Engineering and Computer Science, Mechanical Engineering, Urban Studies and Planning, Architecture, Chemical Engineering, Economics, and Civil and Environmental Engineering, as well as the Engineering Systems Division, the Center for Materials Science and Engineering, the Media Laboratory, the Center for Bits and Atoms, and the Sloan School of Management. Thanks to the continued high interest among MIT students and enabled in part by additional funding from several industry sponsors, the number of fellows will be increased to 57 in AY2016. More than 40 faculty members will be directly involved.

A sister center in India at IIT-Bombay was launched in May 2014 and enrolled its first cohort of students in July. The centers have a similar mission and curriculum, and many faculty and student exchange activities are planned to reinforce and deepen the connection between them. The first joint conference took place in August in Mumbai and was attended by the first IIT cohort and faculty team in addition to the entire incoming 2014–2015 MIT cohort of 24, along with 20 continuing MIT Tata Fellows, eight postdoctoral researchers, and a similar number of faculty members.

Skolkovo Institute of Science and Technology

Since October 2011, MITEI has engaged in Institute-wide efforts to build capacity in education, research, and innovation programs at Skoltech. Over the past year, MITEI supported the establishment and kickoff of the Electrochemical Storage Center for Research Education and Innovation, in which MIT plays the critical role of lead international institution partner. MITEI supported the identification and hiring of the center's energy systems director in addition to other activities related to shaping and forming the center.

MITEI also proposed and led an effort, in collaboration with the MIT-Skoltech Initiative, to create an energy industry immersion program modeled after MIT's Chemical Engineering Practice School. MITEI arranged for the training of several station managers

from Russia at an energy company in the United States. The industrial immersions, launched this summer at Skoltech, were a resounding success. Industry leaders were extremely impressed with the students and their contributions during their stay. The industrial immersion program has led to stronger industry-university interactions and connections and provided students with an invaluable practical experience to help ground their studies.

Throughout the fall of 2013 Dr. Amanda Graham, MITEI's education director, coordinated the efforts of the MIT faculty in helping to develop Skoltech's energy curriculum. Two MIT faculty members created core Skoltech energy classes and taught them in residence in Moscow: professor Amy Glasmeier (Urban Studies and Planning) taught Global Energy Decisions, Markets, and Policies, and professor Konstantin Turitsyn (Mechanical Engineering) taught Energy, Physics, and Technology.

In October 2013, Dr. Raanan Miller gave a talk at the Upgrid 2013 conference in Moscow. His talk focused on energy innovation and MITEI as a model for catalyzing innovation.

Education and Campus Energy Management

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

Energy Studies Minor

The energy studies minor was launched in September 2009 with a multidisciplinary curriculum that integrates energy science, social science, and technology/engineering. It is open to students from all majors. In June 2014, the energy minor's fifth graduating class numbered 35 students, the largest cohort to date and the third largest undergraduate minor in 2013–2014.

Energy Undergraduate Research Opportunities Program

During the summer of 2014, 48 students worked on energy projects in MITEI's Undergraduate Research Opportunities Program (UROP). Projects ranged from quantifying future aviation biofuel potential to mathematical modeling of cement nanocomposites and evaluating public opinion and state energy policy. MITEI summer 2014 UROP students were supported by MITEI founding members BP and Shell; sustaining members Chevron, Lockheed Martin, and Schlumberger; seven affiliate members; and one alumni donor.

Graduate Energy Fellows

The Society of Energy Fellows at MIT has grown to nearly 300 members with the designation of the 2013–2014 cohort of graduate students representing 15 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 graduate students with a wide range of disciplinary perspectives and talents focused on

a common set of energy challenges. Society-sponsored activities in 2013–2014 included dinner meetings with sponsors on the eve of MITEI's Fall Research Conference and a range of informational gatherings.

Internships and Career Development

MITEI continues to expand efforts in the area of internships and career development, with a particular emphasis on connecting students with opportunities at MITEI member companies. As part of this effort, MITEI hosted an Independent Activities Period (IAP) workshop with industry representatives to discuss specific opportunities as well as energy career pathways more broadly. More than 400 students from across the Institute are engaged in energy internship opportunities. MITEI works closely with the MIT International Science and Technology Initiatives program, Global Education and Career Development, and other offices and programs that offer internships to encourage and support energy-related career opportunities.

