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. MITEI began operations in 2007 and celebrated completion of its first five years of work in fall 2011. The objective of the initiative is to develop critical energy research and education to enhance the environmental performance of conventional energy sources and to enable a sustainable energy future through transformational technologies.

In MITEI's first five years, four areas of interest emerged as the most engaging to researchers, students, and MITEI members: solar energy, hydrocarbons, nanotechnologies, and modeling of complex systems. These represent large research areas and have generated significant support.

With these strengths as a foundation, fiscal year 2012 has been a year of capacity building. MITEI is looking toward new interdisciplinary frontiers in energy. MITEI leadership has proactively stewarded our members, encouraging the involvement of established members and pursing new links with major players in the energy world. Two new international partnerships, with the Skolkovo Institute of Science and Technology in Russia and France's National Center for Scientific Research, have been established to extend MITEI's research and educational reach in Western Europe and the emerging economies of the Eastern European countries.

MIT and MITEI leadership have responded to requests for proposal for national hub research projects in the key energy areas of battery storage and critical materials. The critical materials proposal has made it to the final group of contenders. Whether or not the hub proposals are successful, these exercises have enabled MITEI to aggregate MIT's research capacity in these key areas. The information could be the basis of new MITEI initiatives.

To support developing national-level capacity, MIT has partnered this year with the US Department of Energy (DOE) to fulfill the United States' commitment to the Clean Energy Ministerial's Clean Energy Education and Empowerment (C3E) initiative launched by nine governments in 2010. The MIT–DOE Women in Clean Energy program includes the naming of 30 "energy ambassadors," an awards program, and a major conference to be held annually at MIT.

Also under way at MITEI are plans for the second energy policy debate between high-level surrogates from the two presidential campaigns. The 2008 debate was extensively publicized and quoted; the 2012 event is expected to draw equally wide national coverage.

As the Institute welcomes a new president, MITEI's leadership looks forward to a new cycle of progress in organizational development, research, education, campus energy innovation, and outreach in partnership with its public and private partners.

Achievements in each of these areas in the past six years and in academic year 2012 include the actions and accomplishments noted below.

Organization

- Building robust research partnerships and networks with 60 industry and public MITEI members
- Welcoming a new sustaining member and eight new affiliate members in 2011–2012
- Attracting sponsored research and other research support of approximately $390 million in commitments over six years

Research

- Supporting, through its seed grant program, 101 early-stage research proposals, with total funding of more than $12.5 million
- Since MITEI's inception, supporting approximately 700 sponsor-originated research/analysis projects
- Providing funding for 300 principal investigators from 22 departments and 22 lab and centers for energy research, analysis, and education
- Releasing a new major report from the Associate Members Symposium Series on Managing Large-Scale Penetration of Intermittent Renewables
- Publication of The Future of the Electric Grid, the fifth in a series of two-year, in-depth reports that analyze pivotal factors in the future of energy, including nuclear power, the nuclear fuel cycle, coal, and natural gas

Education

- Expanding the Society of Energy Fellows at MIT to more than 250 members (the latest cohort of fellows represents 17 departments and all five MIT schools)
- Cheering the graduation in June 2012 of 23 students with the energy minor—the fifth largest group among all MIT minors this year
- Placing 29 students in energy research laboratories through the Undergraduate Research Opportunities Program (UROP) in summer 2012—to date, 76 students have had energy research experience through the program
- Aiding the development of three new project-based classes and two new textbooks based on the environmental minor core curriculum. More than 20 classes in the energy minor have been published on MIT OpenCourseWare and four more are in the pipeline
- Awarding 19 travel grants to students pursuing energy research across the nation and the globe

Campus Energy

- Surpassing MIT's cumulative two-year target annual energy savings goal of 22 million kilowatt hours (kWh) by saving an additional 10.1 million kWh
- Achieving annual campus energy cost savings totaling more than $4.5 million; of the total 191,038 million BTU (MMBTU) saved since 2007, 30,839 MMBTU (and $1 million) were saved in fiscal year 2012
- Recruiting 400 faculty, staff, and student "green ambassadors" to push for sustainable practices in offices, laboratories, and dormitories
- Reducing the rate of people driving to work alone to 19%, thus increasing the use of alternative modes of transportation

Outreach

- Producing, in whole or as cosponsor, 100 energy-related seminars, colloquia, and special events; this was nearly twice as many as in 2010–2011
- Attracting 5,000 subscribers to *Energy Futures*, MITEI's semiannual magazine, and 6,500 subscribers to the monthly e-newsletter;
- Overseeing the editing and production of 14 integrative studies and reports aimed at decision makers in many sectors (FY2012 saw the publication of The Future of the Electric Grid and a study of Managing Large-Scale Penetration of Intermittent Renewables)
- Expanding MITEI's presence on the web and in the use of social media.

MITEI has cultivated a spectrum of ongoing international relationships, including major programs with Tsinghua University and the University of Cambridge, Shanghai Jiao Tong University, Norwegian University of Science and Technology, the Masdar Institute of Science and Technology, and the government of Portugal. A member consortium is developing an Emissions Prediction and Policy Analysis (EPPA) model of China, and other consortia are forming. A special area of concern is the world's developing countries. In addition to several initiatives with Chinese partners, both new and continuing programs are under way in Colombia, Nigeria, and India.

Organization

MITEI seeks support from partners in industry, private donors, and some public institutions to support a broad portfolio of energy research. For example, one report, Managing Large-Scale Penetration of Intermittent Renewables, originated at a symposium sponsored by MITEI associate members. 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. At the national level, Institute leadership has been actively engaged in raising awareness of the importance of federal investment in energy research and development in the US.

MITEI's leadership team includes its director, professor Ernest Moniz (Physics and Engineering Systems), deputy director professor Robert Armstrong (Chemical Engineering), executive director Melanie Kenderdine, and associate director Robert Stoner. The directors are members of the Energy Council, which helps shape MITEI policy directions. The council also includes professors Angela M. Belcher (Materials Science and Engineering and Biological Engineering), Vladimir Bulovic (Electrical Engineering and Computer Science), John M. Deutch (Chemistry), Leon R. Glicksman (Architecture and Mechanical Engineering), and 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 fifth time in October 2011.

The MITEI Education and Campus Energy programs are each overseen by a task force comprising faculty members and students who develop new directions and support activities in those two realms of opportunity at MIT.

