

## MIT Energy Initiative

The [MIT Energy Initiative \(MITEI\)](#) is MIT's hub for energy research, education, and outreach. Through these three pillars, MITEI plays an important catalytic role in accelerating responses to the many challenges facing our global energy system—developing technologies and solutions to deliver clean, affordable, and plentiful sources of energy. The initiative's mission is to create low- and no-carbon solutions that will efficiently and sustainably meet global energy needs while minimizing environmental impacts, dramatically reducing greenhouse gas emissions, and mitigating climate change.

To advance this mission, MITEI brings together researchers from across the Institute and facilitates collaborations with industry and government. MITEI and its member companies and organizations support hundreds of research projects across the Institute, including those awarded through the MITEI Seed Fund Program for innovative, early-stage energy research projects.

The initiative also delivers comprehensive analyses for thought leaders, policymakers, and regulators, such as the Future of study series, the latest of which is [The Future of Nuclear Energy in a Carbon-Constrained World](#), published in September 2018 with the Nuclear Science and Engineering Department. A new study, [The Future of Storage](#), launched in summer 2018 and will focus on the role of storage in making electricity systems cleaner, more efficient, and more affordable. [The Future of Storage](#) study is scheduled for release in 2021.

Another series of studies, addressing questions that are most relevant to consortia members, examine rapidly changing segments of the energy sector. The first in this series was the 2016 [Utility of the Future](#) study examining the electricity services sector. The next in the series, [Mobility of the Future](#), examines the light mobility segment of the transportation sector and will be released in November 2019.

As a vital component of MIT's Plan for Action on Climate Change and MITEI's research program, the [Low-Carbon Energy Centers](#) present opportunities for faculty, students, industry, and government to advance research and development in key technology areas and energy subsector systems for addressing climate change—from solar energy to electric power systems to mobility, among other areas.

MITEI leads the Institute's [energy education](#) efforts and has engaged thousands of undergraduate, graduate, and postdoctoral students through sponsored research opportunities and other programs—preparing the next generation of innovators, entrepreneurs, and policymakers to collaborate on solutions to global energy challenges. Energy education programs include the energy studies minor; the Undergraduate Research Opportunities Program (UROP) in energy; short modules during the Independent Activities Period; an energy-focused, first-year preorientation program; the graduate Society of Energy Fellows; and other initiatives including a new series of [online classes](#) to reach a global audience. Faculty associated with MITEI help shape energy education at both the undergraduate and graduate levels by teaching, advising, and developing new curricula.

MITEI's comprehensive [outreach efforts](#) foster dialogue within the academic research community; across the academic, industry, and government sectors; and provide the public with context on current energy issues. In addition to informing public policy through research reports, MITEI facilitates this exchange of information by hosting and sponsoring events on campus and by supporting faculty and staff participation in external events. The MITEI communications team also develops content to highlight MIT energy researchers, students, and their work across print and digital platforms, such as *Energy Futures* magazine, MITEI's website, podcasts, and social media, as well as through media outreach.

## Accomplishments and Updates

### Low-Carbon Energy Centers

MITEI continues to develop and evolve its program of Low-Carbon Energy Centers, which launched in the fall of 2015 as part of MIT's [Plan for Action on Climate Change](#). These research centers are dedicated to tackling the most pressing energy challenges related to climate change from key technological and economic perspectives. Each of the centers has a distinct focus: advanced nuclear energy systems; carbon capture, utilization, and storage; electric power systems; energy bioscience; energy storage; materials for energy and extreme environments; mobility systems; and solar energy. Fusion research is conducted in collaboration with the MIT [Laboratory for Innovation in Fusion Technologies](#), supported in part with a \$2 million grant from MITEI member Eni.

To solve the pressing challenges of decarbonizing the energy sector with advanced technologies, it is vital that experts across all disciplines and sectors are engaged. Through the Low-Carbon Energy Centers, MITEI facilitates this important collaboration: enabling faculty members from across MIT to converge around specific technology research areas and work with industry and government members to advance and expand the portfolio of existing MITEI-facilitated research in these areas. Together, MIT researchers and center members are working to develop and scale the technologies that will move us toward a low-carbon energy future.

As of the end of FY2019, MITEI has generated more than \$90 million in sponsored research activity related to the Low-Carbon Energy Centers. To date, 21 new and current MITEI members have committed support for the centers—with some members supporting multiple centers—and interest continues to grow.

### Research

MITEI's research portfolio reflects the initiative's goal of advancing low-carbon energy via diverse channels, from renewable energy and energy efficiency to carbon management technologies. An important component of the portfolio includes research and analysis on the energy systems—power, transportation, industry, and building—into which new technologies need to fit to provide needed energy services to society. The largest single area of research funding at MITEI over the past year was fusion, reflecting the intense effort now underway to develop sufficiently strong magnets to enable net power with the new SPARC fusion reactor concept. Fusion was followed closely by solar and a broad array of other science, technology, and policy programs. Recognizing the long time horizons involved in energy transition, MITEI also includes

projects geared toward meeting contemporary energy needs through more efficient and environmentally responsible use of conventional energy systems.

MITEI members have sponsored over 900 projects to date, many involving collaboration between MIT researchers and member researchers. Approximately 30% of MIT faculty has engaged with MITEI's programs.

## **Research Program Highlights**

### ***Funding for early-stage research***

One of MITEI's core tenets is supporting promising energy research across a wide range of disciplines. MITEI awarded seven early-stage MITEI seed research projects this spring for a total of approximately \$1 million. Including the 2019 grants, MITEI has supported 177 energy-focused seed projects with grants totaling approximately \$23.6 million. These projects have covered the full spectrum of energy research areas, from fundamental physics and chemistry to policy and economics, and have drawn from all five MIT schools and 28 departments, labs, and centers.