Lab4Energy Collaboration with the Cambridge Public Schools

In partnership with MITEI founding member Eni S.p.A., MITEI coordinated an interdisciplinary distance education program for high school students across more than a dozen countries in spring 2014. Eleven MIT faculty members prepared video lectures on energy sources, demand, pricing, and connections to climate change. Two students from Cambridge Rindge & Latin High School were selected to participate in the distance program as well as in a weeklong trip to Italy with students from eight other countries.

Education Task Force

MITEI's Energy Education Task Force guides the development of energy education at MIT. Professors Amy Glasmeier (Urban Studies and Planning) and Jeffrey Grossman (Materials Science and Engineering) serve as the task force's co-chairs. The task force meets regularly throughout the academic year and includes faculty from all five schools at MIT as well as graduate and undergraduate student representatives. Professional staff members in MITEI's Education Office support the task force by implementing energy education programs.

The Energy Education Task Force pursues the following goals with the support of the MITEI Education Office:

- Maintaining and enhancing the undergraduate energy studies minor
- Assessing and supporting further development of MIT's energy curriculum
- Communicating MIT's interdisciplinary energy education model

Campus Energy Management

MITEI is committed to a campus energy program that extends the impact of energy research and education at MIT by developing and demonstrating sustainable energy practices on campus. MITEI supports efforts at MIT to lead and educate by example, including increasing energy efficiency, reducing greenhouse gas emissions, utilizing renewable energy, and reducing energy costs on campus.

The Campus Energy Task Force has supported and coordinated a broad community of departments and people—department heads, research scientists, faculty, department staff, custodians, administrative assistants, and undergraduate and graduate students—to help MIT "walk the talk" on energy. The campus energy program has provided a coordinating structure and opportunity to affect campus energy use, foster an awareness of energy issues across the campus, and facilitate engagement with MITEI in different capacities. The task force is co-chaired by professor Leon Glicksman and executive vice president and treasurer Israel Ruiz. Members include faculty from all five schools and administrative leaders from all major units as well as graduate and undergraduate student representatives.

Campus Energy Efficiency and Community Engagement

In 2014, the MIT Department of Facilities successfully completed the fourth year of Efficiency Forward, the MIT/NSTAR energy efficiency collaboration. Significant progress was made toward meeting the new three-year goal of saving an additional 21 million kilowatt hours annually. In this second phase, Efficiency Forward now includes thermal savings from the reduction of natural gas use on campus, with a goal to save 150,000 therms of natural gas annually over the next three years.

MIT and its partners in the Cambridge Compact for a Sustainable Future, namely the city of Cambridge and Harvard University, have made progress in strengthening the organizational and governance structures for this unique collaboration. A board of directors, executive committee, standing committees, and several ad hoc working groups are now in place. Priority areas of collaboration include sharing best practices in lab energy efficiency, climate adaptation planning, and building energy use.

MIT also engages with the city of Cambridge by serving as a member of its Net Zero Energy Task Force, a group that works with the city to consider strategies to reduce conventional energy use at the local level.

A building-occupant engagement program focused on building green teams is being implemented in the Koch Institute for Integrative Cancer Research. Accomplishments this year include the implementation of pre- and post-consumer food waste collection and composting programs in the Koch Café. This effort is designed to help the Institute develop robust composting programs to meet the requirements of the upcoming Massachusetts state waste ban on compostable materials.

In August 2013, the Office of the Executive Vice President and Treasurer established MIT's first Office of Sustainability, which reports directly to executive vice president and treasurer Israel Ruiz. The office is spearheading an expansion and coordination of energy and sustainability programs across the campus and in the community. Its founding staff includes director Julie Newman, deputy director Steven Lanou, and project manager Susy Jones. Two program managers are expected to be hired in the upcoming year to advance sustainability program planning and implementation.

From 2007 through 2014, MIT saved more than $6 million annually with energy upgrades and programs. This year, major electrical and thermal savings were achieved through investments in lighting, heating/ventilation/air conditioning (HVAC) upgrades, demand ventilation, and variable speed drives.

Student Learning and Research

MIT's campus operations are used as a living laboratory to foster students' emerging technical and leadership skills to help define and solve our own energy challenges.