MITEI Members: Partnerships in Research and Education

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 welcomed United Technologies Corporation as its newest sustaining member and also nine new affiliate members. United Technologies is a diversified company that provides a broad range of high-technology products and services to the global aerospace and building systems industries.

Research

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

- Innovative technologies and underlying policy analysis that will improve how we produce, distribute, and consume conventional energy

- Transformational technologies to develop alternative energy sources that can supplement and displace fossil fuels, including the economic, management, social science, and policy dimensions needed for this transformation
- Global systems to meet energy and environmental challenges through a multidisciplinary systems approach that integrates policy, design, and technology development
- Tools to enable innovation, transformation, and simulation of global energy systems through strategic basic research

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

Seed Fund Program

In the past year, MITEI selected the seventh group of projects submitted by MIT faculty and senior researchers to receive Seed Fund Program research grants. In this year's round of funding, MITEI awarded a total of $1.9 million to 13 new projects, each lasting between one and two years. The funded projects span 10 MIT departments, laboratories, centers, and institutes, and all five schools. Funding for the new grants comes chiefly from MITEI's founding and sustaining members, supplemented by funds from the Chesonis Family Foundation, an anonymous donor, and MITEI. The program supports innovative early-stage research projects that address energy and related environmental issues. Several seed-funded projects have led to major research funding from a variety of sources and to spin-off companies.

Interdisciplinary Forums: Seeking New Research Pathways

As MITEI began to take shape six years ago, the 2006 Report of the Energy Research Council called for new approaches to multidisciplinary research. Forty white papers submitted by faculty from across campus contributed to the ideas that shaped that report and the extensive program of research that, with the engagement of strategic alliances with energy-related companies, has formed the robust body of research now being conducted under MITEI stewardship.

The 2006 report also called for a five-year review. Beginning in 2012, MITEI began to seek ideas and participation in a new format to aid in the search for directions that will benefit from multidisciplinary collaboration across schools. A series of forums—mini "town meetings"—that are open to the community were organized to encourage and expose new ideas. Each forum is opened by comments from a few key faculty members, followed by open discussion.

The first four sessions covered life sciences and energy (March 22); electric power systems and the grid (April 9); built environment, urban systems, and energy (April 30); and energy and water (May 4). Participants in the life sciences and energy forum subsequently organized their own steering group to build on the interdisciplinary ideas outlined at the March 22 meeting.

International Initiatives: Developing Countries

Led by China, developing countries collectively emit the majority of greenhouse gases, and their influence on future climate change and role in energy markets will increase throughout this century as they become richer and their consumption of energy and other resources grows. Recognizing this, MITEI has made a strategic effort in recent years to foster new partnerships with public and private stakeholders in China, India, Latin America, and Africa, where ongoing rapid economic growth is driving innovation and investment and creating unprecedented opportunities for research and education. MITEI's work is now bearing fruit across a range of endeavors.

Tata–MIT Centers for Technology and Design

In June 2012, former MIT president Susan Hockfield and advisory board member Ratan Tata signed a letter of intent to establish the Tata Centers for Technology and Design. This marked the conclusion of a yearlong collaborative planning process undertaken by MITEI and the leadership team of Tata Trusts. The centers are to be established at MIT and in India with a shared mission that is central to the project of global economic development: creating products and systems for the large number of people of modest but growing means who are entering the modern, energy-consuming world. The centers will be funded through a gift from the Tata Trusts for five years. The MIT center was launched this summer with the appointment of 15 Tata fellows selected competitively from among more than 50 applicants admitted to the School of Engineering and Sloan School of Management. Curriculum development and upgrades to shops, laboratories, and classrooms to accommodate a future cohort size of up to 40 students are already under way at MIT. The experience gained from this work will inform the design of the India Center, which will admit its first cohort in three years, if not sooner.

Solar Energy Research Institute for India the United States

MITEI learned in April that its bid to form one of three research consortia under the $125 million U.S.–India Joint Clean Energy Research and Development Center had been successful. The consortium's research will focus on sustainable photovoltaics, multi-scale concentrated solar power, and solar energy integration. The National Renewable Energy Laboratory will lead the US team, which includes eight other universities and two national laboratories, with matching funding provided by five private companies. A parallel Indian team will be led by the Indian Institute of Science, Bangalore, and include the Indian Institute of Technology, Bombay, Indian Institute of Technology, Madras, and eight other Indian research institutions and companies.

MIT research projects will address areas of novel earth-abundant solar cell materials (Professor Buonassisi), and community-scale concentrated solar power (Harold Hemond). Total funding for these projects is $1.1 million over five years.

Masdar Institute

The Masdar Institute of Science and Technology reached the end of its initial five-year cooperative agreement with MIT and the associated founding-member agreement at the end of November 2011. The institute has signed a new five-year cooperative agreement with MIT and extended its founding membership in MITEI for another year, with the

goal of a longer MITEI renewal at the end of the year. As part of the renewal, MITEI hosted a group of Emirate students for the third annual Summer Experiential Learning Program on the MIT campus. The program continues to be a success, and the Masdar Institute's energy research commitment continues to be met through the cooperative agreement research programs.

The Low Carbon Energy University Alliance

The Low Carbon Energy Alliance was formed in 2009, with seed funding from the Chinese government, to provide a platform for collaborative research on low-carbon energy technology and policy with a particular emphasis on China. Its three members are MIT, the University of Cambridge, and Tsinghua University (which also administers the alliance's funds). In its first two years, the alliance made eight seed research awards totaling $4.8 million. The alliance made no awards in the current year; the government of China unexpectedly withdrew its financial support for further research. No new projects are currently planned under the alliance, and MITEI is evaluating options going forward.

In parallel with the alliance's technology and policy program, researchers at Tsinghua University and MIT's Joint Program on the Science and Policy of Global Change launched a project, with funding provided jointly by MITEI founding members ENI and Shell, and associate member ICF International, to analyze China's national economy and its energy system in the context of climate change. The project seeks to develop highly granular simulation models for China that will eventually be comparable with those already developed by the joint program for the US and will serve as a basis for informed negotiations concerning greenhouse gas emissions and climate change mitigation. The planned five-year effort has so far been funded jointly by ENI, Shell, and ICF International. MITEI is actively seeking a fourth, preferably Chinese, partner, and has opened a dialog with the State Grid Corporation of China with partnership, and eventual MITEI membership, as objectives.