### ***Studies and reports***

The Mobility of the Future study, led by Professor William H. Green—faculty chair and professor of chemical engineering, and Randall Field—executive director of the study, will be rolled out November 2019 in Washington, DC. This study explores how consumers and markets will respond to potentially disruptive technologies, business models, and government policies in the transportation sector, with a focus on the uptake of alternative-fuel vehicles for passenger travel. As part of MITEI's Future of study series, which provide comprehensive analyses for policymakers and regulators, *The Future of Energy Storage* study, launched in summer 2018 and scheduled for release in early 2021, will focus on the role of storage in making electricity systems cleaner and more efficient. Last fall, a team of researchers led by Professor Jacopo Buongiorno—TEPCO Professor of Nuclear Science and Engineering—finalized the multidisciplinary study *The Future of Nuclear Energy in a Carbon-Constrained World*, the eighth in MITEI's Future of report series. The study was released in Europe on September 3, 2018, with Asia and US rollouts following. See more details on each of these studies in the Studies section.

### ***Low-Carbon Energy Center meetings***

The Centers for Carbon Capture, Utilization, and Storage; Energy Storage; and Electric Power Systems each held several workshops and meetings to discuss with their members the latest research results and new directions of technology development.

### ***New Low-Carbon Energy Center launch***

Based on positive member feedback on the Mobility of the Future study, MITEI has launched a new Low-Carbon Energy Center on Mobility Systems. The center expands the scope of MITEI's mobility research to include unique challenges facing mobility in high-growth developing countries, clean propulsion, long-haul freight, and urban freight, in addition to our continued focus on disruptive technologies for passenger transport. The Mobility Systems Center has launched its first call for proposals for projects that will commence in September 2019.

## Faculty Research Highlights

### *Materials science*

MIT researchers including Cullen Buie, associate professor of mechanical engineering, have developed a microfluidic technique that can quickly process small samples of bacteria and gauge a specific property that's highly correlated with bacteria's ability to produce electricity. They say that this property, known as polarizability, can be used to assess a bacteria's electrochemical activity in a safer, more efficient manner compared to current techniques. Microbes screened with the new microfluidic process might be used in power generation or environmental cleanup. More can be found on the MIT News article, "[Technique identifies electricity-producing bacteria.](#)"

The biggest source of global energy consumption is the industrial manufacturing of products such as plastics, iron, and steel. Not only does manufacturing these materials require huge amounts of energy, but many of the reactions also directly emit carbon dioxide as a by-product. In an effort to help reduce this energy use and the related emissions, MIT chemical engineers, including Professor Karthish Manthiram, have devised an alternative approach to synthesizing epoxides—a type of chemical that is used to manufacture diverse products—including plastics, pharmaceuticals, and textiles. Their new approach, which uses electricity to run the reaction, can be done at room temperature and atmospheric pressure while eliminating carbon dioxide as a by-product. More can be found on the MIT News article, "[Shrinking the carbon footprint of a chemical in everyday objects.](#)"

A team led by Kripa Varanasi, professor of mechanical engineering, has tackled a new category of consumer and manufacturing woe: How to get much thicker materials to slide without sticking or deforming. The slippery coatings the team has developed, called liquid-impregnated surfaces, could have numerous advantages, including eliminating production waste that results from material sticking to the insides of processing equipment. They might also improve the quality of products ranging from bread to pharmaceuticals, and even improve the efficiency of flow batteries, a rapidly developing technology that could help to foster renewable energy by providing inexpensive storage for generated electricity. More can be found on the MIT News article, "[How slippery surfaces allow sticky pastes and gels to slide.](#)"

### *Energy storage*

Professor Ju Li, MIT postdoctoral associate Weijiang Xue, and others have created a new version of a key component for lithium batteries: the cathode. They describe their concept as a hybrid cathode, because it combines aspects of two different approaches that have been used before—one to increase the energy output per pound (gravimetric energy density), the other for the energy per liter (volumetric energy density). They say the synergistic combination produces a version that provides the benefits of both, and more. More can be found on the MIT News article, "[New approach could boost energy capacity of lithium batteries.](#)"

Combining comprehensive experimental data and artificial intelligence revealed the key for accurately predicting the useful life of lithium-ion batteries before their capacities start to wane, scientists at Stanford University, MIT, and the Toyota Research Institute discovered. After the researchers trained their machine learning model with a few hundred million

data points of batteries charging and discharging, the algorithm predicted how many more cycles each battery would last, based on voltage declines and a few other factors among the early cycles. The study was led by Richard Braatz—professor of chemical engineering at MIT, and William Chueh—assistant professor in materials science and engineering at Stanford, among others. More can be found on [Stanford University’s Energy website](#).

### **Nuclear energy**

In an editorial published in *Science*, Professor Jacopo Buongiorno—lead author of MITEI’s *The Future of Nuclear Energy in a Carbon-Constrained World* report—and others discuss findings from the study, including that extending the life of the existing fleet of nuclear reactors worldwide is the least costly approach to avoiding an increase of carbon emissions in the power sector. More can be found on [Science’s website](#).

A year after announcing a major, public-private collaboration to design a fusion reactor capable of producing more power than it consumes, researchers from MIT, including Dennis Whyte—head of MIT’s Plasma Science and Fusion Center and the startup company Commonwealth Fusion Systems, presented an update on their progress. In a series of talks in January 2019, they detailed the effort’s continuing work to bring about practical fusion power—based on the reaction that provides the sun’s energy—on a faster timescale than any previous efforts. More can be found on the MIT News article, [“MIT continues progress toward practical fusion energy.”](#)

MIT graduate student Caroline Sorensen is using her talent for mechanical engineering to help advance a novel project within the domain of applied science: the commercialization of fusion energy. More can be found on the MIT News article, [“Tapping the MIT talent pool for the future of fusion.”](#)

### **Solar energy**

In a 3Q interview, Vladimir Bulović—the Fariborz Maseeh (1990) Chair in Emerging Technology, director of the Organic and Nanostructured Electronics Laboratory, and founding faculty director of MIT.nano—discusses his work on creating next-generation, lightweight, flexible photovoltaics that could change the way the world deploys solar energy systems. More can be found on [MITEI’s website](#).

