MIT Energy Initiative

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. Our mission is to develop low- and no-carbon solutions that will efficiently, affordably, and sustainably meet global energy needs while minimizing environmental impacts, dramatically reducing greenhouse gas emissions, and mitigating climate change. MITEI has raised over $860 million to date to support energy-related activities throughout MIT.

To advance this mission, MITEI brings together researchers from across the Institute and facilitates collaborations with industry, nonprofit organizations, 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, policy makers, and regulators. One series of reports examines rapidly changing segments of the energy sector; another is the "Future of" study series. The Future of Energy Storage, scheduled for release in fall 2021, was launched in summer 2018 and focuses on the role of storage in making electricity systems cleaner, more efficient, and more affordable.

As a vital component of MIT's Plan for Action on Climate Change and MITEI's research program, the Low-Carbon Energy Centers have presented 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. This fall, as part of MIT's Climate Action Plan for the Decade, MITEI will launch the Future Energy Systems Center, which will bring together the ongoing technoeconomic and systems-oriented research from MITEI's Low-Carbon Energy Centers under a common umbrella.

MITEI leads Institute energy education efforts and has engaged with thousands of undergraduate, graduate, and postdoctoral students through sponsored research opportunities and other programs, preparing the next generation of innovators, entrepreneurs, and policy makers to collaborate on solutions to global energy challenges. Energy education programs include the Energy Studies Minor, Undergraduate Research Opportunities Program (UROP) 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 open to 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 and 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 and by supporting faculty and staff participation in external events. The MITEI communications

team also develops content to highlight MIT energy researchers, students, and their work via media outreach and across print and digital platforms, such as MIT's Energy Futures magazine, MITEI's website, podcasts, and social media.

Accomplishments and Updates

Low-Carbon Energy Centers

Since their launch in the fall of 2015 as part of MIT's Plan for Action on Climate Change, MITEI's Low-Carbon Energy Centers have been tackling the most pressing energy challenges related to climate change from key technological and economic perspectives. Each consortium-funded center has a distinct focus: carbon capture, utilization, and storage; electric power systems; energy bioscience; energy storage; materials for energy and extreme environments; mobility systems; and solar energy.

As announced this spring, the Low-Carbon Energy Centers will be integrated into MITEI's new Future Energy Systems Center as part of MIT's Climate Action Plan for the Decade. The center will formally launch in the fall and will build on the solid foundation of the Low-Carbon Energy Centers. All existing Low-Carbon Energy Center research projects and memberships will continue within the Future Energy Systems Center. Through the Low-Carbon Energy Centers, MITEI has enabled 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. The new center will build on this portfolio of research and analysis with an increased focus on integrated analyses of the energy system, providing insights into the complex multisectoral transformations that will alter the power and transportation systems, industry, and built environment.

Since their launch, the Low-Carbon Energy Centers and other MITEI members have generated more than $166 million in sponsored research activity related to the development of low- and no-carbon technologies. To date, 30 new, former, and current MITEI members have committed support for the centers, with some members supporting multiple centers.

Research

MITEI's research portfolio reflects the Initiative's goal of advancing low-carbon energy via diverse channels, from renewable energy and energy efficiency to carbon management technologies. An important component of the portfolio includes research and analysis on the energy systems—power, transportation, industry, and building—into which new technologies need to fit to provide energy services to society. Climate and the environment garnered the greatest new research support this year, receiving over $5 million to advance technologies that avoid carbon dioxide emissions into the atmosphere. 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 helps facilitate research collaborations with organizations through several project-based research centers. Fusion research is conducted in collaboration with the

MIT Laboratory for Innovation in Fusion Technologies, supported in part by MITEI members Eni and Commonwealth Fusion Systems. The Energy at Scale Center is a research initiative with the MIT Joint Program on the Science and Policy of Global Change to assess the economic, environmental, and geopolitical impacts of scaling up low-carbon technologies. The Center for Energy in the Developing World is concerned with the energy transition as it will unfold throughout the developing world.

MITEI and its members have supported more than 900 projects through fiscal year 2021.