The MIT-China Low Carbon Energy Leaders Program

At the recommendation of the MIT Greater China Strategy Committee, MITEI launched a novel executive education program on energy technology and policy in April 2011. By the beginning of November, MITEI and partner Shanghai Jiao Tong University will have delivered five sessions of the program to more than 100 Chinese executives and senior provincial and national government officials.

With the intent of equipping participants to develop effective strategies to balance, through policy and practice, the competing demands of economic growth and environmental stewardship, each seven-day session presents Western perspectives (as represented by the MIT faculty) on energy, technology, and the environment. The program, which earns a modest profit for MITEI, has created a new platform for faculty to participate in Chinese development and there has been little difficulty in attracting lecturers and panelists. We also see in the contacts we have formed through executives from State Grid, China National Nuclear and other sizable companies the prospect of building a Chinese membership in MITEI.

MIT–Colombia Research and Education Partnership

Following up on the MITEI-supported visit to Colombia last year of a small MIT team to advise on a rural biofuel project, we began a dialog in late 2011 with local universities and government agencies to explore the possible creation of an energy research and education partnership involving MIT. Deputy director Bob Armstrong subsequently travelled to Bogota this summer where he met with the ministers of Energy and Education to explore areas of common interest and ways and means.

Nigeria Program for Research on Energy, Water and the Environment

We have continued to work with Nigerian researchers to establish a long-term partnership for energy education and research with the universities of Nigeria, Africa's most populous country. The program would be modeled in part on the MIT–Masdar relationship, but focused more narrowly on collaborative research and faculty training at MIT (among other leading US universities) that would be funded by the Nigerian government and the World Bank. As a next step, MITEI has requested that the Nigerian government develop and circulate a funded proposal in late 2012 for further consideration.

Developed Country Partnerships

Skolkovo Institute of Science and Technology

Following the signing of a collaboration agreement between MIT, the Skolkovo Foundation, and the Skolkovo Institute of Science and Technology (Skolkovo Tech) in October 2011, MITEI has been engaged in institution-wide efforts to build capacity in education, research, and entrepreneurship programs at Skolkovo Tech. Energy science and technology is one of five strategic areas of focus at the new graduate research university. MIT contributions to Skolkovo Tech's energy programs are being coordinated through MITEI by Dr. Raanan Miller '08.

Beginning with a series of pilot activities, MITEI is taking a leading role in the development of core energy-related graduate programs and curricula of relevance for both Skolkovo Tech and MIT. The Initiative has also been involved with analyzing strategic energy research needs, through the Skolkovo 2030 activity, and identifying research opportunities that align the priorities of Russian industry, Skolkovo Tech, and MIT.

Singapore–MIT Alliance for Research and Technology Centre

The Singapore–MIT Alliance for Research and Technology (SMART) is a major research enterprise established by MIT in partnership with the National Research Foundation of Singapore in 2007. MIT faculty members have laboratories at SMART, mentor postdoctoral associates and graduate students, and collaborate with universities, research institutes, and industries in Singapore and Asia. MITEI PI faculty and research staff members participate in the SMART interdisciplinary research groups on environmental sensing and modeling, future urban mobility, and low-energy electronic systems.

International Joint Unit: French National Center for Scientific Research and MIT

On June 15, MIT president Susan Hockfield and Alain Fuchs, president of France's National Center for Scientific Research (CNRS), marked the beginning of an institutional partnership between MIT and CNRS with energy as one of its central foci. The International Joint Unit (UMI) between CNRS and MIT, called MIT-–CNRS–UMI, is at the center of a strategic association covering research, training, and education in partnership with industry.

In the energy arena, UMI will host a number of senior French researchers working together with MIT professors at MIT under the auspices of MITEI. It will be led by Roland Pellenq, CNRS research director and MIT senior research scientist, and Franz-Josef Ulm, the George Macomber professor of civil and environmental engineering at MIT. French companies and laboratories that focus on energy innovation will offer internships to MIT students through the MIT–France Program. The first CNRS researcher will arrive at MIT early in the next academic year.

Education

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

MITEI's Energy Education Task Force (EETF) guides the development of energy education at MIT. After serving as task force co-chair since 2008, professor Vladimir Bulović (Electrical Engineering and Computer Science) stepped down in June 2012. Professor Jeffrey Grossman (Materials Science and Engineering) joined Amy Glasmeier, professor and chair of the Department of Urban Studies and Planning, as co-chair of the task force. 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 MITEI and EETF in implementing energy education programs.

Energy Studies Minor

The energy studies minor was launched in September 2009. The minor's multidisciplinary curriculum integrates energy science, social science, and technology/engineering and is open to students from all majors. Twenty-three students representing four MIT schools graduated with the energy minor in June 2012, making the energy minor the fifth largest undergraduate minor to be completed by students in 2011–2012.

The Energy Minor Oversight Committee, a subset of the standing Energy Education Task Force with members from all five Schools, is responsible for the intellectual content of the minor. The oversight committee reports to the Inter-School Educational Council, a governance body consisting of one associate dean from each school, the dean of undergraduate education, and one associate provost; it was established in 2009 as a three-year experiment.

Curriculum Development and Dissemination

Three project-based classes developed or modified with support of the EETF debuted in AY2012. One of these, 6.S079 The Nanomaker, was pilot-tested as a freshman seminar in fall 2011 and debuted as a full-fledged subject in spring 2012. Subject 2.75 Precision Machine Design, included a new energy focus area for intensive projects in fall 2011. Subject 11.S192 Re-energizing MIT, engaged students in studying and improving campus energy management in spring 2012. Support was provided for the development of new textbooks based on two subjects within the energy studies minor core curriculum: the physics of energy and fundamentals of advanced energy conversion. More than 20 subjects within the energy minor have been published on OpenCourseWare to-date, with four more currently in the publishing pipeline.

Energy Undergraduate Research Opportunity Programs

MITEI's summer UROP grew to 29 students from 10 departments working on energy projects during summer 2012. Projects ranged from designing a small-scale wave power system to studying the impact of natural gas drilling on local health and economic outcomes to investigating elastic properties of heterophase interfaces. MITEI UROPs in summer 2012 are supported by MITEI founding members BP and Shell, seven MITEI affiliate members, and one alumni donor.

Graduate Energy Fellows

The Society of Energy Fellows at MIT has grown to more than 250 members, with the 2012 cohort of graduate students representing 17 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 2011–2012 included an afternoon symposium and poster reception on the eve of MITEI's Fall Research Conference (October), meetings and discussions hosted by sponsors for their groups of fellows, a dinner seminar with professor Jeffrey Grossman (Materials Science and Engineering), and a range of informal gatherings.