Task force members collaborated closely with several departmental courses to examine key issues in campus sustainability including storm water management, community-based energy efficiency strategies, and building technologies for energy efficiency. For example, Christoph Reinhart (Architecture) led student teams in researching and developing innovative campus energy modeling approaches that can assist in campus energy analysis and planning. In collaboration with the Office of Sustainability, John Fernandez (Architecture) led student teams in developing a detailed material flow analysis of MIT's campus purchases to identify key trends in the acquisition, use, and disposal of materials throughout the campus.

Outreach

MITEI's outreach program has two distinct components. First, MITEI shares the results of MIT and MITEI research and analysis programs with a broad external audience of energy, policy, environmental, and industry leaders through several publications. Second, MITEI brings experts to campus to enrich and broaden the MIT community's understanding of a variety of energy issues and challenges. The program includes a wide range of meetings and published materials that steadily increase in type and number each year. This past year, the group supported more than 150 separate meetings.

The outreach program produces or facilitates:

- Studies and reports (such as the "Future of…" series) and the associate member symposium series
- Publications, including the semiannual *Energy Futures* magazine
- Public and invitational events for a wide range of audiences
- Digital outreach in the forms of the MITEI website, a monthly e-newsletter, and a social media presence
- Documents, video presentations, media relations, and publicity in support of MITEI-sponsored faculty members, studies, reports, and events

Studies and Reports

MITEI's outreach activities have included six major "Future of…" studies in the past seven years. These multiyear, multidisciplinary studies are designed to provide policymakers, researchers, environmentalists, and industry with technically grounded analyses to inform options for a clean energy future. Study participants have briefed trade associations, nongovernmental organizations, elected officials and their staffs, and administration officials; testified on study results at congressional hearings; and spoken at many venues in the United States as well as around the world, including Norway, Cyprus, Abu Dhabi, Hungary, Japan, Peru, Australia, Turkey, Monaco, Spain, and Brazil.

Another group of publications captures the proceedings of the MITEI associate member symposium series. These topical meetings are designed to bring together groups of energy experts and stakeholders to discuss critical and timely energy issues. After each symposium, a report is prepared and published providing a range of findings and recommendations. Graduate student research assistants involved in each project contribute supplemental information to the final presentations. This year, a report was created that addresses the issues associated with the topic of the 2013 symposium, "Growing Concerns, Possible Solutions: The Interdependency of Natural Gas and Electricity Systems." Also, the report from the May 2014 symposium ("Large Opportunities, Complex Challenges: Seizing the Energy Efficiency Opportunity in the Commercial Building Sector") is currently being written.

In June 2014, the Hoover Institution and MITEI released the results of their multiyear Energy Game Changers collaboration. *Game Changers: Energy on the Move* highlights the historic and current effects of research and development efforts from five US universities. The book stresses the importance of sustained support for basic energy research and development if the United States is to meet its goal of a cheaper, cleaner, and more secure national energy system. Drawing from the efforts of Stanford University, MIT, and other leading university research centers, *Game Changers* describes innovations—natural gas from shale, solar photovoltaics, grid-scale electricity storage, electric cars, and LED lighting—that are transforming our energy landscape. It also details how these innovations, now vital to our national energy economy, are rooted in university-based basic scientific research.

In 2014, MITEI published the findings from the MIT-CSIS (Center for Strategic International Studies) Energy-Water-Land Nexus Workshop, which was held in Washington, DC, in May 2013 and supported by MITEI founding member BP. The goals of the workshop were to develop a research agenda around the energy-water-land nexus and to identify the important challenges to be addressed through university, industry, and government collaborations. The workshop was hosted by MITEI director Robert Armstrong and Dr. Francis O'Sullivan, MITEI director for research and analysis. It brought together nearly 200 researchers from many of the 13 universities that are partners in BP's Energy Sustainability Challenge program, along with other leading experts with knowledge and understanding of the technology, economic, policy, and systems issues that accompany the energy-water-land nexus.

In October 2013, MITEI produced an interim study report on the economics of natural gas project development options in Cyprus in collaboration with the Cyprus Institute. The study focuses on natural gas monetization pathways and looks at the country's options using a consistent approach that provides useful guidance for decision making based on relative economics. The report provides an opportunity for an independent analysis of the major options: an onshore liquefied natural gas plant, a transnational undersea pipeline, and the deployment of a compressed natural gas marine transport system. While developed for Cyprus conditions, the approach can be applied to other regions that are in the process of developing their natural gas resources.

