MIT ENERGY INITIATIVE
External Advisory Board Briefing Book

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MITei
MIT Energy Initiative

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Letter from the Director

Dear External Advisory Board members,

The MIT Energy Initiative continues to work toward realizing a decarbonized future by developing clean energy technologies and solutions; educating the next generation of change makers; and connecting academia, industry, and government.

Over the past year, fusion has become the largest single area of research funded through MITEI due to our collaboration with the MIT spinoff Commonwealth Fusion Systems, MITEI member company Eni S.p.A., and the MIT fusion research through the Laboratory for Innovation in Fusion Sciences. MITEI's research portfolio remains diverse, including research and analysis on deep decarbonization of four major energy sectors: power, transportation, industry, and buildings. This fall, we are launching a new Low-Carbon Energy Center on mobility systems, which builds on the foundation of our Mobility of the Future study (to be published in November 2019).

Over the summer, we published our revised Energy Studies Minor curriculum after receiving acceptance from the Committee on Curricula. It will lead to improved curriculum flexibility across the fall and spring course offerings and an increase in the number of advisors across academic departments.

This academic year, MIT is hosting a series of six Climate Action symposia. MITEI is working with MIT's Office of the Vice President for Research and symposium organizers to produce the series, which draws on the objectives of MIT's Plan for Action on Climate Change. Additionally, MITEI hosted a well-received symposium in June to investigate the role of hydrogen as part of a low-carbon future.

We deeply appreciate your guidance and support for our programs as we grow and expand our efforts to accelerate the transition to low- and no-carbon global energy systems. As always, I welcome your input and thoughts regarding our work and any opportunities over the coming year.

Sincerely,

Robert C. Armstrong
Director, MIT Energy Initiative
Chevron Professor of Chemical Engineering

Overview and Mission

The MIT Energy Initiative (MITEI) is MIT's hub for energy research, education, and outreach. Through these three pillars, MITEI plays a catalytic role in accelerating responses to the many challenges facing our global energy system. MITEI's mission is to develop low- and no-carbon solutions to efficiently, affordably, 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" series of reports. The most recent, *The Future of Nuclear Energy in a Carbon-Constrained World*, was published in September 2018 with the Nuclear Science and Engineering Department. A new study, The Future of Storage, is now underway and focuses on the role of energy storage in making electricity systems cleaner, more efficient, and more affordable. Another series of reports examines rapidly changing segments of the energy sector; the upcoming *Insights into Future Mobility* report, resulting from the multi-year Mobility of the Future study, 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, mobility, and other areas.

MITEI leads Institute 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, Undergraduate Research Opportunities Program in energy, short modules during the Independent Activities Period, an energy-focused first-year pre-orientation program, the graduate Society of Energy Fellows, and a new series of online energy 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 outreach efforts foster dialogue within the 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 highlights the work of the MIT energy community across print and digital platforms, such as Energy Futures magazine, MITEI's website, podcasts, and social media, as well as through media outreach.

FY2019

MITEI Director Robert C. Armstrong delivers the welcoming remarks at the Spring Symposium, "Can hydrogen become part of the climate solution?", on Monday, June 3, 2019. The symposium explored hydrogen's potential to impact climate change and the energy transition. *Photo: Kelley Travers*

Assistant Professor Heather Kulik (center) and graduate student Jon Paul Janet (right) 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 (left) is designing better catalysts for methane conversion reactions. *Photo: Stuart Darsch*

Graduate student Aliza Khurram prepares for experiments by pumping carbon dioxide through an electrochemical cell consisting of lithium and carbon electrodes plus a specially designed electrolyte. *Photo: Stuart Darsch*

Research & Analysis

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 collaborations between MIT researchers and member researchers. Approximately 30 percent of MIT faculty has engaged with MITEI's programs.

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 (newly launched); and solar energy. Fusion research is conducted in collaboration with the MIT Laboratory for Innovation in Fusion Technologies (LIFT).

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,

Jacopo Buongiorno, TEPCO Professor and associate department head in the Department of Nuclear Science and Engineering, speaks during the Low-Carbon Energy Center for Advanced Nuclear Energy Systems Symposium on the Digital Nuclear Power Plant. *Photo: Kelley Travers*

The Mobility Systems Center, one of MITEI's Low-Carbon Energy Centers, launches this fall to help guide sustainable and efficient global mobility growth by developing, maintaining, and applying state-of-the-art tools for mobility research.

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.

Read more about new Center members in the **Members section**.

MITEI's Low-Carbon Energy Centers

Update on Fusion Commercialization

The 2018 External Advisory Board meeting included a session titled "Collaboration to Accelerate Fusion Commercialization," led by Dennis Whyte, Hitachi America Professor of Engineering and director of the Plasma Science and Fusion Center (PSFC); and Steve Renter, chief operating officer of Commonwealth Fusion Systems (CFS).

The overall goal of the MIT-Eni-CFS collaboration is to develop a working fusion pilot plant by 2033. CFS funds complementary fusion research at MIT, as researchers from PSFC design and build a powerful experimental fusion device called SPARC (Soonest/Smallest Privately-Funded Affordable Robust Compact). The experiment, which utilizes high-field magnets with newly available high-temperature superconductors, would be the first controlled fusion plasma system to produce net energy output.

CFS completed its series A round of funding in June 2019, securing $115 million from investors. Joining Eni, Breakthrough Energy Ventures, and The Engine as investors are Future Ventures, Khosla Ventures, Lowercase Capital, Moore Strategic Ventures, Safar Partners, Schooner Capital, and Starlight Ventures. This funding will allow CFS/MIT's PSFC to demonstrate high-temperature superconductor magnet technology for SPARC at full scale.

MITEI 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 seed research projects grants this spring for a total of approximately $1 million. Including 2019, 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:** *Insights into Future Mobility*, the report from the Mobility of the Future study team, led by faculty chair William H. Green, professor of chemical engineering, and Randall Field of MITEI, executive director of the study, will be presented in Washington, D.C., in November 2019. 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. Another MITEI study, the Future of Energy Storage, is now underway with a report anticipated in 2021, and will focus on the role of storage in making electricity systems cleaner and more efficient. In fall 2018, a team of researchers led by MIT Department of Nuclear Science and Engineering TEPCO Professor Jacopo Buongiorno completed the multidisciplinary study *The Future of Nuclear Energy in a Carbon-Constrained World*, the eighth in MITEI's "Future of" study series. The study was published in September 2018; researchers held events in Europe, the U.S., and Asia. See more details on each of these studies in the **MITEI 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 recent research results and new directions of technology development with Center members.
- **New Low-Carbon Energy Center launch:** Based on sustained member interest in addressing issues such as those raised in the Mobility of the Future study, MITEI is launching the Mobility Systems Center as a new Low-Carbon Energy Center. 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 a continued focus on disruptive technologies for passenger transport.