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 MITEI seed research projects this spring for a total of approximately $1 million. Including these grants, MITEI has supported 194 energy-focused seed projects with grants totaling over $26 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 MIT's five schools, the MIT Stephen A. Schwarzman College of Computing, and the Institute's 28 departments, labs, and centers.
- **New MITEI leadership position:** Underscoring the crucial role public policy plays in accelerating the energy transition, MITEI has appointed Christopher Knittel, the George P. Shultz Professor of Applied Economics in the Sloan School of Management, as deputy director of policy. He brings important economic and policy analysis skills that will prove critical to MITEI's work decarbonizing the world's energy systems. His appointment officially began on July 1.
- **Studies and reports:** The Future of Energy Storage study, scheduled for release in fall 2021, focuses on the role of storage in making electricity systems cleaner and more efficient. It is part of MITEI's "Future of" study series, which provides comprehensive analyses for policy makers and regulators.
- **Systems modeling tools:** MITEI's internal research team has made substantial progress toward further developing a unique and powerful set of energy system analysis and optimization tools. The Sustainable Energy System Analysis Modeling Environment (SESAME) will be deployed as an open-source web application incorporating a growing number of features and capabilities for modeling energy system emissions scenarios. In April, MITEI demonstrated SESAME for a bipartisan group of Congressional staff. GEN-X, our state-of-the-art electricity system capacity expansion model for investment planning in the power sector, was released as an open source tool in June and is being used extensively in the Future of Energy Storage study.
- **Future Energy Systems Center:** MITEI's Future Energy Systems Center will formally launch in fall 2021 to examine the accelerating energy transition as technologies, policies, demographics, and economics change the landscape of energy supply and demand. The center will provide system-level analysis, giving insights into the complex multisectorial transformations that will alter

the power systems, transportation systems, industry, and built environment toward a decarbonized future energy system. To enable this integrative analysis, the current consortia-funded workstreams from MITEI's Low-Carbon Energy Centers will be combined into the Future Energy Systems Center. This evolution is essential to understand the cross-sectorial impact of the energy transition. For example, the implications of electric vehicle charging are important to both the mobility sector and the electric power sector. Likewise, the topic of hydrogen has important implications for electric power, low-carbon fuels, industry, transportation, carbon management, and the built environment. While the new center's overarching focus is integrative analysis across all sectors, it will have numerous focus areas. The initial focus areas include electric power, energy storage and low-carbon fuels, transportation, industrial processes, carbon management, and the built environment.

- **Low-Carbon Energy Center meetings:** The Carbon Capture, Utilization, and Storage, Energy Storage, Electric Power Systems, and Mobility Systems centers each held several virtual workshops and meetings to discuss the latest research results and new directions of technology development with their members. The Electric Power Systems Center has initiated projects to research decarbonization of heat, assess the role for natural gas in future low-carbon U.S. electricity systems, examine implications of broad electrification on the power networks and large penetration of distributed energy resources, research sector coupling in the context of energy transition, and evaluate the impact of multidimensional uncertainty in long-term investment planning. The Carbon Capture, Utilization, and Storage Center selected a new seed project to utilize high-fidelity monitoring for an integrated geophysical and geochemical investigation of carbon dioxide storage. This project is in addition to an ongoing project to develop methane pyrolysis technology for producing hydrogen without carbon dioxide emissions. The Mobility Systems Center awarded four new projects to examine optimal energy distribution infrastructure for electric vehicle fast-charging and hydrogen stations, future of work and urban mobility, reinforcement learning for guiding drivers to reduce congestion in the developing world, and energy systems analysis for low-carbon power and transportation.
- **Low-Carbon Energy Center webinars:** MITEI's Low-Carbon Energy Center webinars, which began in February 2020 via Zoom, have provided an opportunity to engage a broad spectrum of stakeholders across MITEI's member organizations. MITEI has held eight Low-Carbon Energy Center webinars, including the following three in FY2021:

    - July: "The Role of Hydrogen in the Power Sector," presented by Dharik Mallapragada, principal research scientist, MITEI
    - October: "SESAME: A Novel Tool for Forecasting Emission Impacts of the Evolving Energy System," presented by Emre Gençer, principal research scientist, MITEI
    - January: "Direct Air Capture: A Process Engineer's View," presented by Howard Herzog, senior research engineer, MITEI

Faculty Research Highlights

Materials Science

- **Fine-tuning new materials for energy devices:** Mircea Dincă, the W.M. Keck Professor of Energy in the Department of Chemistry, and his collaborators have revealed the atomic-level structure of metal-organic frameworks (MOFs), a class of highly porous, crystalline materials that can be made electrically conductive in some cases. Their findings provide design principles for developing new MOF materials that could enable advances in energy-related technologies such as batteries, fuel cells, catalysts, and more.
- **Atomic design for a carbon-free planet:** Manipulating materials at a fundamental level, Ju Li, the Battelle Energy Alliance Professor of Nuclear Science and Engineering and professor of Materials Science and Engineering, reveals new properties for energy applications.
- **Using aluminum and water to make clean hydrogen fuel—when and where it's needed:** MIT researchers have produced practical guidelines for generating hydrogen using scrap aluminum and water, confirming that when combined with water, aluminum can provide a high-energy-density, easily transportable, flexible source of hydrogen to serve as a carbon-free replacement for fossil fuels.