Meetings and Events

Attendance at publicly available MITEI-sponsored events is enthusiastic, demonstrating a high level of demand for energy-related information, education, and networking throughout the MIT and local communities. This year's more than 150 meetings included the second annual Women in Clean Energy Symposium, the Fall Research Conference for MITEI members, a series of hands-on energy events during IAP in which Massachusetts state officials discussed adapting to climate variability, and MITEI researchers' participation in IHS CERAWeek.

Women in Clean Energy: In support of developing national-level capacity, MITEI partnered with the Department of Energy to fulfill the US commitment to the Clean Energy Ministerial's Clean Energy Education and Empowerment (C3E) initiative, launched by nine governments in 2010. The US Women in Clean Energy program includes the naming of 30 energy ambassadors, an awards program, and an annual major conference. The second annual, invitation-only Women in Clean Energy Symposium, with over 200 participants, took place in September 2013 at MIT. The gathering continued the broader effort of supporting and enhancing educational and career opportunities for women in clean energy, building on the foundation established at the first symposium in 2012.

The symposium's speakers ranged from those working on small-scale, individualized energy solutions to those working at the highest levels of government or corporations. Key participants pointed out that, with many national and international energy plans stalled, local initiatives often are leading the way. For example, many states and cities have embraced energy efficiency, forging ahead of national standards.

Six midcareer women received awards for their work in clean energy, and Maxine Savitz, former general manager at Honeywell Inc. and current vice president of the National Academy of Engineering, received a Lifetime Achievement Award. Savitz's four decades of service span government, industry, and academia.

IHS CERAWeek: Each year, IHS CERAWeek brings together an international group of industry, policy, technology, and financial leaders for one of the world's preeminent energy conferences. MIT was the only academic institution invited to partner in IHS CERAWeek 2014, with our researchers playing leading roles in several sessions throughout the week.

The keynote session on March 6 spotlighted cutting-edge research by four MIT energy researchers. Led by MITEI director Robert Armstrong and moderated by IHS vice chairman Daniel Yergin, the session—"A Glimpse over the Horizon: Energy Game Changers from the MIT Energy Initiative"—underscored the important role universities play in the innovation pipeline as incubators of talent and technology.

IHS CERA also sponsors the monthly MITEI seminar series that brings thought leaders from colleges and universities across the country to inform the MIT community about critical areas of energy research and analysis that will help the nation and the world meet the enormous energy challenges in the coming decades.

Crowds and Climate: MITEI cosponsored the Climate CoLab's Crowds and Climate, a thought-provoking three-day conference that explored the role new technology-enabled approaches, such as crowdsourcing, social media, and big data, can play in developing creative new ideas and taking action on climate change. The conference, held on the MIT campus in November, was attended by more than 300 people, with an additional 500 joining virtually via live stream and Google Hangout.

The conference combined a traditional format, including keynote speakers, plenary panels, and breakout sessions, with a strong online and crowd-focused approach including virtual engagement, interactive Twitter dialogues, and a half-day open space "unconference" on Friday.

MIT Energy Club Conference: MITEI cosponsored the student-run MIT Energy Club annual gathering and was instrumental in securing Maria van der Hoeven, executive director of the International Energy Agency, as a keynote speaker. MITEI director Robert Armstrong gave the welcoming address and moderated the lead-off panel ("MIT Energy Perspectives: What's New at MIT?"), which included deputy director Robert Stoner, professors Alex Slocum and Don Sadoway, and MIT director of sustainability Julie Newman.

Publications and Digital Media

Energy Futures, MITEI's semiannual magazine, features in-depth research stories as well as stories focusing on news, energy education, and events.

In addition, the monthly e-newsletter, inaugurated three years ago, now has 5,000 subscribers. It updates the community on MITEI activities and progress, particularly events welcoming public involvement. This year a section was added that can be accessed only by MITEI members, providing them with information about upcoming member-only events and programs.