Faculty Research Highlights

MATERIALS SCIENCE

- **Technique identifies electricity-producing bacteria**
  MIT researchers including Cullen Buie, an 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.
- **Shrinking the carbon footprint of a chemical in everyday objects**
  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 byproduct. In an effort to help reduce this energy use and the related emissions, Professor Karthish Manthiram and other MIT chemical engineers 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 byproduct.
- **How slippery surfaces allow sticky pastes and gels to slide**
  A team led by Kripa Varanasi, a 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 could 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.

ENERGY STORAGE

- **New approach could boost energy capacity of lithium batteries**
  Professor Ju Li and postdoc Weijiang Xue, both of the Department of Nuclear Science and Engineering, 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.
- **AI accurately predicts the useful life of batteries, team led by Stanford, MIT finds**
  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 authored by Richard Braatz, a professor of chemical engineering at MIT, and colleagues at Stanford and MIT.

NUCLEAR ENERGY

- **A fresh look at nuclear energy**
  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.
- **MIT continues progress toward practical fusion energy**
  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 Professor Dennis Whyte, head of MIT's Plasma Science and Fusion Center, 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.
- **Tapping the MIT talent pool for the future of fusion**
  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.

SOLAR ENERGY

- **Game-changing solar energy and nanotechnologies**
  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.
- **Solar, renewables, energy transformation reshaping the geopolitical landscape**
  Sergey Paltsev, deputy director of the MIT Joint Program on Science and Policy of Global Change and a 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.

ELECTRIC POWER SYSTEMS

- **Protecting our energy infrastructure**
  Using their "cybersafety" methodology, Professor Stuart Madnick and cybersecurity researcher Shaharyar Khan, both of the MIT Sloan School of Management, and Professor James L. Kirtley, Jr. of electrical engineering and computer science show that today's energy systems are rife with vulnerabilities to cyberattack, and share a new methodology for analyzing and strengthening its cybersecurity.

Professor Stuart Madnick (left), graduate student Shaharyar Khan (right), and Professor James Kirtley Jr. (not pictured) used their "cybersafety" methodology to identify several cyber vulnerabilities in a small power plant. *Photo: Stuart Darsch*

TRANSPORTATION

- **A novel global urban typology framework for sustainable mobility futures**
  Christopher Zegras, associate professor of urban studies and planning, discusses the implications of a new framework for researchers and planners and investigates the relationships between mobility and environmental sustainability indicators. The new typologization spans 331 cities in 124 countries, with a sample representing 40% of the global population.
- **Incorporating multiple uncertainties into projections of Chinese private car sales and stock**
  Chemical Engineering Professor William Green models China's growing energy consumption and pollutant emissions as the country sees an increase in private car sales. The paper develops an application of the Monte Carlo method, conditioned on historical data, to sample parameters for a model projecting aspects of private car diffusion, such as the mix of new and replacement sales.
- **MIT says we're overlooking a near-term solution to diesel trucking emissions**
  Daniel Cohn, a MITEI research scientist, and Leslie Bromberg, a principal research engineer at MIT's Plasma Science and Fusion 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 trucks, 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.

Daniel Cohn (left) and Leslie Bromberg (right) design low-emissions, fuel-efficient replacements for the polluting diesel engines traditionally viewed as the only viable option for powering today's 18-wheelers and other heavy-duty trucks. *Photo: Stuart Darsch*

ENERGY AND CLIMATE ECONOMICS AND POLICY

- **Carbon capture is a policy problem, not a technology problem**
  Howard Herzog, executive 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 carbon dioxide that can be released into the atmosphere, either by setting limits or pricing.

- **Study: For low-income countries, climate action pays off by 2050**
  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, the deputy director of the MIT Joint Program on the Science and Policy of Global Change, examine the impact global climate change mitigation would have on the economies of poorer countries—specifically Malawi, Mozambique, and Zambia.
- **Scientists discover the source of new CFC emissions**
  New research published by an international team of scientists including Ronald Prinn, a 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 (CFC) have increased by nearly 8,000 tons from eastern China.
- **Pathways to a low-carbon China**
  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_2 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.
- **Innovating a Green Real Deal**
  Ernest J. Moniz, special advisor to the MIT President, professor emeritus, and former U.S. 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.

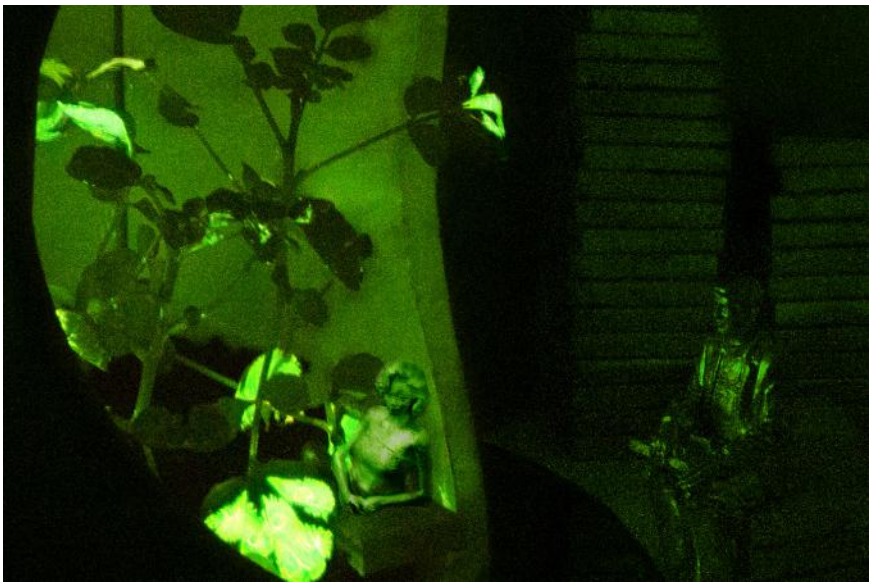
ADDITIONAL LOW-CARBON ENERGY RESEARCH

- **Renewables and storage ready to demonstrate competitiveness**
  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 of the Department of Chemistry. 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 percent 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.
- **Finding novel materials for practical devices**
  Heather Kulik, an 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.

- **Ambient plant illumination could light the way for greener buildings**
  A collaboration between Sheila Kennedy, a professor of architecture, and Michael Strano, a 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.
- **Energy monitor can find electrical failures before they happen**
  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 NILM (non-intrusive load monitoring) dashboard, is described in a paper by MIT professor of electrical engineering Steven Leeb, recent graduate Andre Aboulian MS '18, and seven others at MIT, the U.S. Coast Guard, and the U.S. Naval Academy.
- **Removing CO_2 from power plant exhaust**
  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.
- **A critical step to reduce climate change**
  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, that found that supporting renewable energy with a mix of clean energy solutions—including nuclear and carbon capture and storage (CCS)—would make carbon-free electricity up to 62 percent cheaper than using renewables alone.