Energy Storage

- **Powering the energy transition with better storage:** Researchers from MITEI and Princeton University offer a comprehensive cost and performance evaluation of the role of long-duration energy storage technologies in transforming energy systems.
- **Assessing the value of battery energy storage in future power grids:** A study led by Dharik Mallapragada examines battery storage to determine the key drivers that impact its economic value, how that value might change with increasing deployment over time, and the implications for the long-term cost-effectiveness of storage.
- **Evaluating battery revenues for offshore wind farms using advanced modeling:** MITEI research scientist Apurba Sakti and team investigated six mathematical representations to evaluate the potential added value of a battery in an energy system that pairs battery storage with an offshore wind farm.
- **Looking for new ways to store energy:** Fikile Brushett, MIT associate professor of chemical engineering, leads a group dedicated to developing more efficient ways to store energy, including batteries that could be used to store the energy generated by wind and solar power.
- **Preventing short-circuiting in next-gen lithium batteries:** Researchers including Yet-Ming Chiang, Kyocera Professor in the Department of Materials Science and Engineering, have found a way to prevent dendrite formation in solid-state batteries, which may help unleash the potential of this high-powered battery.

- **Design could enable longer lasting, more powerful lithium batteries:** A new design of lithium batteries by Yang Shao-Horn, Professor of Mechanical Engineering and Materials Science and Engineering, and Ju Li makes use of a novel electrolyte that could allow advanced metal electrodes and higher voltages, boosting capacity and cycle life.

Nuclear Energy

- **Building nuclear power plants:** Researchers including Jessika Trancik, associate professor of energy studies in the MIT Institute for Data, Systems, and Society, and TEPCO Professor of Nuclear Science and Engineering Jacopo Buongiorno have developed tools that nuclear power plant personnel can use to improve their cost projections and to predict how design changes will affect overall costs.
- **Superconductor technology for smaller, sooner fusion:** A demonstration of MIT and Commonwealth Fusion Systems' new superconducting cable is a key step on the high-field path to compact fusion. The high-field pathway to fusion aims to generate fusion in compact devices in less time and at a lower cost than alternative approaches.
- **Why nuclear batteries offer a new approach to carbon-free energy:** Factory-built microreactors, dubbed nuclear batteries, could play a significant role in decarbonizing the world's electricity systems, says Jacopo Buongiorno.

Solar Energy

- **Researchers improve efficiency of next generation solar cell material:** Lester Wolfe Professor of Chemistry Moungi Bawendi, Fariborz Maseeh (1990) Professor in Emerging Technology Vladimir Bulović, and others have developed a new design approach to perovskite cells—a key component of next-generation solar panels—that pushed the material to match or exceed the efficiency of today's typical silicon cell.
- **Homing in on longer-lasting perovskite solar cells:** Moungi Bawendi and Professor of Mechanical Engineering Tonio Buonassisi have helped develop a new approach to identifying long-lasting perovskite formulations that could help solve degradation issues.

Mobility

- **Designing better batteries for electric vehicles:** A team of researchers from MIT and the University of California, Berkeley, has demonstrated the importance of keeping future low-cost, large-scale manufacturing in mind when exploring novel battery concepts.

- **Concept for hybrid-electric plane may reduce aviation's air pollution problem:** MIT researchers have designed a new concept for aircraft propulsion that they estimate would eliminate 95% of aviation's nitrogen oxide emissions.
- **To boost emissions reductions from electric vehicles, know when to charge:** MITEI researchers Emre Gençer, Maryam Arbabzadeh, and Ian Miller examine how to reduce emissions associated with the electricity source used to charge an electric vehicle (EV). Considering regional charging patterns and the effect of ambient temperature on car fuel economy, they found that the time of day when an EV is charged significantly impacts the vehicle's emissions.
- **China's transition to electric vehicles:** China has mandated that 40% of all new cars sold must be electric by 2030. William Green, the Hoyt C. Hottel Professor in Chemical Engineering, and team find that although this ambitious target will have a substantial cost for individual consumers and society, the cost might be outweighed by the many environmental benefits.
- **The price of privacy in ride-sharing app performance:** Jinhua Zhao, associate professor in the Department of Urban Studies and Planning, and others discuss the impacts of different degrees of locational privacy protection on the quality of ride-sharing services.
- **How to get more electric cars on the road:** A study by Jessika Trancik and others measures which kinds of infrastructure improvements could lead to wider adoption of electric vehicles. One key finding is that installing charging stations on residential streets and along highways will greatly increase the potential for vehicle electrification.