In an interview published by *Solar Magazine*, Sergey Paltsev—deputy director of the MIT Joint Program on Science and Policy of Global Change and senior research scientist at MITEI—discusses the degree and extent to which solar and other clean, decentralized renewable energy resources have the potential to reshape the geopolitical landscape, and what that may portend for the future of international relations. More can be found on [Solar Magazine’s website](#).

### **Electric power system**

Using their so-called cybersafety methodology, Professor Stuart Madnick, graduate student Shaharyar Khan, and Professor James L. Kirtley identified several cyber vulnerabilities in a small power plant, including a system that poses a risk because it relies on software rather than mechanical safety devices to keep turbines from spinning out of control. More can be found on the MITEI news article, [“Protecting our energy infrastructure.”](#)

## ***Transportation***

Heavy-duty trucks, such as the 18-wheelers that transport many of the world's goods from farm or factory to market, are mostly powered by diesel engines. They account for a significant portion of worldwide greenhouse gas emissions, but little has been done so far to curb their climate-change-inducing exhaust. Now, researchers at MIT have devised a new way of powering these trucks that could drastically curb pollution, increase efficiency, and reduce or even eliminate their net greenhouse gas emissions. More can be found on [Science Daily's website](#).

Daniel Cohn—MITEI research scientist and Leslie Bromberg—principal research engineer at MIT's Plasma Science and Future Center, published a paper with the Society of Automotive Engineers, suggesting that the best way forward is not to wait for all-electric or hydrogen-powered semis, but to build a plug-in hybrid electric truck with an internal combustion engine/generator that can burn either gasoline or renewable ethanol or methanol. More can be found on the [Ars Technica website](#).

## ***Energy and climate economics and policy***

Howard Herzog—director of the MITEI Carbon Capture, Utilization, and Storage Low-Carbon Energy Center—discusses how difficult it will be for carbon capture projects to proceed until there is a policy that restricts the amount of CO<sub>2</sub> we can put in the atmosphere, either by setting limits or pricing. More can be found on [CAI's website](#).

Successful global efforts to substantially limit greenhouse gas emissions would likely boost GDP growth of poorer countries over the next 30 years, according to new research from the International Food Policy Research Institute and the MIT Joint Program on the Science and Policy of Global Change. Researchers including Sergey Paltsev—deputy director of the MIT Joint Program on the Science and Policy of Global Change—examined the impact global climate change mitigation would have on the economies of poorer countries—specifically Malawi, Mozambique, and Zambia. More can be found on the MIT News article, "[Study: For low-income countries, climate action pays off by 2050.](#)"

New research published by an international team of scientists, including Ronald Prinn—professor of atmospheric science and co-director of the MIT Joint Program on the Science and Policy of Global Change—finds that since 2013, annual emissions of a banned chlorofluorocarbon have increased by nearly 8,000 tons from eastern China. More can be found on the [MIT Joint Program on the Science and Policy of Global Change website](#).

To help the world achieve the long-term 2°C and 1.5°C Paris Agreement goals, China will need to continually decrease its CO<sub>2</sub> emissions intensity targets over the course of the century. A new study led by Jennifer Morris, a research scientist at the MIT Joint Program on the Science and Policy of Global Change, projects a key role for carbon capture and storage in China as part of a portfolio that also includes renewables and possibly nuclear power. More can be found on the MIT Joint Program on the Science and Policy of Global Change article, "[Pathways to a low-carbon China.](#)"

Ernest Moniz—special advisor to the MIT president, professor emeritus, and former US Secretary of Energy—writes about the need to translate the aspirations of the Green New

Deal, which promotes social justice alongside accelerated deep reductions in greenhouse gas emissions, into actions within the constraints of technical, cost, and social realities. More can be found on the *Science* article, [“Innovating a Green Real Deal.”](#)

### **Additional low-carbon energy research**

Wind, solar, and storage are on the cusp of collaborating to provide near carbon-free energy at cost equal to the cheapest fossil fuels, according to John Deutch, MIT chemist and former CIA director. To help with the commercialization of the wind, solar, and storage triad, Deutch proposes setting up a competition between energy developers, allowing them to bid on a 20-year contract to provide a system that meets 95% of demand in an area using solar, wind, and storage alone. Deutch and his collaborators, including Yet-Ming Chiang of the Department of Materials Science and Engineering, demonstrated their proposal by calculating the costs of such a system in central Texas. More can be found on [Forbes’s website](#).

Heather Kulik, assistant professor of chemical engineering, and graduate student Jon Paul Janet are using neural networks coupled with genetic algorithms to examine huge databases of transition metal compounds for potential use in practical devices. Using the same technique, graduate student Aditya Nandy is designing better catalysts for methane conversion reactions. More can be found on MITEI article, [“Finding novel materials for practical devices.”](#)

A collaboration between Sheila Kennedy, professor of architecture, and Michael Strano, professor of chemical engineering, could be at the center of new sustainable infrastructure for buildings. In their project, Strano and Kennedy envision buildings of the future that may be lit by collections of glowing plants and designed around an infrastructure of sunlight harvesting, water transport, and soil collecting and composting systems. More can be found on the MIT News article, [“Ambient plant illumination could light the way for greener buildings.”](#)

A new system devised by researchers at MIT can monitor the behavior of all electric devices within a building, ship, or factory, determining which ones are in use at any given time and whether any are showing signs of an imminent failure. When tested on a Coast Guard cutter, the system pinpointed a motor with burnt-out wiring that could have led to a serious onboard fire. The new sensor, whose readings can be monitored on an easy-to-use graphic display called a non-intrusive load monitoring (NILM) dashboard, is described in a paper by Steven Leeb—MIT professor of electrical engineering, Andre Aboulian SM ’18, and seven others at MIT, the US Coast Guard, and the US Naval Academy. More can be found on [Science Daily’s website](#).