MITEI also posts energy stories from its website on Facebook and Twitter. More than 30 Twitter campaigns were delivered in the past year. One notable campaign solicited votes for Sheila Kennedy's softhouse in the Architizer Design awards. Professor Kennedy's softhouse, which started as a MITEI seed project in 2009, won the award in the Residential Low Rise category. Also, an integrated campaign that included Facebook, Twitter, and Instagram was launched to promote MITEI's presence at IHS CERAWeek.

Affiliated Research Groups

MITEI is affiliated with faculty members in several MIT centers, departments, and laboratories pursuing interdisciplinary energy and environmental activities. MITEI supports the financial administration of certain projects and collaborates on research and education activities with these organizations.

Center for Energy and Environmental Policy Research

Established in 1977, the Center for Energy and Environmental Policy Research (CEEPR) funds research on energy and environmental policy to support improved decision making by government and industry. It is directed by professor Christopher R. Knittel and jointly sponsored by MITEI, the Department of Economics, and the Sloan School of Management.

Affiliated faculty and research staff as well as international research associates contribute to empirical research on policy issues related to coal, oil, gas, and electricity markets; nuclear power; transport; energy infrastructure; investment finance and risk management; and environmental and carbon constraints. CEEPR cooperates closely with government and industry associates from around the globe to enhance the relevance of its research.

Outputs include working papers, policy briefs, and research contributions to larger, interdisciplinary studies as well as two annual research workshops in Cambridge, MA, and a European energy policy conference organized jointly with the Energy Policy Research Group at the University of Cambridge.

Joint Program on the Science and Policy of Global Change

The Joint Program on the Science and Policy of Global Change integrates natural and social science to produce analyses relevant to climate and energy policy debates. Codirected by Dr. John Reilly and professor Ronald Prinn, the program combines traditional strengths in science and economics to conduct the interdisciplinary work needed to evaluate the effects of climate change on the economy and on natural systems and to explore how to adapt to the potential impacts of environmental change. The 22-year-old program is recognized as a world-leading center for integrated assessment of global change.

The program has developed a unique analytical facility and supporting analysis capabilities for investigation of complex connections among human activity and the global environment as well as the associated uncertainties. The cornerstone of this effort is the MIT Integrated Global System Model framework, which is applied to studies of human-earth system interactions and climate change risk, social and environmental impacts, and analysis of potential mitigation and adaptation responses. A team of faculty, professional research staff, postdoctoral fellows, and graduate students carry out the work and communicate research results, analysis methods, and conclusions to a broad range of audiences.

Through publications, presentations, workshops, and briefings, the program's work is conveyed to policymakers in the United States and in other countries, to industry leaders, to other analysis groups in the climate community, and to environmental organizations, journalists, students, educators, and the public at large. The effort is supported by 10 US federal agencies and an international consortium of industrial, foreign government, and foundation sponsors in North America, Europe, Japan, and China.

Laboratory for Energy and the Environment

MITEI research in the area of integrated planning for local and regional energy infrastructures is centered in the Analysis Group for Regional Energy Alternatives (AGREA), led by Stephen Connors. Through collaborations with the MIT Portugal Program and other related projects, AGREA focuses on ways to dramatically reduce energy use and emissions at the local and regional levels. Technology portfolios incorporating high-penetration renewables and smart energy uses, including electric

transportation, energy storage, and transformations of the built environment, require a detailed understanding of local energy system operations as well as the combined dynamics of solar, wind, and other renewables and how they match the dynamics of local energy needs.

The scenario-based tradeoff-analysis approach—developed in the early 1980s by MIT Energy Laboratory researchers—is the primary tool used by AGREA. Ongoing and recent research activities include projects in the MIT Portugal Program's sustainable energy and transportation systems focus area, most recently addressing isolated island systems, as well as efforts elsewhere in Europe and the Middle East, including Saudi Arabia. AGREA's bottom-up approach helps both policymakers and private-sector innovators identify new market niches for clean energy technologies, taking into consideration local economic and resource dynamics. Past projects have focused on New England; Shandong, China; Mexico City; Northern Europe; Switzerland; the United Kingdom; and Argentina.

In addition to the projects and programs listed above, Connors advises numerous graduate and undergraduate students in other projects and programs across MIT, looking at fuel consumption and emissions impacts among renewables and fossil fuels; challenges to the development of new renewable industries such as offshore wind; the 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 options for energy investments involving climate change, economic growth, and energy security.

