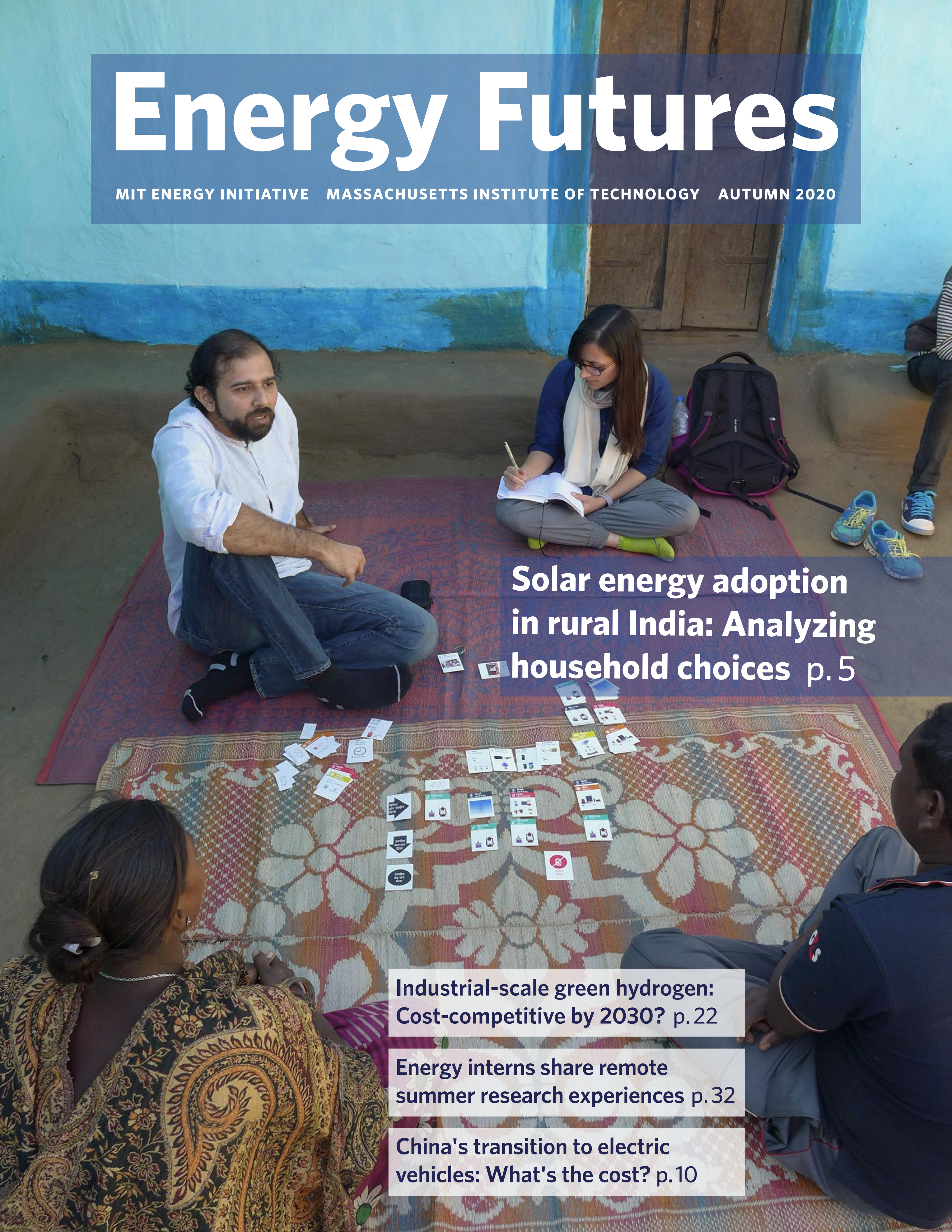
Energy Futures

MIT ENERGY INITIATIVE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AUTUMN 2020



Solar energy adoption in rural India: Analyzing household choices p. 5

MITEI dedicates this issue of *Energy Futures* to William Wynot '44 (1922–2020), in appreciation for his lasting impact on MITEI's undergraduate education programming. See page 3 for MITEI staff and student reflections on his many contributions.

On the MIT Energy Initiative (MITEI) podcast, we continue to share conversations at MIT about the future of energy. Recent additions to the lineup have included:

Climate tech startups
Shreya Dave PhD '16, CEO of Via Separations, and Johanna Wolfson PhD '13, principal at Prime Impact Fund, describe their paths from studying at MIT to working for and investing in climate tech startups.