Assistant Professor Betar Gallant and graduate student Aliza Khurram are developing a novel battery that could both capture carbon dioxide in power plant exhaust and convert it to a solid ready for safe disposal. More can be found on MITEI article, [“Removing CO<sub>2</sub> from power plant exhaust.”](#)

In a blog post, Bill Gates refers to research from a team including Richard Lester—Japan Steel Industry Professor and associate provost of MIT, and Nestor Sepulveda—a PhD student in the Department of Nuclear Science and Engineering, who found that

supporting renewable energy with a mix of clean energy solutions—including nuclear and carbon capture and storage—would make carbon-free electricity up to 62% cheaper than using renewables alone. More can be found on the [Gates Notes website](#).

### **Energy in the developing world**

An award from the US Agency for International Development will support research collaborations through the new Center of Excellence in Energy at Ain Shams University in Cairo, Egypt. Ahmed Ghoniem—the Ronald C. Crane ('72) Professor in MIT's Department of Mechanical Engineering—will co-lead the center. Over the next five years, the team will work to build the research, education, and entrepreneurial capacity of Ain Shams, Mansoura, and Aswan universities to address Egypt's most pressing energy-related problems. More can be found on the MIT News article, "[MIT receives \\$30 million to help address energy challenges in Egypt.](#)"

Robert Stoner—MITEI deputy director and director of the Tata Center for Technology and Design—discusses energy opportunities and challenges for the world's third-largest economy. [More can be found on the MIT News website.](#)

## **MITEI Studies**

### **Mobility of the Future**

The multidisciplinary *Mobility of the Future* study is wrapping up; research results have been finalized and the final report will be publicly launched in November 2019. This study explores how consumers and mobility markets will respond to potentially disruptive technologies, business models, and government policies. The research group and the consortium of MITEI members, which have been meeting since August 2016, defines the scope of the study as ground transportation with an emphasis on the movement of people. The study is part of MIT's Plan for Action on Climate Change.

The study is led by faculty chair William H. Green, professor of chemical engineering, and Randall Field of MITEI, the study's executive director. It is supported by energy, automotive, and infrastructure companies whose representatives provide industry perspectives on mobility problems: Alfa Corporation, BP, Chevron Corporation, ExxonMobil, Ferrovial, S.A., General Motors Company, Saudi Arabian Oil Company (Saudi Aramco), Shell, Equinor, and Toyota Mobility Foundation.

The study team—which includes faculty, researchers, graduate students, and postdoctoral students—has undertaken analyses in many important areas of mobility in response to key questions identified by MIT researchers and consortium members. These analyses include projection of the future cost of battery packs for electric vehicles, assessment of fuel consumption and fleet composition under various climate policy scenarios, and impact of new, on-demand mobility services on mode choice for different cities around the world.

### **The Future of Nuclear Energy in a Carbon-Constrained World**

A team of researchers led by Professor Jacopo Buongiorno, who leads the Low-Carbon Energy Center for Advanced Nuclear Energy Systems, finalized the multidisciplinary study *The Future of Nuclear Energy in a Carbon-Constrained World*, the eighth in MITEI's



Future of report series. The team consisted of seven MIT faculty members from across the Institute, including Senior Lecturer John Parsons of MIT Sloan as report co-author, as well as two Harvard University faculty members and four external consultants. The study, which was released in September 2018 with events in the United States, Europe, and Asia, provides an objective assessment of the opportunities and challenges affecting the ability of nuclear energy technologies to meet US and global energy needs in the context of the imperative to dramatically reduce carbon emissions in order to address climate change.

### ***The Future of Energy Storage***

*The Future of Energy Storage* study, launched in summer 2018 and scheduled for release in early 2021, focuses on the role of storage in making electricity systems cleaner and more efficient. Howard Gruenspecht, MITEI senior energy economist, is the executive director of the study, and Robert Armstrong, MITEI director and Chevron Professor of Chemical Engineering, and Yet-Ming Chiang, Kyocera Professor of Materials Science and Engineering are co-chairs of the study. Although multiple resources and technologies can provide clean generation, variable renewable energy (VRE) resources such as wind and solar are of particular interest given their widespread availability, public acceptance, scalability, and increasingly attractive cost. Traditional electric systems are built on a paradigm where generation (supply) is adjusted by system operators to follow load (demand). However, unlike generation sources that can follow load, wind and solar photovoltaics cannot be dispatched at will. Therefore, the feasibility of a future electricity supply system in which they play a central role depends directly on the future availability and cost of energy storage technologies suitable for large-scale deployment.

The study considers storage technologies; the economics of storage; practical system transformation pathways for industry; and possible government roles in market design and regulation, research, and deployment support for storage in the 2020 to 2040 timeframe. The multidisciplinary faculty study team's main focus is on electricity-to-electricity storage systems in four broad categories: electrochemical storage (batteries), kinetic storage (including pumped hydro and compressed air energy storage), hydrogen and other chemical storage, and heat storage. The study will also consider how storage interacts with strategies such as increased load flexibility and expanded transmission networks that might also be part of a cost-effective approach to accommodate a VRE-rich generation mix.