Energy and Climate Economics and Policy

- **Study reveals plunge in lithium-ion battery costs:** The price of batteries has dropped significantly since 1991, according to new analysis by Jessika Trancik and others. The analysis shows that the drop parallels similar improvements in solar and wind technologies and that further steep declines could be possible.
- **Can U.S. states afford to meet net-zero emissions targets by 2050?:** A study led by Mei Yuan, research scientist at the Joint Program on the Science and Policy of Global Change, finds that increasing hydropower transmission capacity between Quebec, Canada, and New England could ensure that the Northeastern U.S. achieves its midcentury emissions goals.

Carbon Capture

- **Decarbonizing our energy systems:** By developing novel electrochemical reactions, Professor of Chemistry Yogesh Surendranath hopes to find new ways to generate energy and reduce greenhouse gases.

- **Powering through the coming energy transition:** Jennifer Morris, research scientist at MITEI and the Joint Program on the Science and Policy of Global Change, led a study that projects the likely role of carbon capture and storage (CCS) in the power sector in a portfolio of low-carbon technologies. The study assessed the potential of CCS and its competitors in mitigating carbon emissions in the power sector under a policy scenario aligned with the 2 degrees Celsius goal of the 2015 Paris Agreement.
- **A controllable membrane to pull carbon dioxide out of exhaust streams:** A new, electrically switchable system developed by Professor of Chemical Engineering T. Alan Hatton and others could continuously separate gases without the need for moving parts or wasted space.
- **Boosting the efficiency of carbon capture and conversion systems:** A new design created by Yang Shao-Horn, Professor of Mechanical Engineering Kripa Varanasi, and others could speed up reaction rates in electrochemical systems for pulling carbon out of power plant emissions.
- **Turning down the temperature:** T. Alan Hatton is working to expand the possibilities of different CCS technologies by looking to use different chemical interactions and power sources than used traditionally.
- **Controlling bubble formation on electrodes:** Associate Professor of Mechanical Engineering Betar Gallant and Professor of Mechanical Engineering Evelyn Wang find that the wettability of porous electrode surfaces is key to making efficient water-splitting or carbon-capturing systems.
- **Negative emissions, positive economy:** A study by Howard Herzog, senior research engineer at MITEI, and Jennifer Morris finds that bioenergy with carbon capture and storage could be an economically effective tool to meet global climate goals when paired with emissions-reduction measures.

Energy in the Developing World

- **Encouraging solar energy adoption in rural India:** Associate Professor of Urban and Environmental Planning David Hsu and team devised a card-playing interview technique to better understand the motivations behind rural Indian households' energy-related decisions to help expedite the spread of solar technologies for electrification in rural settings.
- **Designing off-grid refrigeration technologies for crop storage in Kenya:** A team of MIT researchers are using the thermodynamic properties of water evaporation to bring off-grid cold storage of produce to remote, arid regions.

Additional Low-carbon Energy Research

- **Tiny particles power chemical reactions:** Carbon P. Dubbs Professor of Chemical Engineering Michael Strano and others have discovered a new way to generate electricity by using tiny carbon particles that create a current simply by interacting with liquid surrounding them.

- **How can you reduce the environmental impact of your next virtual meeting?:** A study conducted by a team of researchers from MITEI, Yale University, and Purdue University uncovered the overlooked environmental impacts of internet use by estimating associated carbon, land, and water footprints.
- **MITEI researchers build supply chain model to support hydrogen economy:** MITEI researchers have developed a new hydrogen supply chain planning model where trucks are used both as a means of energy transmission and storage, reducing costs in the hydrogen supply chain by 9%.
- **Can industrial-scale green hydrogen be cost-competitive by 2030?:** Dharik Mallapragada, Emre Gençer, and team identified system design choices and U.S.-based locations that could produce cost-effective, low-carbon hydrogen to supply industrial processes round the clock by 2030.

MITEI Studies

The Future of Energy Storage

The Future of Energy Storage study, scheduled for release in fall 2021, focuses on the role of storage in making electricity systems cleaner and more efficient. Robert Armstrong, the director of MITEI and Chevron Professor of Chemical Engineering, and Yet-Ming Chiang are co-chairs of the study. Howard Gruenspecht, a senior energy economist at MITEI and former deputy administrator of the U.S. Energy Information Administration, serves as its executive director. 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 is adjusted by system operators to follow load. However, unlike generation sources that can follow load, VRE resources cannot be dispatched at will. Therefore, the feasibility of a future electricity system in which VRE resources play a leading role will likely depend 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 2050 time frame. The multidisciplinary study team's focus is on electricity-to-electricity storage systems in four broad categories: electrochemical storage (batteries), mechanical storage (including pumped hydroelectric and compressed air energy storage), hydrogen and other chemical storage, and thermal storage. The study also considers how storage interacts with strategies such as increased load flexibility, expanded transmission networks, and overbuilding of VRE generation capacity as part of a cost-effective approach to accommodate a VRE-rich generation mix.