Martin Family Society of Fellows for Sustainability

Seventeen advanced graduate students from 10 departments were selected for the 2014–2015 Martin Fellows cohort. The Martin Family Society of Fellows for Sustainability has supported more than 300 doctoral students from all five schools and more than 25 departments since its formation in 1997. Professor Eran Ben-Joseph (Urban Studies and Planning) was the featured speaker at the annual induction dinner in October, and more than a dozen Martin Fellows attended a retreat at Harvard Forest in Petersham, MA, that focused on long-term ecological research on global change. In 2014, faculty coordination of the Martin Family Society of Fellows for Sustainability was transferred to the leadership of professor Judy Layzer (Urban Studies and Planning).

MultiScale Material Science for Energy and Environment Laboratory

MITEI continues to host the MultiScale Material Science for Energy and Environment Laboratory, an international joint collaboration between the French National Center for Scientific Research (CNRS) and MIT. The laboratory, led by director Roland Pellenq and codirector Franz Ulm, plays a critical role in MIT's ability to respond to the research challenges of sustainable shale gas exploration. In the X-SHALE project, lab carbon scientists and MIT faculty are leading the development of the fundamental nanoscale knowledge required for the sustainable asset management of shale gas. This project is conducted in collaboration with MIT, Schlumberger, and Shell.

Through this collaboration, MIT has become a partner in various CNRS labs in France. Two significant projects are the SOLEIL synchrotron in Paris, the latest generation of synchrotron light combining and exceeding the performance of Berkeley and Berlin synchrotrons, and the CINaM Lab, the latest-generation transmission electron microscope that studies the kinetics of the dissolution/precipitation reaction of cement.

The dual affiliation of the laboratory's researchers as visiting professors allows successful project integration into the educational landscape of MIT. Specifically, the lab's researchers are contributing at the graduate level through out-of-the-box topics such as "soft matter physics of muds."

Carbon Capture and Sequestration Technologies Program

MITEI's continuing work on carbon capture and sequestration (CCS) technologies focuses on three areas: assessment, education/outreach, and research. Senior research engineer Howard Herzog leads this effort. Active internal collaborations include Ahmed Ghoniem (Mechanical Engineering) on oxy-combustion and gasification technologies, Alan Hatton (Chemical Engineering) on stimulus-response sorbents for CO_2 capture, Ruben Juanes (Civil and Environmental Engineering) on geologic storage modeling, and John Parsons (Sloan School) on CCS regulatory frameworks and business organization.

The core of the program is the Carbon Sequestration Initiative (CSI), an industrial consortium on carbon management. The 12 members are Alstom Power, American Petroleum Institute, Chevron, ConocoPhillips, Duke Energy, Electric Power Research Institute, Entergy, ExxonMobil, Shell, Southern Company, Suncor, and Vattenfall. The initiative funds research and hosts the annual two-day Carbon Sequestration Forum to examine critical technical and policy issues related to CCS.

Below are some highlights from the past year:

- The 15th MIT Carbon Sequestration Forum was held in January 2014. The forum took place in Austin, in collaboration with the University of Texas (the second time the forum has been held away from Cambridge).
- A key paper on environmental science and technology ("Assessment of the US EPA's Determination of the Role for CO2 Capture and Storage in New Fossil Fuel-Fired Power Plants") was published.
- The quarterly CCS regulatory newsletter was published.
- An online database of CCS demonstration projects is available for interested users.

The group has strong interactions with the national and international CCS community, including:

- Participating in the Coal Utilization Research Council's CCS Technology Collaborative
- Serving as a member of an international network on CCS costs
- Serving as members of the steering committee and program committee of the Twelfth International Conference on Greenhouse Gas Control Technologies, which will be held in Austin, TX, in October 2014

From 1989 to 2008, CCS saw significant year-to-year growth in terms of both interest and expenditures. However, since 2008, a major slowdown in growth and expenditures has occurred. The major cause is the disarray in climate policy at both the national and international levels, which creates much uncertainty about the development of commercial markets for CCS technology. During this period, the number of CSI members has dropped from 18 to 12.

Robert C. Armstrong
Director
Chevron Professor of Chemical Engineering