Energy Education Without Borders

In fall 2011, the EETF created and implemented a pilot program to support graduate students performing field studies or presenting research results at conferences around the world. Short-term travel grants were awarded to 19 MIT graduate students from across the Institute. Based on the success of the pilot program, MITEI established Energy Education Without Borders, an ongoing program to enable MIT graduate students to pursue their work in energy studies across the nation and the globe.

Internships and Career Development

In 2011–2012 MITEI expanded efforts in the area of internships and career development, with a particular emphasis on connecting students with opportunities at MITEI member companies. More than 140 students from across the Institute are engaged in an energy-

internship opportunities email list. MITEI also hosted dinner seminars and information sessions for students with industry representatives to discuss specific opportunities as well as broader career pathways. MITEI's online resource page for energy internship programs received more than 2,000 visitors since its launch in October 2011.
MITEI works closely with the MIT International Science and Technology Initiatives Program and other internship-related offices and programs on campus to encourage and support energy-related career opportunities.

Campus Energy Activities

The Campus Energy Task Force continues to advance MITEI's vision of engaging the entire MIT community in campus energy activities. The task force has supported and coordinated a broad community of departments and people—department heads, research scientists, faculty, department staff, custodians, administrative assistants, undergraduate and graduate students, et al.—to help MIT "walk the talk" on energy and sustainability. The campus energy program has provided a guideline and opportunity to affect campus energy use, to foster an awareness of energy issues across campus, and to allow many more people to engage with, learn from, and enrich the MIT Energy Initiative in different capacities. This year, the task force was fortunate to welcome Israel Ruiz, MIT's new executive vice president and treasurer as task force co-chair. He replaced Terry Stone, who had given more than five years of service to the task force.

FY2012 highlights include:

- Successful completion of the second calendar year of MIT Efficiency Forward—the industry-leading energy conservation and efficiency program to save 34 million kWh over three years and $50 million over the lifetime of projects. In calendar year 2011, MIT surpassed its cumulative two-year target annual energy savings goal of 22 million kWh by saving an additional 10.1 million kWh.
- To date, achieved annual campus energy cost savings totaling over $4.5 million. Of the total 191,038 MMBTU saved since 2007, 30,839 MMBTU (and $1 million) were saved in FY2012.
- After a full year of operation and measurement of energy performance, the new Sloan School of Management and the Koch Institute for Integrative Cancer Research buildings have met or surpassed energy performance expectations.
- 400 faculty, staff, and student "green ambassadors" have been recruited to promote sustainable practices in offices, laboratories, and dormitories. A new pilot building-occupant engagement program focused on building "green teams" is being implemented in the Koch Institute.
- MIT's campus transportation program continues to be recognized for its efforts in reducing the rate of people driving to work alone to 19%, thus increasing the use of alternative modes of transportation. The Department of Facilities successfully installed two advanced, Level II electric vehicle charging stations on campus, thus helping to support the city's efforts to build electric vehicle infrastructure.
- MIT is on track to install two Boston Hubway bicycle stations, bringing the Boston-based commercial bicycle rental program across the river to Cambridge.

- In collaboration with the Department of Urban Studies and Planning and the Energy Education Task Force, the Campus Energy Task Force helped pilot-test the new undergraduate subject, 11.S195 "Re-Energizing MIT," which focused on researching key campus energy challenges.
- MIT submitted its second progress report to the Global University Leaders Forum's Sustainable Campus Charter—a group that President Hockfield joined in 2010. The report outlines progress that has been made to advance the charter and shares MIT's results with the international community.
- MIT has made strong progress toward the US Department of Energy's new Global Superior Energy Performance Partnership, pilot-testing the program's new building energy management certification program, and is also nearing completion of MIT's ISO 50001 energy management documentation. MIT's participation in DOE's Commercial Building Partnership is deploying national laboratory technical assistance to implement advanced energy efficiency strategies in Buildings 32 and W91.

Energy Conservation, Efficiency, and Sustainable Design

Energy Conservation and Efficiency

From FY2007 through FY2012, MIT has successfully accumulated more than 191,000 MMBTU of annual energy savings from thermal and electrical projects, resulting in over $4.5 million cumulative annual savings. In FY2012, MIT successfully reduced over 5.6 million kWh in electricity use. Of the total 160,000 MMBTU saved since 2007, 30,839 MMBTU were saved in FY2012. Major electrical and thermal savings were achieved through investments in lighting, central utility plant upgrades, new construction systems, demand ventilation, variable speed drives, air change rate reductions, chiller upgrades, and residence hall refrigerator replacements.

In January 2012, MIT completed its second year of its three-year collaboration with NSTAR Electric and Gas's Efficiency Forward program. MIT exceeded the first-year energy savings goal of Efficiency Forward by 30 percent. In the second year of the program, ending on December 31, 2011, MIT surpassed its cumulative two-year goal of reducing annual electricity use by 22,000,000 kWh. In calendar year 2011, MIT successfully reduced its electricity use by approximately 10,142,000 kWh. This year's electricity savings goal was met through the following efficiency strategies:

- Lighting retrofits achieved approximately 5.5 million kWh savings (50% of total)
- Mechanical and operational improvements on heating, ventilation, and air conditioning systems through monitoring-based building commissioning (25%)
- High-performance new construction (20%)
- Other strategies (5%)

By the end of FY2012, energy efficiency investments have been completed in nearly 85% of all buildings on the Cambridge campus. In addition to the above efforts, MIT's Information Services and Technology office has fostered the use of more efficient

equipment and operating practices. Information Services and Technology activities in FY2012 included sustaining momentum in the following areas: participating in the W91 data center energy efficiency study as part of the MIT-DOE Commercial Buildings Partnership; promoting individual smarter printing practices and consolidating single-function devices to multi-function devices; implementing "hold and release print" infrastructure to minimize unclaimed print jobs in public Athena clusters; and hosting several seminars and web resources to promote more energy- and resource-efficient computing and printing.

Sustainable Design

In FY2012, the Sloan School of Management and the Koch Institute for Integrative Cancer Research buildings were awarded a "gold" rating from the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program because of these buildings' high degree of sustainable design. In FY2012 metered operation, the new Sloan School building has met or exceeded the goals MIT set for the architect and engineers for peak loads: for every square foot of floor area, it uses 0.75 watts for lighting and 10 Btu per hour for heating, and for every 1,000 square feet, 1 ton of cooling. These figures are all about 50% of typical building design values for lighting, heating, and cooling.