ENERGY IN THE DEVELOPING WORLD

- **MIT receives $30 million to help address energy challenges in Egypt**
  An award from the U.S. 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 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 the country's most pressing energy-related problems.
- **Clean energy for India**
  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.



Michael Strano, the Carbon P. Dubbs Professor of Chemical Engineering at MIT, continues his work on ambient plants with a collaboration with Sheila Kennedy, a professor of architecture. Pictured here are glowing nanobionic watercress plants illuminating the Plant Properties Reading Room.
Photo: KVA Matx and Strano Research Group

MITEI Studies

MOBILITY OF THE FUTURE STUDY

The report from the multidisciplinary Mobility of the Future study team, *Insights into Future Mobility*, will be published 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 has been meeting since August 2016. The group 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, BP, Chevron, ExxonMobil, Ferrovial, General Motors, Saudi Aramco, Shell, Equinor, and Toyota Mobility Foundation.

The study team—which includes faculty, researchers, graduate students, and postdocs—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 MIT Department of Nuclear Science and Engineering Professor Jacopo Buongiorno, who leads the Low-Carbon Energy Center for Advanced Nuclear Energy Systems (CANES), completed the multidisciplinary report *The Future of Nuclear Energy in a Carbon-Constrained World,* the eighth in MITEI's "Future of" report series. The team consisted of six MIT faculty members from across the Institute, as well as Senior Lecturer John Parsons of MIT Sloan as report coauthor, two Harvard University faculty members, and four external consultants. The study report, 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 U.S. 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, 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 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. Discussions at an initial meeting of the study's external advisory committee in February 2019 helped to set the study's focus. More recently, their focus has been on building teams of students and postdocs to execute research for the study. The study is expected to be published in 2021.

Reports and Studies

A selection of MITEI-supported reports and studies published in FY2019.

Martin Z. Bazant, et al. "Microscopic theory of capillary pressure hysteresis based on pore-space accessivity and radius-resolved saturation." ***Chemical Engineering Science*****. March 2019.**
bit.ly/capillary-pressure
Proposes a macroscopic property "accessivity" (α) to characterize the network connectivity of different sized pores in a porous medium, and macroscopic state descriptors "radius-resolved saturations" (ψw(F),ψn(F)) to characterize the distribution of fluid phases within. Small accessivity (α→0) implies serial connections between different sized pores, while large accessivity (α→1) corresponds to more parallel arrangements, as the classical capillary bundle model implicitly assumes. Funded by Saudi Aramco through MITEI.

Moshe Ben-Akiva, et al. "From traditional to automated mobility on demand: A comprehensive framework for modeling on-demand services in SimMobility." ***Transportation Research Record*****. June 2019.**
bit.ly/SimMobility
Introduces a comprehensive framework that models various facets of Mobility on Demand (MoD), namely heterogeneous MoD driver decision-making and coordinated fleet management within SimMobility, an agent- and activity-based demand model integrated with a dynamic multi-modal network assignment model. To facilitate such a study, researchers propose an event-based modeling framework.

Scott Burger, et al. "The efficiency and distributional effects of alternative residential electricity rate designs." ***National Bureau of Economic Research*****. February 2019.**
bit.ly/rate-designs
Explores the impacts of improving the economic efficiency of electricity rates on customers of different socioeconomic backgrounds. Findings show that a rate containing a real-time energy price and fixed charges for residual cost recovery deliver substantially more economic benefits than alternatives like critical peak prices. However, if fixed charges are uniform across all customers, transitioning to this economically efficient rate can be regressive, raising costs disproportionately for low-income customers. Researchers demonstrate that simple changes to fixed charge design can mitigate or eliminate these distributional impacts, charting a path to economically efficient and distributionally equitable rates.

Scott Burger, et al. "Why distributed?: A critical review of the tradeoffs between centralized and decentralized resources." ***Institute of Electrical and Electronics Engineers*****. February 2019.**
bit.ly/why-distributed
Examines the tradeoffs between centralized and decentralized resources like utility scale and rooftop scale solar photovoltaics. Proposes a simple heuristic for determining when decentralized resources will deliver more value to society than their larger scale counterparts: when the locational value exceeds incremental unit costs. This heuristic can help policymakers and regulators consider new models for incentivizing distributed energy resource deployment. Funded by MITEI's Utility of the Future study.

Scott Burger, et al. "Restructuring revisited Parts 1 and 2: Competition and coordination in electricity distribution systems." *MIT Center for Energy and Economic Policy Research*. 2019.
Part 1: bit.ly/restructuring-revisited-1 Part 2: bit.ly/restructuring-revisited-2
Examines the regulations and market designs needed to maintain or enhance competition and coordination in electric power systems as distributed energy resources (DER) proliferate. Presents practical models for coordinating DERs, networks, and traditional generation and highlights paths for further research. Funded by Iberdrola.

Yet-Ming Chiang, et al. "Learning only buys you so much: Practical limits on battery price reduction." *Applied Energy*. April 2019.
bit.ly/price-reduction
Two-stage learning curve model projects the active material costs and NMC-based lithium-ion battery pack price with mineral and material costs as the respective price floors. The improved model predicts nickel-manganese-cobalt (NMC) battery prices will fall only to about $124 per kWh by 2030—much cheaper than today, but still too expensive to truly compete with ICEVs, due primarily to the high prices of cobalt, nickel, and lithium. Funded by MITEI's Mobility of the Future study.

Daniel Cohn and Leslie Bromberg. "Flex fuel gasoline-alcohol engine for near zero emissions plug-in hybrid long-haul trucks." *SAE International*. April 2019.
bit.ly/flex-fuel
Uses computer simulation to develop new approaches for high efficiency flex fuel gasoline-alcohol engines in plug-in hybrid powertrains for long haul trucks. These powertrains provide near-zero air pollutant emissions and also reduce greenhouse gas emissions when using low-carbon alcohol fuels. They can accelerate introduction of externally charged battery-powered propulsion by reducing battery energy storage requirements. Funded by the MIT Arthur Samberg Energy Innovation Fund.

Mircea Dincă, et al. "Viewpoint on the partial oxidation of methane to methanol using Cu- and Fe-exchanged zeolites." *ACS Catalysis*. August 2018.
bit.ly/methane-oxidation
In nature, as in artificial systems, the ability to generate reactive oxygen species at metal active sites is critical to selective methane oxidation. In the soluble MMO (sMMO) catalytic cycle, Dincă and co-authors confirmed the previously hypothesized structure of Q as a bis-μ-oxo diiron diamond core structure. Funded by ExxonMobil through MITEI.