Following meetings among faculty through mid-2019 to set the study's focus, research activities involving faculty, MITEI staff, postdocs, and students began in the summer and fall of 2019. In spring 2021, research teams concluded their analysis and prepared draft chapters for the report. Final meetings with the study's External Advisory Committee were held in July to review main findings and recommendations.

Global Commission to End Energy Poverty

In collaboration with the Rockefeller Foundation, MITEI initiated an ambitious new effort in late 2018 to bring electricity to the remaining billion people across the globe who live without it. The Global Commission to End Energy Poverty is led by Robert Stoner, MITEI deputy director for science and technology and director of the Tata Center for Technology and Design, and co-chaired by Ernest Moniz, special advisor to the MIT president, professor emeritus, and former U.S. Secretary of Energy; Dr. Rajiv Shah, president of the Rockefeller Foundation; and Akinwumi Adesina, president of the African Development Bank. In December, the Commission published its first annual report, in which it identified dysfunction within the electricity distribution sectors of many developing countries as a common theme that must be addressed by the international community, national governments, and the private sector working together. The Commission launched a new agenda in May tied closely to a groundbreaking Rockefeller Foundation initiative to which it and the IKEA Foundation have pledged a total of $1 billion to seed a global effort to enact many of the Commission's recommendations. The initiative seeks to mobilize a total of $20 billion in pledges from the development finance community.

Education

MITEI's role as an educator of future energy change agents is critical to its mission as a catalyst for tomorrow's low-carbon energy solutions. Through programs created for graduate and undergraduate students, MITEI provides a robust educational toolkit to MIT students who want to contribute to the energy transition. These programs allow students to take classes; conduct research in diverse areas, from energy science and social science to technology and engineering; practice their skills; and network with peers and professionals. MIT faculty members work with MITEI's education team to develop curricula 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 UROP. After completing their first year at MIT, students can participate in a 10-day field trip to experience practical examples related to the energy transition through visits to energy companies, demonstration projects, and research facilities. Unfortunately, the 2020 and 2021 field trips were cancelled due to the Covid-19 pandemic.

Students participating in MITEI's Solar Spring Break program can immerse themselves in energy practice by installing solar panels in underserved communities. Due to continued travel restrictions, MITEI organized a speaker series in partnership with 22.003 NEET Seminar: Renewable Energy Machines to replace the 2021 spring break service-learning trip.

Graduate students and postdoctoral associates 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 hosts activities for graduate student fellows including dinner meetings with sponsors at MITEI's Annual Research Conference, energy talks, and a range of informational gatherings and networking events.

MITEI has also collaborated in developing three graduate-level energy courses for edX, with a fourth in development. The courses are freely available in almost every country, and are geared toward working professionals, policy makers, and graduate students who are seeking the skills to expedite the energy transition and mitigate climate change. To date, the courses have attracted over 45,000 enrolled learners.

MITEI Education Program Highlights

- **Graduate Fellows:** MITEI welcomed 35 new graduate students and postdocs to the Society of Energy Fellows in academic year 2021 (AY2021). The Energy Fellows network now totals more than 500 current and former graduate students and postdoctoral fellows, spanning 20 departments and divisions at MIT's five schools and college. This year's fellowships were made possible through the generous support of five MITEI member companies: Chevron, Commonwealth Fusion Systems, Eni, ExxonMobil, and Total.
- **Online energy courses:** To help train the global network of professionals needed to realize a low-carbon energy future, the MITEI education team organized a series of graduate-level online energy courses based on interdisciplinary residential MIT subjects. The MITx courses engage four critical aspects of future electricity systems: load and demand-side management, economics and regulation, production, and distribution and transmission. The first course, Sustainable Building Design with Professor Christoph Reinhart of the School of Architecture + Planning, launched in January 2020 and has run twice more (in June 2020 and in May 2021). The next course, Sustainable Energy with Professor of Nuclear Science and Engineering Michael Golay, launched in September and will be offered again in September 2021. A third course, Principles of Modeling, Simulation, and Control for Electric Energy Systems with Marija Ilic, senior research scientist at the Institute for Data, Systems, and Society, launched in June. A fourth, Energy Economics and Policy with Christopher Knittel, will launch in early 2022.
- **Sustainability course support:** MITEI provided support for two teaching assistants for a course co-taught by Institute Professor Emeritus John Deutch and Maria Zuber, MIT vice president for research and E. A. Griswold Professor of Geophysics in the Department of Earth, Atmospheric and Planetary Sciences. The half-semester course, 5.000 Dimensions of Geoengineering, drew from a wide range of disciplines to explore the many controversies, risks, and uncertainties surrounding R&D in geoengineering.