Energy technology evolution
MIT Research Affiliate Gökşin Kavlak PhD '17 and MIT Associate Professor Jessika Trancik talk about their work to explain and forecast energy technology evolution.

Energy entrepreneurship
Tod Hynes, senior lecturer in the Martin Trust Center for MIT Entrepreneurship, discusses success, spinouts, and advice from teaching Energy Ventures.

2020 MIT Clean Energy Prize winners
Teams from Nitricity and Harmony Desal discuss the startup technologies that won the 2020 MIT Clean Energy Prize, the largest and longest-running competition for student cleantech startups.

Corporate climate strategy
Mariko Meier, vice president of marketing at Enel X, talks about building a career in energy and recent trends in corporate climate strategy.

…and more

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On the cover
In a remote village in India, Ameya Athavandar (left) of twobythree, a Mumbai-based company, and Elise Harrington PhD '20 use playing cards to help people recall why and how they had acquired various solar-based devices. The project, led by MIT Professor David Hsu, aims to understand how to encourage the adoption of such devices, which bring basic lighting and charging capabilities to people far from state-run power grids. See page 5.
Photo: David Hsu, MIT

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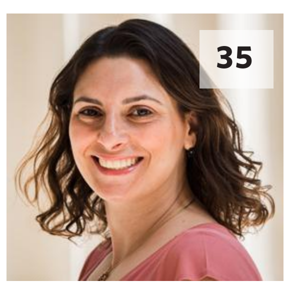
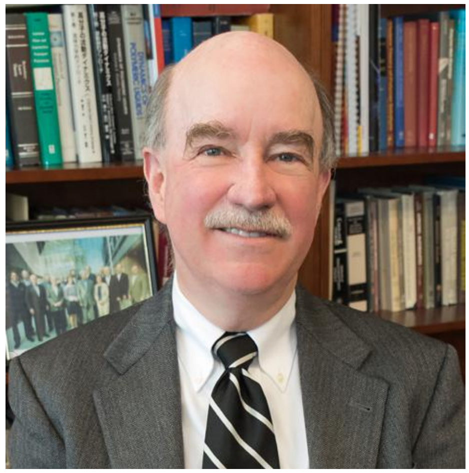


A letter from the director

Dear friends,

MIT recently announced an important next step in its ongoing work to take action against global climate change: the "Climate Grand Challenges." This Institute-level commitment seeks to stimulate and fund new ideas for high-impact, science-based mitigation and adaptation solutions for rapid, large-scale change. It builds on work that MITEI and others have done to develop faculty capability, collaborations, and foundational programs in the underlying science, technology, and policy needed to confront climate change. But if the world's efforts to address the climate challenge are to succeed, we must continue to grow our diverse talent base to make game-changing advances on shortened time scales. MITEI is expanding its work to develop the research teams, partnerships, and resources that will address the dual challenge of mitigating climate change while ensuring equitable energy access to all people on the planet. We look forward to applying our capabilities to the Climate Grand Challenges.

This summer, MIT made another important commitment: to address systemic racism at the Institute to create a more equitable, inclusive, and just MIT. President L. Rafael Reif has called for the development and implementation of a comprehensive, Institute-wide action plan for diversity, equity, and inclusion. In August, MIT held a community event—the Day of Dialogue on race and anti-racism—to initiate an ongoing conversation that will guide our community to an anti-racist ethos. We continued the discussion at our Discover Energy First-Year Pre-Orientation Program by introducing a panel of students to discuss their experiences as researchers of color.



MITEI's research, education, and outreach programs are spearheaded by Professor Robert C. Armstrong, director. Photo: Kelley Travers, MITEI

We have now begun the fall semester; and with safety measures in place to control the spread of Covid-19, MIT has welcomed a limited number of students, faculty, and staff back on campus. As many of us remain remote, we are continuing to find ways to keep our community engaged and connected virtually. In this issue of *Energy Futures*, you will read about a virtual toast for our 2020 graduating Energy Studies Minor students (page 34), weekly calls between volunteer coaches and students to provide support navigating online education and the pandemic (page 35), and the annual MIT Energy Conference's rapid transition to a virtual platform (page 37).

Additionally, MITEI has moved its events and seminars online. You can learn about upcoming events and how to attend at energy.mit.edu/events. We are also pleased to report that MIT's Climate Symposia resumed virtually this fall. Begun in October 2019, this six-part series examines the current state of climate science and policy and aims to generate solutions to address climate change.