Emre Gençer, et al. "Parametric modeling of life cycle greenhouse gas emissions from photovoltaic power." *Applied Energy*. March 2019.
bit.ly/parametric-modeling
Uses a modeling tool to integrate photovoltaic life cycle inventories, background emission factors, known physical correlations, and modern photovoltaic performance modeling, including temperature-dependent performance ratios. Using this tool, four novel findings are produced on life cycle greenhouse gas emissions from photovoltaic power: temperature effects on modules, emission impacts of tracking, impact of manufacturing location, and sensitivity to inverter loading. Funded by ExxonMobil Research and Engineering.

Emre Gençer, et al. "A general model for estimating emissions from integrated power generation and energy storage." *Processes*. December 2018.
bit.ly/estimating-emissions
Proposes a model for estimating emissions from integrated power generation and energy storage. The model applies to emissions of all pollutants, including greenhouse gases (GHGs), and to all storage technologies, including pumped hydroelectric and electrochemical storage. As a case study, the model is used to estimate the GHG emissions of electricity from systems that couple photovoltaic and wind generation with lithium-ion batteries and vanadium redox flow batteries. Funded by members of MITEI's Low-Carbon Energy Centers.

Emre Gençer and Rakesh Agrawal. "Toward supplying food, energy, and water demand: Integrated solar desalination process synthesis with power and hydrogen coproduction." *Resources, Conservation and Recycling*. June 2018.
bit.ly/solar-desalination
Explores synergistic integration alternatives of multi-stage flash desalination, solar thermal power, and hydrogen production processes using proposed Solar Electricity, Water, Food, and Chemical (SEWFAC) process synthesis concept. Research supported as part of the Center for Direct Catalytic Conversion of Biomass to Biofuels, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences.

Emre Gençer, et al. "Global CO_2 Initiative complete oxymethylene ethers study 2018." *Global CO_2 Initiative (University of Michigan)*. February 2019.
bit.ly/global-co2
Investigates economic opportunities and barriers for OME3-5, derives R&D pathways, and benchmarks values. The OME3-5 production process included seven system elements: membrane carbon capture, PEM water electrolysis, as well as the synthesis of methanol, formaldehyde, trioxane, methylal (OME1), and OME3-5.

Abbas Ghandi and Sergey Paltsev. "Representing a deployment of light-duty internal combustion and electric vehicles in economy-wide models." *Joint Program Technical Note*. February 2019.
bit.ly/light-duty
Presents a methodology for incorporating private transportation details into an economy-wide model and (using an example of the MIT Economic Projection and Policy Analysis [EPPA] model, a global energy economy model) a description of calibrating the model to the data. The authors provide results both for light-duty internal combustion engine vehicles and electric vehicles.

William Green, et al. "Incorporating multiple uncertainties into projections of Chinese private car sales and stock." *Transportation Research Record*. August 2018.
bit.ly/chinese-car-sales
China is in a fast-growing stage of mobility development, and its increasing demand for private cars comes with growing energy consumption and pollutant emissions. Uncertainty in Chinese parameterization of car ownership models makes forecasting these trends a challenge. Researchers developed an application of the Monte Carlo method, conditioned on historical data, to sample parameters for a model projecting aspects of private car diffusion, such as the mix of new and replacement sales. Funded by MITEI's Mobility of the Future study.

Howard Herzog, et al. "Assessment of CCS technology in a climate mitigation portfolio." *MIT Joint Program Special Report*. January 2019.
bit.ly/ccs-assessment
Assesses the future role for carbon capture and storage (CCS) in a portfolio of mitigation options as a basis for strategies to advance the CCS option. Uses the MIT Economic Prediction and Policy Analysis (EPPA) model, a global energy economy model, to examine different long-term scenarios to estimate the importance of factors influencing CCS deployment and its role in mitigating carbon emissions. Funded by ExxonMobil through MITEI.

Christopher R. Knittel and Elizabeth Murphy. "Generational trends in vehicle ownership and use: Are millennials any different?" *National Bureau of Economic Research*. March 2019.
bit.ly/ownership-trends
Tests whether millennials' vehicle ownership and use preferences differ from those of previous generations using data from the U.S. National Household Travel Survey, Census, and American Community Survey. Estimates both regression and nearest-neighbor matching models to control for the confounding effect of demographic and macroeconomic variables.

Steven Leeb, et al. "Wire less sensors for electromechanical systems diagnostics." *Institute of Electrical and Electronics Engineers*. September 2018.
bit.ly/wireless-sensors
Proposes a complete solution for providing actionable information from a collection of sensors installed with a minimum effort. This solution is demonstrated through an example sensor node, a vibration assessment monitoring point with integrated recovery of energy. Funded by ExxonMobil through MITEI.

John H. Lienhard, et al. "Direct electrosynthesis of sodium hydroxide and hydrochloric acid from brine streams." *Nature Catalysis*. February 2019.
bit.ly/brine-streams
Examines direct electrosynthesis of sodium hydroxide (NaOH) and hydrochloric acid (HCl) from sea-water desalination brine. Funded by Cadagua through MITEI.

John H. Lienhard, et al. "Integrated valorization of desalination brine through NaOH recovery: Opportunities and challenges." *Angewandte*. February 2019.
bit.ly/integrated-valorization
Discusses opportunities and challenges for integrated valorization of desalination brine through NaOH and HCl recovery. Funded by Cadagua through MITEI.

Ashley Nunes and Kristen Hernandez. "The cost of self-driving cars will be the biggest barrier to their adoption." *Harvard Business Review*. January 2019.
bit.ly/cost-of-self-driving
Asks, "Is it realistic to expect robotaxis to become cost-competitive with owning older vehicles any time soon?" Funded by MITEI's Mobility of the Future study.

Shuhei Ono, et al. "Experimental investigation on the controls of clumped isotopologue and hydrogen isotope ratios in microbial methane." ***Geochimica et Cosmochimica Acta*****. September 2018.**
bit.ly/isotope-ratios
Carries out a series of batch culture experiments to investigate the origin of the non-equilibrium signals in microbial methane by exploring a range of metabolic pathways, growth temperatures, and hydrogen isotope compositions of the media.

P. Christopher Zegras, et al. "A novel global urban typology framework for sustainable mobility futures." ***Environmental Research Letters*****. May 2019.**
bit.ly/typology-framework
Presents a new typologization spanning 331 cities in 124 countries. The sample represents 40% of the global urban population and contains the most recent data from 2010 to date. Using a factor analytic and agglomerative clustering approach, researchers identify nine urban factors and 12 typologies. They discuss the implications of this new framework for researchers and planners and investigate the relationships between mobility and environmental sustainability indicators. Funded by MITEI's Mobility of the Future study.