- **Chevron Fellows:** In 2019, MITEI partnered with the Systems Design and Management (SDM) program to provide more resources and educational opportunities for students interested in the energy transition and working to complete a master's degree in SDM with an energy concentration. Chevron sponsored 16 of its employees to take part in this program in the 2020 academic year and another 16 in AY2021. The goal for this additional training is to prepare them for a future in which the energy industry increasingly applies digital tools such as machine learning, artificial intelligence, and blockchain. The MITEI education team supported the cohorts' transition to MIT, helped introduce each participant to faculty doing energy-related research to serve as thesis advisors, and welcomed them into the Society of Energy Fellows. Since the Chevron Fellows' time at MIT is condensed to 12 months rather than the typical 18–24 months, MITEI's support has been critical to help them complete their theses in this shortened timeframe.

- **Energy Studies Minor:** In the spring, 12 students graduated with the Energy Studies Minor. The MITEI education team hosted a virtual toast over Zoom for the new graduates the week before Commencement.

- **Undergraduate energy research:** MITEI supported 64 student projects through the MITEI UROP during the 2021 academic year, bringing its total number of sponsored projects up to 655. During the summer term, MITEI funded 23 UROP students, both on site and remote.

- **First-Year Pre-Orientation Program:** MITEI's summer energy pre-orientation program was, by necessity, remote, but welcomed 20 new first-year students to the MIT community. Activities included a conversation and workshop with Jing Li, William Barton Rogers Career Development Chair of Energy Economics at the MIT Sloan School of Management; building solar car models (students were sent kits by mail and worked on them synchronously); a panel discussion on race and the undergraduate experience during UROPs; speed networking; energy "campfire questions" with the older student counselors; and "energy *Jeopardy!*"

- **Energy Justice Speaker Series:** To replace the 2021 spring break service-learning trip, MITEI organized a speaker series in partnership with the New Engineering Education Transformation Renewable Energy Machines seminar class. Speakers included Ford Professor of Urban and Environmental Planning Larry Susskind, Jennie Stephens of Northeastern University, Terzah Poe of Harvard University, Chris Johnson of the Passamaquoddy Tribe, and Massachusetts State Representative Maria Robinson.

- **High school curriculum:** Christopher Knittel is developing the Climate Action Through Education program with support from MITEI. This project is focused on developing free digital classroom resources and lesson plans that explore climate change science and policy-based solutions for high school students and teachers. The final product will have components for English/language arts, math, history, and science teachers alike.

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 2021 academic year, MIT hosted the final two symposia in the six-part Climate Symposia series. These were held virtually after being postponed due to the Covid-19–related campus closure and in-person event cancellations. The series drew upon MIT's work to date on the MIT Plan for Action on Climate Change and considered the current state of knowledge on key aspects of this global problem. These discussions provided an important opportunity for engagement among members of the MIT community, other leading researchers, industry leaders, and policy makers to explore options for facilitating the necessary transition to a low-carbon economy. MITEI-affiliated faculty and staff provided support for the six symposia.
- **MIT Engagement Forum:** As MIT prepared to issue the updated version of its Climate Action Plan in the spring, MITEI co-hosted an engagement forum with the Office of the Vice President for Research (VPR) as an opportunity for the MIT community to learn about and discuss some of the low-carbon research projects between MIT and key industry collaborators. The forum, Research Collaborations to Decarbonize the Energy System, brought together MIT faculty and researchers, industry liaisons, and venture capital leaders to highlight the benefits of these collaborations. MITEI also provided staff support for the second engagement forum, which was co-hosted by VPR and the Environmental Solutions Initiative.
- **MIT Plan for Action on Climate Change:** MITEI has continued to support MIT's Plan for Action on Climate Change through its interdisciplinary Low-Carbon Energy Centers, which enable MIT faculty and member company collaboration, energy systems analysis and studies, work in developing countries, and education. As part of MIT's updated climate action plan, MITEI will launch the Future Energy Systems Center with several events in fall 2021.
- **Guest speakers:** MITEI hosted its public seminars with leaders in policy, academia, and industry over Zoom in AY2021, which had the benefit of reaching a large virtual audience. Speakers included Fatih Birol, executive director, International Energy Agency; Ernest Moniz; Deborah Gordon, senior fellow, Watson Institute at Brown University; Scott Tinker, director of the Bureau of Economic Geology and professor, University of Texas at Austin; Joanna Moody,