The team met regularly in late 2018 and early 2019 to set the study's focus, benefiting from discussions at an initial meeting of the study's external advisory committee in February 2019. More recently, their focus has been on building teams of students and postdoctoral fellows to execute research for the study.

### **Tata Center for Technology and Design**

During AY2019, the [Tata Center for Technology and Design](#) supported 40 master's and PhD students as they traveled abroad at least twice a year to immerse themselves in the social, political, and economic aspects of their research in the developing world. Now at the end of its seventh year, the Tata Center has seen students work extensively throughout India, as well as in Nepal, Kenya, Nigeria, Tanzania, Uganda, Rwanda, Brazil, Colombia, and Venezuela. Their experiences abroad inform their ongoing research with the goal of catalyzing positive social impact in the form of policy support

and affordable products and services. Through support for these students, and through thoughtfully crafted research projects in the fields of energy, water, environment, housing, health, and agriculture, the Tata Center advances its mission of bringing technical talent and experience to bear on the challenges of the developing world.

Many Tata Center students have had noteworthy accomplishments in the past year. Examples include the following:

Malvika Verma won the 2019 MIT Graduate Women of Excellence award, the 2019 Leader of Tomorrow award at the Gap Summit, and the 2018 Wishnok Prize for Best Bioengineering Talk.

Eric Miller won the Grand Prize at the IDEAS Global Challenge in April 2019. He was also a semifinalist at the MIT \$100K Launch competition and the MassChallenge Incubator. Miller won first place in Audience Choice at the ChemE Science Slam in March 2019, and was accepted into the MIT delta v incubator at the Martin Trust Center in April 2019. He was the Advanced Lateral Flow Course Innovation Award finalist in October 2018, and he won the Sandbox Innovation Fund Grant in August 2018.

Lin Zhao received the Wunsch Foundation Silent Hoist and Crane Awards for Outstanding Graduate Research in Mechanical Engineering at MIT.

Brendan Derek Smith won \$10,000 at the MIT Ideas awards. Smith's startup, SiPure, won the 2019 Water Innovation award for developing a silicon membrane that purifies textile wastewater. He was also part of the National Science Foundation Innovation Corps program where he won \$50,000.

Justin Lueker received the American Society of Heating, Refrigerating and Air-Conditioning Engineers Graduate Student Grant-in-Aid Award for 2018.

Lastly, Somya Singhvi won the 2019 Production and Operations Management Society College of Sustainable Operations Best Student Paper competition for his paper "Artificial Shortage in Agricultural Supply Chains."

To date, Tata Center-funded projects have led to more than 45 patent disclosures to MIT's Technology Licensing Office. Eleven projects are already on the path to commercialization through startups, and other projects have resulted in licensing arrangements, while many others have attracted follow-on funding from government agencies and commercial sponsors. As projects continue to mature, the Tata Center continues to translate these projects into practice partly in cooperation with the Tata Trusts and the Foundation for Innovation and Social Entrepreneurship, a nonprofit incubator established in Bangalore by the trusts with the government of India.

The Tata Center hosted its fourth annual Symposium at MIT in 2018. Distinguished guests from India, seasoned entrepreneurs, members of NGOs, as well as vital partners of the Tata Center gathered to participate in a discussion titled, "Translating Research into Impact at the Tata Center," and to participate in sectorial workshops on the second day of the event. Speakers with diverse perspectives on entrepreneurship held panel discussions. The event also featured poster sessions and presentations that introduced guests to the center's newest projects in agriculture, energy, environment, health, housing, and water.

## Global Commission to End Energy Poverty

In collaboration with the Rockefeller Foundation, MITEI initiated an ambitious new effort in late 2018 to bring electricity to the remaining billion people across the globe who currently live without it. The Global Commission to End Energy Poverty is led by Robert Stoner, MITEI deputy director and director of the Tata Center for Technology and Design; and co-chaired by Ernest Moniz, special advisor to the MIT president, professor emeritus, and former US Secretary of Energy; Dr. Rajiv Shah, president of the Rockefeller Foundation; and Akinwumi Adesina, president of the African Development Bank. The commission will convene for the first time in September 2019 in Italy, and will publish its findings and recommendations at the United Nations General Assembly in 2020. The Global Commission's leaders hope to define an actionable, long-term agenda underpinned by commitments by the major development banks, private firms and investors, governments, and national utilities that will make universal electrification a reality by 2030.

## Education

MITEI's role as an educator of future energy change agents is critical to its mission as a catalyst for tomorrow's low-carbon energy solutions. Through programs created for graduate and undergraduate students, MITEI provides a robust educational tool kit to MIT students who want to contribute to the energy transition. These programs allow students to take classes; conduct research in diverse areas, from energy science and social science to technology and engineering; practice their skills; and network with peers and professionals. MIT faculty members work with MITEI's education team to develop the curriculum and act as advisors to aspiring and current energy students.

Students interested in energy at MIT can start as soon as they step onto campus: MITEI runs the Discover Energy First-Year Pre-Orientation Program at the end of the summer before classes begin. The journey continues in the classroom, where undergraduate students can take interdisciplinary courses through the energy studies minor and participate in laboratory research through the MITEI UROP.

Students participating in MITEI's Solar Spring Break program have the opportunity to immerse themselves in energy practice by installing solar panels in underserved communities. In 2019, MITEI partnered with GRID Alternatives, a California nonprofit where Anna Bautista '05 is vice president of construction and workforce development.

Graduate students and postdoctoral fellows receiving funding from MITEI through the member education fund are an equally important part of the initiative's energy education ecosystem. In addition to contributing their own research to MITEI's areas of inquiry and collaborating with researchers on white papers and studies, graduate students mentor UROP students and contribute to the development of the energy studies minor curriculum. Through the Society of Energy Fellows, MITEI also hosts activities for graduate student fellows, including dinner meetings with sponsors at MITEI's Annual Research Conference and a range of informational gatherings and networking events.