Jinhua Zhao and Joanna Moody. "Car pride and its bidirectional relations with car ownership: Case studies in New York City and Houston." ***Transportation Research*****. June 2019.**
bit.ly/car-pride
Introduces and validates a standard measure of car pride estimated from 12 survey statements using a cross-sectional sample of 1,236 commuters in New York City and Houston metropolitan statistical areas. Researchers find that car pride is higher in Houston than in New York City. Funded by the New England University Transportation Center.

Tata Center for Technology and Design

During the 2018-2019 academic year, 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 Malvika Verma (Biological Engineering), who won the 2019 MIT Graduate Women of Excellence award, the 2019 Leader of Tomorrow award at the Gap Summit, and the 2018 Wisnok Prize for Best Bioengineering Talk. Eric Miller (Chemical Engineering) won the Grand Prize at the IDEAS Global Challenge in April 2019. He was also a semifinalist at the Launch 100K competition, as well as the MassChallenge Incubator. Miller won first place in Audience Choice at the ChemE Science Slam in March 2019, and was accepted into the deltaV Incubator at the Martin Trust Center in April 2019. He was the Advanced Lateral Flow Course Innovation Award Finalist in October 2018, and also won the Sandbox Innovation Fund Grant in August 2018. Lin Zhao (Mechanical Engineering) received the Wunsch Foundation Silent Hoist and Crane Awards for Outstanding Graduate Research in Mechanical Engineering at MIT. Brendan Derek Smith (Materials Science and Engineering) 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 (Architecture) received the American Society of Heating, Refrigerating, and Air-Conditioning Engineers Graduate Student Grant-in-Aid Award for 2018. Finally, Somya Singhvi (Operations Research) 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 discuss the topic, "Translating research into impact at the Tata Center," and to participate in Sectorial Workshops, "Building bridges for impact," 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

MITEI researchers are supporting an ambitious new effort initiated in late 2018 to develop a viable pathway for providing electricity services to hundreds of millions of under-served homes and businesses more quickly and more cost effectively than the current trajectory. The Global Commission to End Energy Poverty is led by The Rockefeller Foundation and co-chaired by Ernest Moniz, special advisor to the MIT President, professor emeritus, and former U.S. Secretary of Energy; Dr. Rajiv Shah, president of the Rockefeller Foundation; and Akinwande Adesin, president of the African Development Bank. Robert Stoner, MITEI deputy director and director of the Tata Center for Technology and Design, and Ignacio Perez-Arriaga, a visiting professor at MITEI, lead the research team, which is focused on identifying and addressing the barriers to achieving universal, economically impactful electrification. Stoner also serves as Secretary of the Commission.

The Commission convened for the first time in September 2019 in Italy, and will publish its findings and recommendations at the United Nations General Assembly in 2020. Commissioners include leaders from utilities, off-grid companies, multilateral development banks, academics, and from across the electricity and development sectors.

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.

Technology and Policy Program master's students Annette Brocks (left) and Nelson Lee (right) engage in a rapid prototyping exercise with Tufts master's student Alexis Washburn (center) and other participants during a Martha's Vineyard net-zero carbon design thinking workshop. *Photo: Maud Bocquillod*

Professor David Hsu (center) discusses findings with Yeva Yin (left) and Luis Garcia (right). Garcia and Yin, along with Grace Bryant (not pictured), worked with Hsu to analyze political spending and corresponding utility rates during their summer UROP through the MIT Energy Initiative. *Photo: Kelley Travers*

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 undergraduate and graduate students, MITEI provides a robust educational toolkit for 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 undergrads can take interdisciplinary courses through the Energy Studies Minor and participate in laboratory research through the MITEI Undergraduate Research Opportunities Program (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 (Electrical Engineering and Computer Science) is vice president of construction and workforce development.

Graduate students and postdocs 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.

During the class 15.366 Energy Ventures, Senior Lecturer Francis O'Sullivan (left) leads a discussion with a team working on contactless steam generation technology for heating water in remote locations. The graduate students with him are, from left: Brian Gaudio, Robert Addy, Matt Severson (of Harvard Business School), Bidusha Poudyal, and Yoichiro Tsurimaki. *Photo: Kelley Travers*

Moises Trejo, a student participating in the Discover Energy First-Year Pre-Orientation Program (DE FPOP) tests the flexibility of a wind turbine blade at the Wind Technology Testing Center. *Photo: Corey Watanabe*

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 was 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 Undergraduate Research Opportunities Program during the 2019 academic year, 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 postdocs to the Society of Energy Fellows in 2018-2019. 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, Eni S.p.A., ExxonMobil, Shell, and Total; and one former member, Bosch.
- **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. They also attended various networking and educational events.

- **First-Year Pre-Orientation Program:** MITEI's summer 2018 energy 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, an energy economics workshop with Professor Jing Li of the 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 (Chemical Engineering), Robert Jaffe (Physics), Julia Ortony (Materials Science and Engineering), and David Hsu (Urban Studies and Planning).
- **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, more than 50 undergraduate and graduate students had the opportunity to meet with 22 representatives from industry and government, gaining insights into the many 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^3 dinner series. The dinner series brings MIT energy community members together with distinguished alumni 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 2018-2019 dinners included Matthew Zedler '07, head of product and application engineering at Lockheed Martin Advanced Energy Storage, LLC, and Sandhya Murali '15, 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 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 early 2020.
- **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. The trip included visits 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 electrochemistry to architecture. The students, all MITEI-sponsored participants in the energy UROP, had the opportunity to network with energy professionals while showcasing their research.

Energy Education Taskforce

MITEI's Energy Education Task Force guides the development of energy education at MIT. 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 task force by implementing energy education programs.

ENERGY EDUCATION TASK FORCE FACULTY MEMBERS FY2019

Co-chair: Bradford Hager, Cecil and Ida Green Professor of Earth Sciences; Director, Earth Resources Laboratory
Co-chair: Rajeev Ram, Professor of Electrical Engineering and Computer Science; Associate Director, Research Laboratory of Electronics

William H. Green, Hoyt C. Hottel Professor of Chemical Engineering
David Hsu, Assistant Professor of Urban Studies and Planning
Robert Jaffe, Jane and Otto Morningstar Professor of Physics
Ruben Juanes, ARCO Associate Professor in Energy Studies
Christopher Knittel, George P. Shultz Professor of Applied Economics; Director, Center for Energy and Environmental Policy Research
Steven Leeb, Professor of Electrical Engineering and Computer Science
Yogesh Surendranath, Assistant Professor of Chemistry
Konstantin Turitsyn, Associate Professor of Mechanical Engineering

MIT Student Energy Groups

MITEI provides financial and staff support for a number of student groups throughout the year.

e4Dev–Energy for Human Development is a student group and discussion forum on energy and human development challenges in the developing world. e4Dev brings together students, faculty, and practitioners at MIT and beyond who are devoted to working on critical issues at the intersection of energy and the developing world.