After 18 months in operation, the Koch Institute consumes dramatically less energy during peak loads than had been predicted across the board: electrical peak demand, anticipated by engineers at 14.6 watts per square foot, came in at 3.8 watts per square foot; steam heat was forecast at 35,000 pounds per hour for the coldest days, and turned out to be around 20,000 pounds per hour; and the building's peak cooling demand is actually 2,354 tons of chilled water, compared with the engineers' predicted 3,350 tons. The building reduces total energy use by about 35% compared with a standard laboratory research building.

MIT also recognizes the importance of integrating sustainable design into major renovations of existing buildings as collectively these buildings are responsible for the vast majority of energy use on campus and provide the greatest opportunities for conservation and efficiency. This past year, the major renovation and restoration project of Maseeh Hall was completed and integrated a high degree of sustainable design, including an energy-efficient mechanical system, operable windows, efficient lighting, and sustainable finish materials. The building also uses an innovative new refrigeration compressor for cooling. Registered with the LEED program, energy models indicate the building is expected to use 34 percent less energy than a baseline building built only to required codes.

In addition, a renovation of the historic Arthur D. Little building (E60), built in 1916, was completed. The work integrated the latest in sustainable design strategies while preserving the historic qualities of this landmark building. It features heat recovery, chilled beams, low-energy lighting, daylighting controls, and high-performance spray foam insulation. The building is currently being considered for LEED certification. It is expected to use about 33% less energy than a baseline building built only to required codes.

MIT's Department of Facilities continued to study and confirm performance objectives of its sustainable design strategies in operations. For example:

- An innovative aspect of the E60 renovation included the use of spray-on insulation in a masonry wall construction—an approach that is not commonly used because of concerns about interior moisture. To ensure there would be no compromise of the renovation from moisture and to improve understanding of the effect of spray-on insulation, an electronic moisture monitoring system in the masonry walls has been installed to provide data on current conditions.
- Recent testing of building envelopes (via a blower door test) in E62 and E60 confirmed that the efficiency strategies employed in those buildings are working extremely well and have superior air infiltration and exfiltration rates. In fact, for air leakage, the new Sloan School building (E62) was shown to perform almost three times better than the old Sloan School building (E52); and the renovated E60 is performing more than two and a half times better than the unrenovated E52.

Engaging the entire community

A network of change agents

This year, a new building-level occupant engagement program was started to test a new approach to foster sustainable practices by individuals within buildings. Now in pilot testing in the Koch Institute, the program is centered on the development of building-level "green teams" that conduct baseline assessments of energy use, waste management, and procurement practices; identify key strategies to improve sustainable practices; and support individual action through building awareness and providing incentives. The Sustainability Program of the EHS Headquarters Office is supporting this pilot program.

The Green Ambassadors Program—established to create and empower a network of individuals interested in taking action in his or her own laboratory, office, or dormitory to promote more sustainable practices at MIT—has grown to include more than 400 staff, faculty, and student volunteers to model and promote the Institute's energy and environmental stewardship objectives.

Building Awareness On and Off Campus

A key component of the campus energy program is building awareness in the community of campus activities, both to inform and to expand support and input for these activities. In FY2012, several activities reached out to different constituencies on campus and in the community. Some examples include:

- In April, MIT pilot-tested its first Earth Day Challenge program to engage the whole MIT community in new ways to promote more sustainable practices on campus and in the community. MIT students and staff participated in the challenge to "take action, earn points, and win prizes." Nearly 100 participants engaged in 32 "green action" projects that ranged from helping to weatherize a Cambridge home, to promoting energy-efficiency opportunities on campus.

- Task force members participated in many on campus outreach activities to share information on task force activities, including new student orientation, MIT's Transportation Fair, Earth Day Challenge, MIT Energy Club Energy Night, and so on.
- Nine new news articles were written and published on campus energy projects.
- New campus energy web content was developed for the forthcoming redeveloped MITEI website.
- This past year, MIT staff has been asked to brief several organizations on the Efficiency Forward program and to share MIT's experience. Recently, MIT gave a presentation on Efficiency Forward to the federal General Services Administration and organized a workshop on Efficiency Forward for the Greater Boston Chamber of Commerce that was attended by 100 people, including Massachusetts undersecretary of energy Barbara Kates-Garnick and Boston Chamber president Paul Guzzi.
- As a member of Mayor Menino's Boston Green Ribbon Commission, MIT continues to share its experience and to support implementation efforts of the Boston Climate Action Plan.
- On the invitation of the City of Cambridge, MIT hosted the only New England installation of the Das Haus Pavilion, a building showcase of renewable energy and efficiency construction technologies.

Improving Transportation Options

Aggressive transportation demand management programs at MIT include subsidized Massachusetts Bay Transportation Authority (MBTA) passes; ridesharing, vanpool, and local car-sharing services; and significant investments in bicycle infrastructure. A key metric for measuring transportation program success has remained strong in FY2012: MIT's proportion of single occupant vehicle trips is 19%—a rate significantly below the state and national average.

In FY2012, task force members, through the Department of Facilities' Commuters Connection program, continued several successful commuter programs intended to decrease the number of full-time parkers and increase the use of other commuting options. This has resulted in:

- 10% increase in carpool parkers
- 10% increase in occasional parkers
- 6% increase in T-passes distributed to employees
- 5% decrease in student resident parkers
- 2% decrease in full-time parkers
- Continued 50% MBTA subsidy after MBTA's 23% fare increase

Facilitating the adoption of electric vehicles was a priority of transportation planning initiatives in FY2012. In addition to piloting one of ZipCar's first plug-in electric hybrid vehicles, MIT introduced its first all-electric cargo van for mail services. The Azure Dynamics/Ford Transit Connect uses an advanced lithium-ion battery; it has a range of 50–80 miles and a top speed of 75 mph. MIT will use the vehicle to explore possible expansion opportunities for all-electric vehicles on campus. In FY2012, MIT also partnered with the City of Cambridge to install two advanced electric-vehicle charging stations that are on campus and available to the public. The stations are part of a regional program to promote the infrastructure required to support expansion of use of all-electric vehicles. MIT also introduced into service a novel aftermarket gas-electric hybrid system installed on a Department of Facilities van.

Working with the City of Boston to expand the city's local commercial bike-share program, Hubway, MIT is working to install two bike-share stations for commercial bicycle rentals to bring the popular program into the City of Cambridge. Stations are expected to be completed in August 2012.