## **MITEI Education Program Highlights**

### ***Energy studies minor***

After two years of hard work, the revised curriculum created by the Energy Studies Minor Oversight Committee has been accepted by the Committee on Curricula and will be published in August 2019. Updates include improving curriculum flexibility across fall and spring offerings, as well as increasing the number of advisors across academic departments to provide a go-to resource for students planning their course schedules.

### ***Undergraduate energy research***

MITEI supported 56 student projects through the MITEI UROP during AY2019, bringing its total number of sponsored projects up to 531, including Tata Center and Center for Energy and Environmental Policy Research projects. This cohort's research spanned a breadth of unique subjects, among them solar-driven sterilization under ambient pressure and low solar flux, cost modeling of solar in sub-Saharan Africa, and grid-scale energy storage.

### ***Graduate fellows***

MITEI welcomed 26 new graduate students and postdoctoral fellows to the Society of Energy Fellows in AY2019. The Energy Fellows network now totals more than 430 current and former graduate students and postdoctoral fellows, spanning 20 MIT departments and divisions and all five MIT schools. This year's fellowships are made possible through the generous support of six MITEI member companies: Commonwealth Fusion Systems, Chevron Corporation, Eni S.p.A., ExxonMobil, Shell, and TotalEnergies SE; and one former member, Robert Bosch GmbH.

### ***Solar Spring Break***

In March 2019, nine undergraduate students and two graduate students participated in MITEI's Solar Spring Break program in partnership with the nonprofit GRID Alternatives. The students installed solar panels on the home of a low-income family in Los Angeles, California, over the course of a week. Participants met the homeowner and heard firsthand about the impact of their work, and attended various networking and educational events.

### ***First-Year Pre-Orientation Program***

MITEI's summer 2018 Discover Energy First-Year Pre-Orientation Program sent 15 first-year students to on- and off-campus locations to learn about opportunities for energy research and education at MIT. Activities included a meeting with representatives from the Institute's Undergraduate Energy Club, a tour of a wind turbine blade testing facility, a visit to the Fraunhofer Center for Sustainable Energy Systems, an energy economics workshop with Professor Jing Li of the MIT Sloan School of Management, and a workshop on building DC motors with Professor Steven Leeb of the Department of Electrical Engineering and Computer Science. Students also met with professors in informal settings, including William Green, Robert Jaffe, Julia Ortony, and David Hsu.

### ***Career Insights Speaker Series***

This year, rather than focusing on small group meetings with individuals, the MITEI Education Office held a day-long forum in April 2019 on careers in energy called Working the Energy Transition. Throughout the day, over 50 undergraduate and graduate students had the opportunity to meet with 22 members of industry and government, gaining insight into the wide breadth of options for careers in energy.

### ***Conversations with energy leaders***

MITEI works with the MIT Energy Club throughout the academic year to organize the monthly E<sup>3</sup> dinner series. The dinner series brings MIT energy community members together with distinguished alums in the energy industry. The dinners are intended to not only foster connections between alumni and current students, but also to build bridges between current students from different MIT undergraduate and graduate communities over shared interests in energy. Speakers for the AY2019 dinners included Matthew Zedler '07—head of product and application engineering at Lockheed Martin Advanced Energy Storage, and Sandhya Murali—co-founder and chief operating officer of Solstice (an award-winning social enterprise dedicated to expanding access to clean energy to all Americans).

### ***Online energy courses***

To help train the global network of professionals needed to realize a low-carbon energy future, the MITEI education team has organized a new series of online energy courses based on interdisciplinary MIT graduate classes currently taught on campus. The courses will be part of the MITx massive open online courses slated to run on the edX platform. The MITx courses will engage four critical aspects of future electricity systems: load and demand-side management; economics and regulation; production; and distribution and transmission. The first class, Professor Christoph Reinhart's 4.464 Environmental Technologies in Buildings, is projected to launch in late summer 2019.

### ***Energy field trip***

In June 2019, Antje Danielson—MITEI's director of education—led a group of six undergraduate students to visit energy sites in Denmark and Germany, including a visit to the island of Samsø and to a radioactive waste storage facility. This pilot program was aimed at rising sophomores as a means of furthering engagement with the energy field beyond the classroom and encouraging student enrollment in the energy studies minor.

### ***Annual Research Conference***

At MITEI's December 2018 Annual Research Conference, 26 undergraduate students presented posters of energy-related work in a wide range of disciplines, from architecture to electrochemistry. The students, all MITEI-sponsored participants in the UROP, had the opportunity to network with energy professionals while showcasing their research.

### ***Outreach***

MITEI's fact-based analysis of current energy topics informs public policy, fosters dialogue within the academic research community, and provides the public with context on vital issues. Convening events throughout the year, MITEI hosts thought leaders from

across the energy value chain. MITEI staff, faculty affiliates, and graduate students share their research and perspectives at domestic and international events. Staff members also participate in Institute-wide efforts focused on addressing climate change. MITEI's communications team highlights the research and achievements of faculty and students through articles, media outreach, social media, podcasts, and other digital and print platforms to reach a diverse audience.

## **Outreach Program Highlights**

### ***MIT Climate Symposia***

During AY2020, MIT will host six symposia to examine the urgent challenge of climate change. This series will draw upon MIT's work to date on the MIT Plan for Action on Climate Change and consider the current state of knowledge on key aspects of this global problem. These discussions will provide an important opportunity for engagement among members of the MIT community, other leading researchers, industry leaders, and policymakers to explore options for facilitating the necessary transition to a low-carbon economy. MITEI-affiliated faculty and staff are providing support for the six symposia.