research program manager, Mobility Systems Center, MITEI; Daniel Yergin, vice chairman, IHS Markit; Asegun Henry, Robert N. Noyce Career Development Professor, MIT; Dirk Smit, vice president of research strategy and chief scientist, Shell; and Kathleen Theoharides, Massachusetts Secretary of Energy and Environmental Affairs.

- **Energy Innovation Webinar Series:** MITEI and MIT's Industrial Liaison Program co-hosted the Energy Innovation Webinar Series, a series of 12 webinars on topics including innovations in critical low-carbon technologies, energy storage systems, scaling up low-carbon energy, decarbonizing buildings, low-carbon fuels, and decarbonizing the industrial sector. The virtual format allowed for high levels of viewership, including individuals from more than 1,000 companies over the course of the series.

- **Annual Research Conference 2020:** The event, held virtually, brought together energy researchers, policy makers, and industry members working on cutting-edge technologies and business models for the transition to a low-carbon future. The two-day conference included panels on the role of the university in educating for the energy transition; multidisciplinary approaches to low-carbon fuels; decarbonizing industry; the role of carbon capture, utilization, and storage in achieving net-zero emissions; and tackling sustainable mobility. Conference speakers included Angela Knight, senior manager of university recruiting, enterprise hiring, and strategic partnerships, Chevron; Torben Orla Nielsen, science attaché, Innovation Centre Denmark Boston; James Rincon, manager and corporate innovation lead, Avangrid; Joe Powell, chief scientist of chemical engineering, Shell; Daniel Yergin, vice chairman, IHS Markit; MITEI researchers; and MIT faculty members.

- **C3E 2020 Women in Clean Energy Symposium:** In December, the ninth annual Clean Energy, Education, and Empowerment (C3E) Women in Clean Energy Symposium and Awards was held virtually and hosted by MITEI in collaboration with the U.S. Department of Energy (DOE), Stanford Energy, 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's Jessika Trancik—and rich conversations on strategies and technologies to accelerate the clean energy transition in a changing world. The U.S. C3E Initiative aims to advance clean energy by closing the gender gap and increasing the participation, leadership, and success of women in clean energy fields. Stanford Energy will host the symposium virtually in the fall in collaboration with MITEI, DOE, and Texas A&M Energy Institute.

- **Podcasts:** MITEI produced and released a number of podcasts that explore energy from a variety of angles to make its research more accessible to a large audience and to illustrate how energy impacts our everyday lives. Subjects covered this year include sustainable hydropower, energy connectivity in Africa, digitalization and the power grid, the cost of car ownership, and energy and filmmaking.

Organization

MITEI Leadership Team

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

Robert C. Armstrong, Director

Christopher Knittel, Deputy Director for Policy

Robert Stoner, Deputy Director for Science and Technology

Martha Broad, Executive Director

Louis Carranza, Associate Director

Antje Danielson, Director, Education

Tom Melville, Director, Communications

Robert Tolu, Manager of Financial Operations

MITEI Energy Council

The Energy Council helps shape MITEI's research, education, and outreach directions. The Council includes MITEI executive leadership and faculty from MIT's five schools and college.

Energy Education Task Force

MITEI's Energy Education Task Force (EETF) guides the development of energy education at MIT. Bradford Hager, Cecil and Ida Green Professor of Earth Sciences in the Department of Earth, Atmospheric and Planetary Sciences, serves as chair. The task force meets regularly throughout the academic year and includes faculty from all five schools at MIT as well as graduate and undergraduate student representatives. MITEI's education team members support the EETF by implementing energy education programs.

MITEI Members

MITEI draws on MIT's research capabilities, innovation, expertise, and experience to create successful industry collaborations to meet its research partners' key strategic objectives. A tiered membership structure enables diverse private-sector partners to sponsor multidisciplinary flagship research programs with MIT faculty; contribute to energy-focused labs, programs, and centers at MIT; fund critical energy fellowships; support innovative energy concepts from proposals solicited across the campus; and participate in MITEI's seminars, lectures, and colloquia.