Student Learning, Research, and Engagement

Using our campus as a living laboratory

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

In spring 2012, the Campus Energy Task Force partnered with the Energy Education Task Force and the Department of Urban Studies and Planning to develop and support an energy minor class, 11.S195 Re-Energizing MIT (now known as 11.160). The class is an opportunity for students to make a direct contribution to the Institute's efforts to "walk the talk" when it comes to improved energy management. Using a project-based approach, students work in teams to explore energy usage on campus and develop strategies to reduce the environmental and climate burdens associated with this energy use. Research topics are identified by MIT operational units and entail data gathering and verification, cost–benefit analysis, policy analysis, or survey design and implementation. In spring 2012, student teams explored the amount and cost of energy consumed by mini-refrigerators in the undergraduate dorms; calculated the plug load in E62; and assessed the potential viability of the conversion of some or all of the MIT vehicle fleet to hybrid-electric or all-electric vehicles.

Through the MITEI Student Campus Energy Project Fund, MIT has supported more than 40 student projects on campus that engage students and advance MIT's campus energy objectives while simultaneously providing rich learning opportunities. For example, in the fall, the task force provided additional support to the MIT Generator, which is a coalition of student groups dedicated to catalyzing and supporting student projects with a focus on energy, environment, and sustainability issues on MIT's campus.

Administrative units, including the Department of Facilities and Environmental Health and Safety's headquarters office, continued to support curricular, project-based learning activities by developing and advising campus energy-related projects, including a freshman pre-orientation program (FPOP) that featured a campus energy module; working with researchers in MIT's SENSEable City Lab to test license plate recognition technology and a Smart Parq smart phone application; and supporting campus Mobility Pass research with the Civil and Environmental Engineering Department.

Campus Energy Task Force faculty members have integrated coursework to address important issues confronting the campus. For example, two Building Technology Program classes developed several projects to measure and assess different energy-efficiency strategies that could be considered for use on MIT's campus. The undergraduate subject 1.044/2.66/4.42 Fundamentals of Energy in Buildings provided a first course in energy and thermo-sciences with applications to sustainable energy-efficient architecture and building technology. This spring, there were students from eight different MIT courses enrolled. Students worked in teams to study a particular MIT building, identify a key inefficiency, design an innovative solution, and in most cases, measure the resulting improvement. Student projects were undertaken in, for example, the Johnson Center ice rink, classroom 1-190, McCormick Hall, the walk-in refrigerated room in a fraternity house, and Simmons Hall. In 4.481, a graduate subject, students did a short exercise to study a particular MIT building and critique one of two key functions, such as energy or lighting.

Looking Forward

The Campus Energy Task Force has established a strong track record of fostering solutions to the current energy challenges facing large institutions: how to reduce emissions, minimize energy use, and create an informed and engaged community. The task force has been able to leverage the expertise and experience of MIT's staff, faculty, and students to provide a unique complement and integrative space for the Energy Initiative's research and education work.

Moving forward, there are several key areas on which to focus and resources needed to enable success. These include:

- Providing key guidance to the Institute's Vision 2030 process for future development of MIT's campus. The task force will advise on appropriate energy and sustainability-related goals, objectives, and metrics for measurement
- Exploring new strategies to expand and scale the "campus energy living laboratory" approach to increase the academic engagement of students and faculty in research on MIT's campus energy issues
- The task force will continue to rely on critical subgroups that are focused on developing specific new goals, with the full task force acting to integrate these activities;
- Developing campus energy-program–focused UROPs sponsored each semester by MITEI

- Establishing a campus energy-focused research assistant program to support in-depth, faculty-sponsored graduate research into, and experimentation on, considerations that affect institutional energy issues
- A renewed focus on measurement and verification for campus projects—including possible deployment of web-based energy dashboards, behavioral change demonstrations, and outreach and education

Outreach

The outreach group, led by communications director Rebecca Marshall-Howarth, is responsible for producing a wide range of meetings and published materials that have been increasing steadily over the past five years. The list of public and private events supported by the group in FY2012 included more than 100 separate meetings. Most of these were concentrated into the academic year, September through May.

High points of the year included the introduction of major publications on the electric grid and managing large-scale penetration of intermittent renewables. In each case, a panel of authors outlined the findings of the report to both a physical and a virtual audience via webcast. Virtual participants were invited to join in the question and comment period following the panel presentation. The webcast presentations have been very effective and the outreach group looks forward to organizing more of them in future.

Attendance at public MITEI-sponsored events has been enthusiastic, demonstrating a high level of demand for energy-related information throughout MIT and local communities. To mark the start of its second five years, MITEI started a forum series with the intent to solicit input about important research directions from the MIT community. MITEI identified several broad areas that could present important energy-related research and educational opportunities and could benefit from MITEI's convening, organizational, and research support capabilities. MITEI then began to host a series of mini town-hall meetings to gather input. This past year, there were held four sessions—on life sciences and energy; electric power systems and the grid; the built environment, urban systems and energy; and energy and water, with MIT experts in each area discussing future needs.

Selected Events 2011–2012

Seminar Series

October 18: Mircea Dinca, MIT Department of Chemistry, Crystalline Microporous Metal-Organic Frameworks: Opportunities in Energy Research

November 8: Joe Aldy, Harvard Kennedy School, A Preliminary Review of the American Recovery and Reinvestment Act's Clean Energy Package

February 16 : Amory B. Lovins, The Rocky Mountain Institute, Reinventing Fire

April 17: Dr. Jeff Neaton, Lawrence Berkeley National Laboratory, Exploring New Materials for Energy Applications with Theory and Computation

May 8: Professor Jim Fleming, Colby College, Historical Perspectives on Climate Change: Scientific, Technological, and Social Dynamics

Colloquia and Symposia

September 8: Colloquium – Edward Kiczek

October 24: Colloquium – Steve Koonin, US Department of Energy, Quadrennial Technology Review

October 26: Colloquium, Robert Solow, The State of the Economy and Some Implications for the Energy Industry

December 14: Colloquium – Daniel Yergin, IHS CERA, Energy, Security, and the Remaking of the Modern World

April 18: MITEI/Joint Program Colloquium – Tom Strickler, Toyota, The Open Fuels Standard: Solving the Chicken-and-Egg or Just Plain "Foul"?