### ***MIT Plan for Action on Climate Change***

MITEI continues to support MIT's Plan for Action on Climate Change with the ongoing development of its interdisciplinary Low-Carbon Energy Centers, which include new types of member companies, energy systems analysis and studies, work in developing countries, and education.

### ***Guest speakers***

Leading executives in policy, academia, and industry gave talks at MITEI-hosted events. Speakers included Naomi Hirose, executive vice chairman of Fukushima Affairs at the Tokyo Electric Power Company; Frances Beinecke, past president of the Natural Resources Defense Council; and Asegun Henry, director of the Atomistic Simulation and Energy Research Group.

### ***IHS Seminar Series***

In October 2018, IHS sponsored a seminar titled "Molecular Approaches to Solar Energy Conversion," led by Michael R. Wasielewski, Clare Hamilton Hall Professor of Chemistry and executive director of the Institute for Sustainability and Energy at Northwestern University, and director of the Center for Light Energy Activated Redox Processes—a US-DOE Energy Frontier Research Center.

### ***MIT Climate Night***

On April 25, 2019, MITEI co-hosted Climate Night with the MIT Environmental Solutions Initiative as part of MIT's Earth Week 2019 programming. The event included a climate conversation as well as open discussions with Maria Zuber—MIT vice president for research, John Fernandez—MIT Environmental Solutions Initiative director, and Robert Armstrong—MIT Energy Initiative director.

### ***Annual Research Conference 2018***

The 2018 Annual Research Conference event brought together energy researchers, policymakers, and industry members working on cutting-edge technologies and business models for the transition to a low-carbon future. Panels ranged from the latest developments in the fight against climate change to innovations for creating a better business environment in which energy startups can thrive. A special segment of the conference, presented in collaboration with the recently launched MIT Quest for Intelligence, focused on the role of artificial intelligence and machine learning in the energy sector. Conference speakers included Barbara Burger, president of Chevron Technology Ventures; Bashir Dabbousi, director of technology strategy and planning at Saudi Aramco; Chris Fall, principal deputy director at Advanced Research Projects Agency-Energy at the US Department of Energy; Robert Mumgaard, CEO of Commonwealth Fusion Systems; Emily Reichert, CEO of Greentown Labs; and MIT faculty members.

### ***C3E 2018 Women in Clean Energy Symposium***

In December 2018, the Seventh Annual Clean Energy, Education, and Empowerment (C3E) Women in Clean Energy Symposium and Awards, was hosted by Stanford Energy in collaboration with the US Department of Energy, MITEI, and Texas A&M Energy Institute. The conference featured award presentations to midcareer women and a lifetime achievement award presentation, as well as diverse speakers such as Betar Gallant—MIT professor of mechanical engineering, and rich conversations on strategies and technologies to enable the transition to a low-carbon future. The US C3E Initiative aims to advance clean energy by closing the gender gap and enabling the full participation of women in the sector.

### ***Spring Symposium***

In June 2019, MITEI held a symposium to investigate the resurgence of global interest in low-carbon hydrogen. More than 100 people joined MIT researchers and industry leaders to learn about the current state of hydrogen in the energy system and the ways in which it could be employed as part of a low-carbon future. The day-long event, sponsored by MITEI associate members Cummins and Électricité de France, featured sessions on topics ranging from transportation and infrastructure to technological advances coming out of laboratories to government policies.

### ***Tata Center Symposium***

The Tata Center held its fourth annual symposium in October 2018. The two-day event, titled Translating Research into Impact, highlighted the need to invest in technologies for the developing world from a market-driven perspective. Speakers included Manoj Kumar—head of entrepreneurship and innovations at Tata Trusts, Maurizio Vecchione—the executive vice president of Global Good and Research, and Ernest Moniz—the Cecil and Ida Green Professor of Physics and Engineering Systems Emeritus and former US Secretary of Energy.

### ***Support for campus energy events***

MITEI sponsored and provided staff support for numerous campus energy events, including the student-run MIT Energy Conference, the Undergraduate Energy Research Fair, the Energy Career Fair, and the Energy Hackathon.

## **Podcasts**

MITEI produced and released a number of podcasts that explore energy from a variety of angles to make its research more accessible to a large audience and to illustrate how energy impacts our everyday lives. Subjects covered this year include electricity markets, artificial intelligence, batteries and storage, and game-changing fusion.

## **ORGANIZATION**

### **MITEI Leadership Team**

Director Robert Armstrong’s leadership team continues to build on MITEI’s strong foundation and bold, multidisciplinary approach to deliver global energy solutions. In addition, the team is broadening MITEI’s membership base, seeking out potential members for the Low-Carbon Energy Centers, increasing opportunities for faculty research, strengthening operations, and playing a lead role in energy education and outreach at MIT.

Robert C. Armstrong—Director

Robert Stoner—Deputy Director for Technology and Science; Director, Tata Center for Technology and Design

Martha Broad—Executive Director

Louis Carranza—Associate Director

Emily Dahl—Director, Communications

Antje Danielson—Director, Education

Robert Tolu—Senior Fiscal Officer, Finance

### **MITEI Energy Council**

The MITEI Energy Council helps shape MITEI’s research, education, and outreach directions. Armstrong, Stoner, and Broad are members of the council, which also includes Professors Angela Belcher, John Deutch, Leon Glicksman, Bradford Hager, Christopher Knittel, and Yang Shao-Horn.

### **Energy Education Task Force**

MITEI’s Energy Education Task Force (EETF) guides the development of energy education at MIT. Bradford Hager—Cecil and Ida Green Professor of Earth Sciences in the Department of Earth, Atmospheric and Planetary Sciences; and Rajeev Ram—professor of electrical engineering and computer science in the Research Laboratory of Electronics, 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. MITEI’s education team members support the EETF by implementing energy education programs.