The **Edgerton Center** supports about a dozen student clubs and teams such as the MIT Motorsports team, the MIT Solar Electric Vehicle team, the MIT Robotics team, and more. Whether it's welding the frame for an electric Formula style race car or designing a battery pack for a Hyperloop pod capable of traveling up to 200 miles per hour, MIT students are creating their own challenging projects to prove what is possible.

The **Electricity Student Research Group** fosters interdisciplinary energy research by bringing together graduate students who study electric power systems across different courses, divisions, and research centers at MIT and neighboring institutions for regular seminars and discussions on the latest research from across MIT and beyond.

The **MIT Clean Energy Prize (CEP)** is the world's premier student competition for early-stage energy ventures aimed at mitigating climate change. The MIT CEP endeavors to inspire and train entrepreneurs to build companies that will significantly accelerate the pace of energy innovation. The competition offers a low-risk, high-reward environment for student entrepreneurs to develop business ideas with the aid of expert mentorship and insightful judging feedback, while gaining exposure to some of the biggest thinkers in the clean energy space.

The **MIT Energy Club** is one of the largest student-run organizations at MIT. Its mission is to bring students, professionals, and policymakers together for fact-based analyses of the most pressing challenges in energy. The club is known for its annual three flagship events–MIT Energy Night, MIT EnergyHack, and the MIT Energy Conference—and hosts smaller events and gatherings throughout the academic year. The club's emphasis is on building a community at MIT with a deeper understanding of global energy trends and challenges through objective, open-minded discussion. Underneath the MIT Energy Club umbrella, the Undergraduate Energy (UGE) and the Sloan Energy Club play active roles in the MIT energy community. UGE organizes the Energy Career Fair each spring and has co-sponsored MITEI's career forum, and the Sloan Energy Club coordinates energy treks to major U.S. cities and hosts professional development events.

The **MIT Transportation Club** aims to bring together the campus's transportation community for education, networking, and research collaboration. Founded in spring 2010, the organization has grown rapidly to include over 300 members from across all schools. The MIT Transportation Club is open to any member of the wider MIT community. Key events include a weekly seminar series, tours to transportation centers, and the MIT Transportation Showcase.

The **MIT Undergraduate Association Committee on Sustainability** is charged with being a leading force in sustainability, spreading environmental awareness, and inspiring community action. This committee interfaces with other student advocacy and policy groups, facilitating communication to induce change. It also identifies and addresses needs within the undergraduate sustainability community, collaborating with faculty and the administration to pull together projects like the Trashion Show and Trash2Treasure.

The **Technology Policy Student Society** is composed of student representatives in the Technology Policy Program who provide opportunities for professional engagement and community building within the TPP cohort and IDSS student body. These include events such as policy discussion nights, student retreats, and speaker series.

The **MIT Water Club** is the leading student network for water research and innovation at MIT. The group organizes annual conferences (Water Summit), research showcases (Water Night), multi-stage entrepreneurship competitions (Water Innovation Prize), and weekly lectures, convening leaders and innovators to explore the most pressing issues in water technology, policy, and science.

During the 14th annual student-run MIT Energy Conference, Stephen Pike, CEO of MassCEC (Clean Energy Center), and Emily Reichert, CEO of Greentown Labs, discussed the best ways to foster innovation and entrepreneurship in the clean energy sector. *Photo: Cherry Tree Photography*

Yang Shao-Horn, the W.M. Keck Professor of Energy at MIT (center), engages with the audience during MITEI's Spring Symposium. From left to right: Cathy Choi, Cummins; Yogesh Surendranath, MIT; and Clay Sutton, ExxonMobil. *Photo: Kelley Travers*

At the 2018 Annual Research Conference, Antonio Torralba, director of the MIT Quest for Intelligence and director of the MIT-IBM Watson AI Lab, introduces a panel examining where and how more capable intelligent machines and methods can be applied to the most difficult energy challenges. *Photo: Eric Haynes*

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 the 2019-2020 academic year, 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 is providing strategic guidance and operational support for the six symposia and many MITEI-affiliated faculty and staff members are speaking at the events.
- **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

Past Natural Resources Defense Council President Frances Beinecke (left) and MITEI Director Robert Armstrong (right) have a fireside chat at MITEI's annual Fall Colloquium. *Photo: Kelley Travers*

(From left to right) Janice Lin, founder and CEO of Strategen; Catherine Von Burg, president and CEO of SimpliPhi Power, Inc.; Betar Gallant, assistant professor in the Department of Mechanical Engineering at MIT; and Ellen Anderson, founder of Minnesota Energy Storage Alliance; speak at the 7th Annual C3E Women in Clean Energy Symposium. *Photo: Bill Rivard*

at the Tokyo Electric Power Company; Frances Beinecke, past president of the Natural Resources Defense Council; Asegun Henry, director of the Atomistic Simulation and Energy Research Group; and Michael R. Wasielewski, executive director of the Institute for Sustainability and Energy at Northwestern University.

- **MIT Climate Night:** On April 25, 2019, MITEI co-hosted a Climate Night with the MIT Environmental Solutions Initiative as part of an Earth Week celebration. The event featured a climate conversation among MIT Vice President for Research Maria Zuber, MIT Energy Initiative Director Robert Armstrong, and MIT Environmental Solutions Initiative Director John Fernández, as well as open discussion.
- **Annual Research Conference 2018:** MITEI's signature annual conference 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; Robert Mumgaard, CEO of Commonwealth Fusion Systems; Emily Reichert, CEO of Greentown Labs; and MIT faculty members.
- **C3E 2018 Women in Clean Energy Symposium:** The U.S. C3E Initiative aims to advance clean energy by closing the gender gap and enabling the full participation of women in the clean energy sector. In December 2018, the seventh annual Clean Energy, Education, and Empowerment (C3E) Women in Clean Energy Symposium and Awards took place at Stanford University. Stanford Energy hosted the event in collaboration with the U.S. Department of Energy, MITEI, and Texas A&M Energy Institute. The conference featured award presentations to mid-career women and a lifetime achievement award presentation, as well as diverse speakers—including MIT professor of mechanical engineering Betar Gallant—and conversations on strategies and technologies to enable

the transition to a low-carbon future. The eighth symposium takes place November 13-14, 2019, at Texas A&M; MITEI will host in 2020.

- **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, 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 U.S. 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—which also featured several MITEI speakers—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 in FY2019 include electricity markets, artificial intelligence, batteries and storage, and game-changing fusion.