April 23: MITEI Earth Day Colloquium – Andrew Revkin, *New York Times*, Building the #Knowosphere: How new ways to share and shape ideas can help build durable progress on a finite planet

Events

August 22–26: DELTA FPOP 2011

September 12: MITEI/LIDS Seminar—Dr. Ralph Masiello, Future Energy Networks

September 20: MITEI Seminar, Professor Zhonglin Wang, Georgia Institute of Technology, Nanogenerators and self-powered system and portable electronics

September 27: Fall 2011 Poster Scholars Program Dinner/Seminar

October 14: Undergrad Energy Research Poster Session

October 18: MITEI/S3TEC Seminar, Eli Yablonovitch, Opto-Electronic Physics

November 29: MITEI Special Seminar—Joschka Fischer, Joschka Fischer and Co., former foreign minister and vice chancellor of Germany (1998–2005): "Energiewende: German Angst or Bold Step Ahead?"

December 8 : MITEI Seminar—Bruce Cook, BP, BP Future for Refineries

December 13: MITEI Special Seminar—John Deutch, MIT, The Secretary of Energy Advisory Board Subcommittee on Shale Gas Production

December 13: MITEI Seminar—Thomas Jaramillo, Stanford University, Tailoring electrocatalyst materials at the nano-scale: Enhancing activity, selectivity, and stability for energy conversion reactions

April 9: MITEI Seminar—Anne Harrington

April 12: MITEI Seminar with Palestine@MIT—Applications of Geothermal Energy Initiative in Middle East

April 20: MITEI Special Seminar—James Turner, Lotus Engineering, Prospects For Sustainable Transport Fuel: Solar and Wind Derived Alcohol

April 20: MITEI Campus Preview Weekend open house CPW Academic/Arts Fair

May 1: MITEI at the movies, pre-screening of Scott Tinker's movie *Switch*

May 11: MITEI Seminar—Fort Felker, NREL, Wind Energy Research at the National Wind Technology Center

June 18-28: Masdar Institute Practical Program at MIT

Forum Series

March 22: Life Sciences & Energy

April 9: Electric Power Systems and the Grid

April 30: Built Environment, Urban Systems & Energy

May 4: Energy & Water

Publications

Reports

Future of the Electric Grid

Managing Large-Scale Penetration of Intermittent Renewables

Publications and Digital Media

Energy Futures, MITEI's semiannual magazine, edited by Nancy Stauffer, conveys the high points of MITEI activities to a wide audience. MITEI also produced a volume of the 2011 research, education, and outreach spotlights that were featured on the MITEI website and news office home pages. In addition, the monthly e-newsletter, inaugurated last year, now has 4,000 subscribers. It keeps the community updated on MITEI activities and progress, particularly events where public involvement is welcome.

As web-based activities become more complex and demanding, this year MITEI hired a webmaster to oversee the daily maintenance and update of its site and to spearhead a comprehensive redesign. In the process, other design elements will also be coordinated to reflect changes at the Initiative. The webmaster has initiated a social media plan, which stories being posted on Facebook and Twitter, and MITEI had its first "tweet up" this past year to promote the Women in Clean Energy Program. MITEI is also looking into creating a LinkedIn group for members and students.

The outreach group also edited and produced two reports, The Future of the Electric Grid and Managing Large-Scale Penetration of Intermittent Renewables. Both of these are available on the MITEI website or in hard copy.

Laboratory for Energy and the Environment

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. Howard Herzog (senior research engineer) 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 carbon dioxide capture; Ruben Juanes (Civil and Environmental Engineering) on geologic storage modeling; John Parsons (Sloan School) on CCS regulatory frameworks and business organization; and Mort Webster (Engineering Systems Division) on decision making under uncertainty.

The core of the program is the Carbon Sequestration Initiative, an industrial consortium on carbon management. The 14 members are Alstom Power, American Petroleum Institute, Chevron, ConocoPhillips, Duke Energy, Electric Power Research Institute, Enel, Entergy, ExxonMobil, Schlumberger, Shell, Southern Company, Suncor, and Vattenfall. The initiative funds research and hosts an annual two-day carbon sequestration forum to examine critical technical and policy issues related to CCS.

Below is a listing of recent research project areas:

- Strategies for Implementing CCS at Coal-Fired Power Plants
- Policies for Promoting Innovation in CCS
- Methodology for Uncertainty Analysis of Capacity Estimates and Leakage Potential for Geologic Storage in Saline Aquifers
- Modeling of Cost and Performance of CCS Plants in the Western Interconnect
- Costing CCS Technologies
- Comparison of Solvents for Postcombustion Capture of CO2 by Chemical Absorption
- Stimulus-Responsive Structure Fluids for Dynamic Mediation of Carbon Dioxide Separation
- Representation of CCS Technology in 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

Several high-visibility papers were published in *Proceedings of the National Academy of Sciences* (and featured on the MIT home page):

> House, K.Z., A.C. Baclig, M. Ranjan, E.A. van Nierop, J. Wilcox, H.J. Herzog, "Economic and Energetic Analysis of Capturing CO_2 from Ambient Air,"

Proceedings of the National Academy of Sciences, Vol. 108:51, pp. 20428–20433 (December 2011).

Szulczewski, M.L., C.W. MacMinn, H.J. Herzog, and R. Juanes, "Lifetime of Carbon Capture and Storage as a Climate-change Mitigation Technology," *Proceedings of the National Academy of Sciences*, Vol. 109:14, pp 5185–5189, (April 2012).

For the past 20 years, CCS has seen significant year-to-year growth in terms of both interest and expenditures. However, there is now seeing a slowdown in the growth of interest and a probable shrinking in expenditures. 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. Contributing to the problem is the global financial crisis. At present, this has not had a significant impact in the CCS program at MIT, but could become problematic if these issues persist for several more years.

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

Analysis Group for Regional Energy Alternatives

MIT Energy Initiative 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 the MIT–Portugal program and other related projects, AGREA focuses on how to reduce energy use and emissions on the local and regional scale. 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 the local energy system operations, and 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 Systems Focus Area, most notably the Azores Green Islands Project, as well as new efforts elsewhere in Europe and the Middle East. AGREA's bottom-up approach helps both policy makers and private sector innovators identify new market niches for clean energy technologies. Other past projects have focused on New England; Shandong, China; Mexico City; Northern Europe; Switzerland; the UK; and Argentina.

In addition to the projects and programs listed above, Connors advises many graduate and undergraduate students in other projects and programs at MIT, looking at fuel consumption and emissions impacts among renewables and fossil fuels; challenges to the development of such new renewable industries 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 real options applications to energy investments involving climate change, economic growth, and energy security. Details are available at http://web.mit.edu/agrea/.