## MITEI Members

MITEI's members are critical in the energy innovation chain, linking MIT's world-class research teams with innovators in industry and government to address pressing energy challenges and move solutions into the marketplace. Along with delivering valuable industry perspectives on current technology challenges, members offer research opportunities and critical funding for next-generation energy technologies and for analysis of integration of these into existing and future energy systems.

MITEI draws on MIT's research capabilities, innovation, expertise, and experience to create successful industry collaborations to meet its research partners' key strategic objectives. A multitiered membership structure enables diverse private-sector partners to sponsor multidisciplinary, flagship research programs with MIT faculty; 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.

## Member Highlights

- New Low-Carbon Energy Center members in FY2019 include the following: Associated Electric Cooperative Incorporated, ENN Energy Holdings Limited, PT Indonesia Asahan Aluminium (INALUM), Shell, and Xignux; these new center members include companies that are expanding on their current MITEI memberships and others that are joining MITEI as first-time members
- New associate members in FY2019 include Sertecpet
- Building on the success of the *Mobility of the Future* study, MITEI launched Mobility Systems as a new Low-Carbon Energy Center
- A key Member Services activity in FY2019 was working on renewal agreements for four of MITEI's founding members (Saudi Aramco, ExxonMobil, Shell, and Eni), most of which are due to renew early and late fall 2019, as well as three sustaining members, including Equinor, Total, and Chevron
- Exelon, the first Low-Carbon Energy Center member of MITEI, became a sustaining member; Exelon exceeded their sponsored research obligation by \$11,250,000 during their first three years as a MITEI member
- On June 3, 2019, MITEI hosted its Spring Symposium, titled, Can Hydrogen Become Part of the Climate Solution?; over the course of AY2019, hydrogen became a topic of much interest to MITEI members; the symposium was sponsored by associate members Électricité de France and Cummins
- CERAWEEK 2019: MITEI facilitated the participation of 23 faculty, including Maria Zuber; seven students; and four MITEI-related startups at this annual event in Houston, Texas

A complete list of members is available on the [MITEI website, current members section](#).

## Affiliated Groups

MITEI is affiliated with faculty members in a number of MIT departments, labs, and centers 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) promotes research on energy and environmental policy to support improved decision making by government and industry. It is directed by Professor Christopher Knittel and jointly sponsored by MITEI, the Department of Economics, and the MIT 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 associates in government and industry from around the globe to enhance the relevance of its research.

CEEPR produces working papers, policy briefs, and research input for larger, interdisciplinary studies; two annual research workshops in Cambridge, Massachusetts; and an international energy policy conference organized jointly with the Energy Policy Research Group at the University of Cambridge in the United Kingdom.

The E2e project is a collaborative program initiated by Knittel, Professor Michael Greenstone (formerly at MIT, now at the University of Chicago), and Professor Catherine Wolfram of the University of California at Berkeley, to leverage cutting-edge scientific and economic insights on the causes of the persistent energy-efficiency gap. E2e focuses these talents on solving one of the most perplexing energy questions today and communicating those findings to policymakers and the public. E2e's research generates rigorous and accurate evaluations of energy-efficiency technologies and programs using state-of-the-art empirical methodologies.

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

Led by Co-directors Ronald G. Prinn and John Reilly, the joint program's integrated team of natural and social scientists studies the interactions among human and Earth systems to provide a sound foundation of scientific knowledge to aid decision makers in confronting interwoven challenges, including future food, energy, water, climate, and air pollution. This mission is accomplished through the following:

- Quantitative analyses of global changes and their social and environmental implications, achieved by employing and constantly improving an Integrated Global System Modeling framework
- Independent assessments of potential responses to global risks through mitigation and adaptation measures

- Outreach efforts to analysis groups, policymaking communities, and the public
- The cultivation of a new generation of researchers with the skills to tackle complex global challenges in the future

Building on the twin pillars of science and policy, the program was founded in 1991 as a joint effort of two distinct groups: the MIT Center for Global Change Science and CEEPR.

### **MultiScale Materials Science for Energy and Environment Laboratory**

MITEI continues to host the MultiScale Materials Science for Energy and Environment Laboratory, an international joint unit (UMI) between France's National Center for Scientific Research (CNRS) and MIT at the center of a strategic association covering research, training, and education in partnership with industry. The UMI aims at bottom-up simulation and experimental verification of properties of complex, multiscale materials—from atomic-scale to microns, and from nanoseconds to years. Materials with important technological, economic, energy, and environmental applications are addressed, including cement, ceramics, nuclear fuels, steels, and geomaterials. The UMI hosts French researchers at MIT, each for multiple years, and is seen as a gateway to further collaboration between CNRS and MIT. The UMI, which is housed at MIT under the auspices of MITEI, has been designated by the CNRS as the lead unit of an international research network consisting of multiple institutions engaged in materials science in the United States and Europe. In July 2019, MIT, CNRS, and Aix-Marseille Université held a symposium in Marseille to highlight past accomplishments of this collaboration; we are working on a renewal for another five years.

### **Office of Sustainability**

The mission of the MIT Office of Sustainability (MITOS) is to transform MIT into a powerful model that generates new and proven ways of responding to the unprecedented challenges of a changing planet via operational excellence, education, research, and innovation on campus. Established in 2013 under the Executive Vice President and Treasurer's Office, MITOS works to integrate sustainability across all levels of campus by engaging the collective brainpower of students, staff, faculty, alumni, and partners. MITOS has set out to have an impact across scales, from the individual to the global.

MITEI staff and faculty affiliates collaborate with the Office of Sustainability through initiatives such as the Campus Sustainability Task Force, living lab projects, and the MIT Climate Action Advisory Committee.

**Robert Armstrong**  
**Director**  
**MIT Energy Initiative**