Events

MITEI SEMINARS AND COLLOQUIA, AND MITEI-SPONSORED EVENTS, 2018-2019 ACADEMIC YEAR

October 3, 2018:	IHS Seminar Series: "Molecular approaches to solar energy conversion" Michael R. Wasielewski, Clare Hamilton Hall Professor of Chemistry and executive director of the Institute for Sustainability and Energy, Northwestern University; and director, Center for Light Energy Activated Redox Processes, a U.S. DOE Energy Frontier Research Center
October 19, 2018:	MIT Energy Night
October 24, 2018:	MITEI Fall Colloquium: "2030 U.S. Climate Goals: Drifting further from the target—how can we get there?" Frances Beinecke, Past President, Natural Resources Defense Council
November 2-4, 2018:	MIT Energy Hackathon

November 7, 2018:	"Powering the Blue Economy: Turning the ocean from an electricity desert into a power oasis" Alejandro Moreno, director, Water Power Technologies Office, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
January 16, 2019:	"Electricity network design and operation in an era of solar and storage" Duncan Callaway, associate professor of energy and resources and a faculty affiliate in electrical engineering and computer science, University of California, Berkeley; and faculty scientist, Lawrence Berkeley Laboratory
January 30, 2019:	"'Sun in a box:' Thermal energy grid storage using multi-junction photovoltaics" Asegun Henry, director of the Atomistic Simulation and Energy Research Group and associate professor in the Department of Mechanical Engineering, MIT
March 19, 2019:	IHS Seminar Series: "Understanding why defective materials are key to developing energy technologies that will advance the viability of low-cost renewable electricity" Will Chueh, assistant professor of materials science and engineering, Stanford University
April 17, 2019:	MITEI Special Seminar: "Can Japan revitalize its nuclear industry after Fukushima?" Naomi Hirose, executive vice chairman of Fukushima Affairs, Tokyo Electric Power Company
April 25, 2019:	MIT Climate Night
May 14, 2019:	"Massively digitized power grid: Opportunities, dangers, and challenges" Le Xie, professor and Eugene Webb Faculty Fellow, Texas A&M University
May 24, 2019:	"Path to making power systems highly efficient, reliable, resilient, and sustainable" Javad Lavaei, associate professor, University of California, Berkeley
June 3, 2019:	MITEI Spring Symposium: "Can hydrogen become part of the climate solution?"

As part of MIT Climate Night, MIT Vice President for Research Maria Zuber (center) talks with John Fernández (left), director of the MIT Environmental Solutions Initiative, and Robert Armstrong, director of the MIT Energy Initiative. *Photo: Kelley Travers*

Robert Stoner, deputy director of the MIT Energy Initiative and director of the Tata Center for Technology and Design, addresses the fourth annual Tata Center Symposium. *Photo: Kelley Travers*

Governance

Members of the External Advisory Board at the Fall 2018 meeting of the board. *Photo: Emily Dahl*

MITEI Leadership Team

Director Robert Armstrong's leadership team continues to build on MITEI's 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 Energy Council helps shape MITEI's research, education, and outreach directions.

Professor Robert C. Armstrong
Robert C. Armstrong is MITEI's director and the Chevron Professor of Chemical Engineering. A member of the MIT faculty since 1973, Armstrong served as head of the Department of Chemical Engineering from 1996 to 2007. His research is focused on pathways to a low-carbon energy future.

In 2008, Armstrong was elected into the National Academy of Engineering for conducting outstanding research on non-Newtonian fluid mechanics, co-authoring landmark textbooks, and providing leadership in chemical engineering education. Armstrong received the Warren K. Lewis Award and the Professional Progress Award in 1992, both from the American Institute of Chemical Engineers, and the 2006 Bingham Medal from the Society of Rheology, which is devoted to the study of the science of deformation and flow of matter.

Armstrong was a member of MIT's Future of Natural Gas and Future of Solar Energy study groups and is co-chairing the new study on the Future of Storage. He co-edited *Game Changers: Energy on the Move* with former U.S. Secretary of State George P. Shultz.

Professor Angela M. Belcher

Angela Belcher, a member of the MIT faculty since 2001, is the James Mason Crafts Professor of Biological Engineering and Materials Science and Department Head of Biological Engineering. Belcher is a materials chemist with expertise in biomaterials, biomolecular materials, organic-inorganic interfaces, and solid-state chemistry. Her work focuses on evolving organisms to build new materials and devices for clean energy, electronics, the environment, and medicine. She is the co-director of MITEI's Low-Carbon Energy Center for Energy Bioscience. Belcher was awarded the 24th annual MacArthur Foundation Fellowship, the 2013 MIT-Lemelson Prize, the 2010 Eni Prize for Renewable and Non-conventional Energy, and the 2004 Four Star General Recognition Award. In 2006, she was named *Scientific American*'s Research Leader of the Year. She was inducted into the National Academy of Inventors in 2015 and the National Academy of Engineers in 2018.

Martha Broad

Martha Broad, MITEI's executive director, oversees MITEI's finance, operations, human resources, communications, and events teams that support MITEI's research, education, and outreach activities. In addition, as a member of MITEI's leadership team, she plays a key role in managing the ongoing development of MITEI's Low-Carbon Energy Centers. She has represented MITEI as an invited speaker at Chatham House's Energy Transitions Conference, ARPA-E's Energy Innovation Summit, the MIT Energy Conference, and other events. She served on MIT's Climate Action Advisory Committee for implementing the Institute's Plan for Action on Climate Change. She also served on the World Economic Forum's Global Agenda Council on Decarbonizing Energy.

Broad also leads MITEI's collaboration with the U.S. Department of Energy to design, manage, and host the annual Clean Energy Education and Empowerment (C3E) Women in Clean Energy Symposium, working with Stanford University's Precourt Institute for Energy and Texas A&M's Energy Institute. She also serves as a C3E Ambassador.

Previously, as part of the senior management team of the Massachusetts Clean Energy Center, Broad led programs and studies that focused on the commercialization of clean energy technologies. In addition, by collaborating with universities and public and private partners, she helped facilitate the state's successful installation of hundreds of megawatts of wind and solar systems.

Professor John M. Deutch

John Deutch, Institute Professor Emeritus, joined the MIT faculty in 1970. He served as chairman of the Department of Chemistry, Dean of Science, and Provost. Deutch was instrumental in the creation of MITEI's "Future of…" series and has published widely in the area of physical chemistry as well as on technology, energy, international security, and public policy issues. Deutch served in the U.S. Department of Energy as director of energy research and undersecretary of the department in the Carter Administration and as undersecretary for acquisition and technology, deputy secretary of defense, and director of central intelligence in the first Clinton Administration. In 2009, Deutch was appointed to the Secretary of Energy Advisory Board, the independent 19-member advisory board comprised of scientists, business executives, academics, and former government officials, in which he served under former U.S. Secretaries of Energy Steven Chu and Ernest J. Moniz.