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

Member Highlights

- Exelon, MITEI's first Low-Carbon Energy Center member, expanded its membership to become a MITEI sustaining member as well as a member of the Electric Power Systems Center. Others that joined one or more new Low-Carbon Energy Centers in FY2021 include Dominion Energy, Eversource, Golden Spread Electric Cooperative, and Washington Gas & Light.
- During FY2021, MITEI Member Services worked on renewal agreements for several members. Ferrovial, a MITEI associate member, renewed its membership for another five-year term. Duke Energy, IHI Corporation, and National Grid renewed their Low-Carbon Energy Center memberships.
- As part of MIT's new climate plan, MITEI will be launching the Future Energy Systems Center. This member consortium brings together the ongoing technoeconomic and systems-oriented research from MITEI's Low-Carbon Energy Centers under a common umbrella, creating a unified energy system analysis capability with integrated research workstreams. All existing Low-Carbon Energy Center members also receive Future Energy Systems Center membership benefits.
- MITEI hosted its Annual Research Conference on November 16–17. The event focused on development and deployment of key decarbonization technologies—from the lens of science, students, and scale. Daniel Yergin, the vice chairman of IHS Markit and a Pulitzer Prize winner, presented a keynote on his new book, *The New Map: Energy, Climate, and the Clash of Nations*. The individual Low-Carbon Energy Centers also held invitation-only sessions for members and guests.
- In June, MITEI held its well-established Spring Symposium. This year's program focused on bioenergy with carbon capture and storage (BECCS). The symposium brought together panelists with a variety of expertise on BECCS to explore the contributions it could make in decarbonizing the world's economies and the challenges it faces.
- In partnership with MIT's Industrial Liaison Program, MITEI hosted the Energy Innovation Webinar Series. The 12 webinar topics included innovations in critical low-carbon technologies, decarbonizing buildings, low-carbon fuels, and decarbonizing the industrial sector. The viewership included individuals from more than 1,000 companies.

Affiliated Groups

MITEI is affiliated with faculty pursuing interdisciplinary energy and environmental activities in a number of MIT centers, departments, and laboratories. 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 Christopher Knittel and jointly sponsored by MITEI, the Department of Economics, and the MIT Sloan School of Management.

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

CEEPR produces working papers and policy briefs, as well as research input to larger, interdisciplinary studies; hosts two annual research workshops in Cambridge, Massachusetts; and hosts an international energy policy conference organized jointly with the Energy Policy Research Group at the University of Cambridge in the United Kingdom. CEEPR is also involved in a number of collaborative research projects.

The E2e Project is a joint initiative founded by Christopher 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 policy makers and the public. Its research generates rigorous and accurate evaluations of energy-efficiency technologies and programs using state-of-the-art empirical methodologies.

The Roosevelt Project takes a multidisciplinary approach to examine the transitional challenges associated with progress toward a deeply decarbonized U.S. economy. The project aims to chart a path forward through the transition that minimizes worker and community dislocations and enables at-risk communities to sustain employment levels by taking advantage of the economic opportunities present for regional economic development. The first phase of the project involves an assessment of cross-cutting topics related to the transition. The second phase of the project involves developing regional action plans for individual case studies, working with local partners on the ground in specific transition contexts. The project was initiated by former U.S. Secretary of Energy Ernest J. Moniz and engages MIT and Harvard faculty and researchers across academic domains including economics, engineering, sociology, urban studies and planning, and political science.

Joint Program on the Science and Policy of Global Change

The pace and complexity of global environmental change is unprecedented. Nations, regions, cities, and the public and private sectors face increasing pressures to confront critical challenges in future food, water, energy, climate, and other areas. Led by director Ronald G. Prinn, TEPCO Professor of Atmospheric Science, the Joint Program's integrated team of natural and social scientists produces comprehensive global and regional change projections under different environmental, economic, and policy scenarios. These projections enable decision-makers to better assess impacts and the associated costs and benefits of potential courses of action.

To achieve its mission—advancing a sustainable, prosperous world through scientific analysis of the complex interactions among co-evolving, interconnected global systems—the Joint Program accomplishes the following outcomes:

- Combines scientific research with risk and policy analyses to project the impacts of—and evaluate possible responses to—the many interwoven challenges of global socioeconomic, technological, and environmental change
- Communicates research findings through its website, publications, workshops, and presentations around the world, as well as frequent interactions with decision-makers, media outlets, government and nongovernmental organizations, schools, and communities
- Cultivates and educates the next generation of interdisciplinary researchers with the skills to tackle ongoing and emerging complex global challenges

Building on the twin pillars of science and policy, the Joint 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.

Office of Sustainability

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

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

Robert Armstrong
Director
MIT Energy Initiative