Martin Family Society of Fellows for Sustainability

Nineteen advanced graduate students from 10 departments were selected for the 2012–2013 Martin Fellows cohort. More than 280 doctoral students from all five schools and more than 25 departments have been supported by the Martin Family Society of Fellows for Sustainability since its formation in 1997. In September 2011, current and past Martin Fellows participated in the annual Martin Fellows retreat, which focused on long-term ecological research at Harvard Forest in Petersham. Chancellor Eric Grimson and professors Elfatih Eltahir (Civil and Environmental Engineering) and Susan Solomon (Earth, Atmospheric, and Planetary Sciences) were featured speakers during the year.

Affiliated Groups

Faculty members in several MIT centers, programs, and laboratories pursuing interdisciplinary energy and environmental activities are affiliated with MITEI or the Laboratory for Energy and the Environment 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.

All five faculty members of BTP have had strong input into MITEI's energy research and teaching: professors John Fernandez, Leon Glicksman, John Ochsendorf, Les Norford, and Christoph Reinhart, who joined the faculty this year. 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 Electrical Engineering and Computer Science, Civil and Environmental Engineering, and Mechanical Engineering, as well as the Harvard School of Public Health, the Singapore–MIT Alliance for Research and Technology, Chalmers University of Technology, the Swiss Federal Institute of Technology, and Tsinghua University (China). Typically, 20 to 25 graduate students are involved in building technology research at any given time. Some students receive degrees in the Department of Architecture and others in the School of Engineering. BTP faculty and students are working on major projects on the natural ventilation of commercial buildings; urban heat island conditions; design tools; fault detection, monitoring, and control; sustainable buildings for developing countries; daylighting; industrial ecology; and the application of option theory. They are also working with the MITEI Campus Energy Management and Education task forces, and there are joint programs with researchers and academics in Portugal, Singapore, Abu Dhabi, China and Japan.

Center for Advanced Nuclear Energy Systems

Center for Advanced Nuclear Energy Systems (CANES) faculty and staff were the recipients of several research awards. A $7.5 million integrated project to study the technology of salt-cooled reactors was begun under the direction of professor Charles Forsberg. The project involves the University of California, Berkeley, and the University of Wisconsin. Professor Ballinger received a DOE award to study degradation of fuel stored in dry casks. Professor Kazimi received parts of two DOE awards related to water-cooled self-sustaining reactors. The center organized for the second time a two-week summer course for the staff of the Emirates Nuclear Energy Company, which is building four reactors in Abu Dhabi. The United Arab Emirates thus is the first new country to break ground on new reactors since China started its program in the 1980s.

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 current director of CANES. Information on the center's extensive research and outreach activities is available at http://web.mit.edu/canes/.

Sloan Automotive Laboratory

A significant amount of MITEI's research volume supports work at the Sloan Automotive Laboratory (SAL). Many of the laboratory's projects involve quantitative and cross-disciplinary study of the complex energy and environmental issues created by use of current transportation propulsion and vehicle technologies and fuels. SAL is directed by professor Wai Cheng (Mechanical Engineering), with participation from professor John Heywood, Dr. Tian Tian, Dr. Victor Wong, and professor William Green (Chemical Engineering). It continues to pursue promising research to improve powertrain performance, efficiency, and fuel utilization in internal combustion engines and to reduce adverse emissions.

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

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

Center for 21st Century Energy

The Center for 21st Century Energy is dedicated to developing technologies for a sustainable energy future. The center brings together existing and new energy research programs carried out in the Department of Mechanical Engineering'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's research focuses on technologies for efficient and clean energy conversion and utilization, groundwater, and some aspects of aerospace propulsion. The 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, biomass and bioenergy, hydrogen and alternative fuels, and water purification and desalination. The center director is professor Ahmed Ghoniem, and faculty participants include professors John Brisson, Wai Cheng, John Heywood, Alexander Mitsos, John Lienhard, Gang Chen, Yang Shao-Horn, Kripa Varanasi, Tonio Buonassisi, Leon Glicksman, Paul Sclavounos, Cullen Buie, and Evelyn Wang. A brief description of the different research areas follows.

Solar Energy

These researchers are developing novel approaches to engineer low-cost, naturally abundant manufacturable materials into defect-tolerant, high-efficiency devices. They work on nanostructured solar thermoelectric and thermophotovoltaic materials and devices, combined heat and power in concentrated solar thermal electrics, and optimal system design.

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

The program's objective is to provide the knowledge base and engineering science for enabling CO_2 capture, including research on gasification of solid fuels, oxy-combustion technologies for solid and gaseous fuels, systems integration and optimization, and novel gas separation technologies, including ion transport membranes and chemical looping.

Transportation

This 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

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

Faculty members are involved in developing fundamental knowledge of efficient and higher-energy-density lithium ion batteries. 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.

Biomass and Bio-energy

Thermochemical conversion using different combinations of low-temperature pyrolysis and intermediate- to high-temperature gasification is the gateway to significantly expand biofeedstock options and better control the quality of the fuel produced.

Building Technology

The program's work on small cryogenic systems can provide precision cooling to small areas. This work is being expanded to scales and temperatures suitable for cooling electronics, sensors, and personal spaces.

Microtechnology and Nanotechnology

The faculty members are engaged in fundamental research on transport phenomena at the macroscale and microscale, including enhanced heat transfer, high-heat-flux heat transfer, and microscale and nanoscale heat and mass transport, with applications to a range of issues, such as advanced water purification and desalination through thermal and membrane-based processes.

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. CEEPR is codirected by professors Christopher Knittel and Richard Schmalensee.

CEEPR research has a number of focuses. They include the restructuring of electricity markets; evaluating the functioning and performance of markets created for environmental services; and evaluating the future of nuclear, coal, gas and renewable energy sources, as well as the functioning of global trade in oil and natural gas. CEEPR also supports econometric work in the evaluation of environmental regulations and programs. Finally, research includes analyses of the financing of large-scale investments, as well as the price dynamics and risk in these markets.

Joint Program on the Science and Policy of Global Change

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 MIT Joint 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 21-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 capabilities for investigation of the complex connections among human activity and the global environment, and of 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 the 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 policy makers in the US 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 seven US federal agencies and an international consortium of industrial, foreign government, and foundation sponsors in North America, Europe, Japan, and China.

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