Professor Leon R. Glicksman

Leon Glicksman is a professor post tenure of building technology and mechanical engineering, a member of the MIT faculty since 1966, and the director of MIT's Building Technology Program for 19 years. His research focuses on energy-efficient, sustainable building technologies and designs, including natural ventilation, software design tools, and the integration of energy-efficient measures with indoor air quality considerations. He is an expert on energy-efficient urban housing for the developing world with ongoing projects in India, Nepal, and Africa.

Professor Bradford H. Hager

Brad Hager is the Cecil and Ida Green Professor of Earth Sciences at MIT. He earned his PhD from Harvard University in 1978, began his career as a professor at Caltech's Seismological Laboratory, and joined MIT in 1989. He is the co-director of MITEI's Low-Carbon Energy Center for Carbon Capture, Utilization, and Storage, and a member of the Energy Education Task Force. From June 2012 through April 2018, he was the director of MIT's Earth Resources Laboratory (ERL) and now serves as associate director. Hager's research interests include the relationship among space-geodetic observations of surface deformation, earthquakes, and dynamical processes in Earth's interior. He has expertise on tectonic earthquakes in regional fault systems, as well as deformation and earthquakes induced by fluid injection and reservoir production. He is a Fellow of the American Geophysical Union and the American Academy of Arts and Sciences. He has been awarded the Macelwane and Lehmann Medals by the American Geophysical Union, the Woollard Award by the Geological Society of America, and the Augustus Love Medal by the European Geophysical Union.

Professor Christopher Knittel

Christopher Knittel is the George P. Shultz Professor of Applied Economics in the Sloan School of Management and the director of the Center for Energy and Environmental Policy Research at MIT. He joined the faculty at MIT in 2011, having taught previously at UC Davis and Boston University. Knittel co-led MITEI's Utility of the Future study and serves on the Energy Education Task Force and Energy Minor Oversight Committee. He is also co-director of MITEI's Low-Carbon Energy Center for Electric Power Systems.

Knittel's research focuses on environmental economics, industrial organization, and applied econometrics. He is a research associate at the National Bureau of Economic Research in the productivity, industrial organization, and energy and environmental economics groups.

Robert Stoner
Robert Stoner is MITEI's deputy director for science and technology. He is also the founding director of the Tata Center for Technology and Design—an MIT graduate program that trains future engineering and business leaders to apply science and technology to the needs and opportunities in the developing world. His current research involves planning and optimization of electrical power systems. Stoner also leads the Global Commission to End Energy Poverty, which endeavors to bring electricity to the remaining billion people across the globe who currently live without it.

He is the inventor of numerous optical and electronic devices and has an extensive international business background, having held senior positions at Intel and Zygo Corporations and founded technology companies in the United States and Europe. He earned his PhD in condensed matter physics at Brown University and was an adjunct professor of engineering there from 1995 through 2002. Immediately prior to joining MIT, he served in senior roles at the Clinton Foundation in Africa and India.

Professor Yang Shao-Horn
Yang Shao-Horn is W.M. Keck Professor of Energy at MIT. Her research focuses on the chemical physics of surfaces with emphasis on metal oxides, searching for descriptors of catalytic activity, wetting properties and ion transport, and design materials for solar fuel and batteries including electrochemical/photoelectrochemical water splitting and CO_2 reduction, ion/electron storage, and ion conductors. Shao-Horn is a member of the National Academy of Engineering and was listed in Thomson Reuter's "World's Most Influential Scientific Minds" and ranked in their list of "Highly Cited Researchers." She is also a fellow of the Electrochemical Society and International Society of Electrochemistry.

External Advisory Board

An External Advisory Board composed of industry, academic, nonprofit, and public sector leaders—chaired by former U.S. Secretary of State George Shultz—provides oversight to the Initiative. The views and guidance of the board greatly assist MITEI in maximizing its impact in helping to meet the world's energy needs, reduce the environmental impacts of energy production and consumption, and inform public discourse on energy and the environment. The board meets annually each fall.

Energy Education Task Force

The Energy Education Task Force, composed of faculty members and students from all five of MIT's schools, oversees the Initiative's Education program. Task Force members develop new directions and support activities in this realm of opportunity at MIT. (See the **Education** section for full details).

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 the analysis of integrating these technologies into existing and future energy systems.

MITEI draws on MIT's research capabilities, innovation, expertise, and experience to create successful industry collaborations that advance shared objectives and support the energy transition. A multi-tiered membership structure enables diverse private-sector entities to sponsor multidisciplinary "flagship" research programs with MIT faculty; contribute to energy-focused labs, programs, and centers at MIT; fund vital 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: Associated Electric Cooperative Incorporated, ENN, 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.
- Sertecpet joined as an Associate Member.
- Building on the success of the Mobility of the Future study, MITEI launched the Mobility Systems Center as a new Low-Carbon Energy Center.
- Exelon, MITEI's first Low-Carbon Energy Center member, 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?", responding to increasing interest from MITEI members in exploring the potential for scaling up this fuel source. The symposium was sponsored by Associate Members Électricité de France and Cummins.
- CERAWeek 2019: MITEI facilitated the participation of 23 faculty, including MIT Vice President for Research Maria Zuber; seven students; and four MITEI-related startups, in this annual event in Houston, Texas held by MITEI Seminar Series Sponsor IHS Markit.

A complete list of members is available on the MITEI website.

Affiliated Groups

Sergey Paltsev (center), a deputy director of the MIT Joint Program on the Science and Policy of Global Change, speaks on a panel at the UN Climate Change Conference (COP24). Other panelists included Claude Nahon (left), senior vice president of sustainable development at Électricité de France; and George Heyman (right), British Columbia's climate minister. *Photo: Emily Dahl*

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

Center for Energy and Environmental Policy Research

Established in 1977, the Center for Energy and Environmental Policy Research (CEEPR) promotes research on energy and environmental policy to support improved decision making by government and industry. It is directed by Professor Christopher Knittel (MIT Sloan) 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 electricity markets, gas, oil, and coal 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 UK.

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, 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 Professor Ronald G. Prinn (EAPS) and Senior Lecturer John Reilly (MIT Sloan), 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:

- 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; and
- 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 the MIT Center for Energy and Environmental Policy Research, under the administrative auspices of MITEI.

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 geo-materials. 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 as well as in 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.

STAY CONNECTED

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To sign up for MITEI's weekly newsletter, visit: energy.mit.edu/subscribe

Events calendar: energy.mit.edu/events

Energy Futures Magazine: energy.mit.edu/energyfutures

"Future of" studies: energy.mit.edu/futureof

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