Here at MITEI, researchers continue to explore and develop the technologies and policies needed to decarbonize our energy systems and mitigate the effects of greenhouse gas emissions. In this issue, you will read about an analysis of the costs and benefits of China's efforts to transition to electric vehicles (page 10), an examination of what it would take to make industrial-scale green hydrogen cost-competitive by 2030 (page 22), and more. You will also learn about new projects funded through our Seed Fund program, such as building hurricane-resilient electric grids (page 20), and through our Mobility Systems Center, such as the impacts of the Covid-19 pandemic on urban mobility (page 24).

Finally, I would like to take a moment to share our deep sorrow over the passing of two members of our community, Arthur Samberg '62 and William A. Wynot '44—both champions of clean energy research and education. Art served on our External Advisory Board from its inception, imparting critical guidance as MITEI has worked to develop clean energy solutions. Bill was a tireless advocate of our undergraduate energy program, providing support and feedback for our Energy Studies Minor. They will be dearly missed. Read about their contributions on page 3.

Thank you for reading this issue of *Energy Futures* and for continuing to follow along and engage with us as we work toward a decarbonized future in which all people have fair and just access to energy and the prosperity it enables. Stay safe and healthy; and as always, please keep in touch.

Warm regards,

Professor Robert C. Armstrong
MITEI Director
October 2020

Remembering friends of MITEI

William "Bill" Wynot (1922–2020)

William "Bill" Wynot '44 was a champion of MITEI's undergraduate energy education program and a friend to us all. Here, MITEI staff and energy alumni reflect on Bill's lasting impact through his support of the Energy Studies Minor (ESM). View the full video that our 2014 ESM students filmed for Bill at bit.ly/mitei-esm.

Rachel Shulman, undergraduate academic coordinator at MITEI "Bill's generous endowment of MITEI's Energy Studies Minor [ESM] is a key part of MIT's contribution to the clean energy transition. Until we achieve the energy transition, we need the [ESM] to help expand the number of MIT classes that address climate change and provide students with the skills they need to effect change. Through his endowment, Bill gave the ESM the gift of stability and a foundation upon which we can continue to build."

Antje Danielson, director of education at MITEI "We are facing the triple challenge of climate change: To increase the availability of energy, decrease carbon emissions, and do it all very quickly. The Energy Studies Minor prepares students to meet this challenge. Bill's passion for and support of energy education was and remains an invaluable contribution that will make many of our students clean energy leaders."

Jacob Jurewicz '14, Nuclear Engineering and Physics "I've always been interested in where we get our energy from, but I really wanted to learn not just the physics and the engineering behind energy, but the economics and the social/political influences that go into it as well…The best part, I thought…of the energy minor is just how interdisciplinary it was. The MIT Energy Initiative…[is] attacking the problem [on] so many different levels, both large and small—at a technological level, and at a [systemic] level—and I was so happy to be a part of it. Thank you so much for contributing to such an important issue in our society today."

Zainab Lasisi '14, Chemical Engineering "Coming from Nigeria, I just know the value of energy, especially to a Third World country, and I hope one day to actually move back to Nigeria, so I thought energy would be a wonderful industry for me to work in…I think there is so much progress that needs to be made, and I'd like to be a part of that. A special thank you…[The ESM is] a wonderful program to have students from different academic departments at MIT come together and just really get to learn and to speak about what they're really passionate about. It's been very informative. I'm glad I…took the [ESM] at MIT."

Samuel Shames '14, Materials Science and Engineering "The Energy Studies Minor really prepared me to make an impact [on] whatever type of energy problem I want to look at, whether that's from a fundamental science perspective and engineering perspective, or sort of a policy and people perspective. I'm working on a startup company that's developing a technology to help people save energy and help buildings be more energy-efficient, and in that process, I'm really getting to apply some of the things I've learned in the minor…I think choosing to pursue an energy studies minor has been one of the best academic choices I made at MIT. I'm just really grateful and want to say thank you."

Arthur "Art" Samberg (1941–2020)

Arthur "Art" Samberg '62, a pioneer in investment management and longtime member of the MIT Corporation, died of leukemia on July 14, 2020. He was 79.

Reflecting his wide-ranging interests at MIT, Samberg served on the executive committee of the MIT Corporation and on visiting committees for the departments of Aeronautics and Astronautics, Mathematics, and Nuclear Science and Engineering. He also served on the School of Science Dean's Advisory Council, the MIT Energy Initiative External Advisory Board, and the MIT Investment Management Company Board. Samberg joined the Corporation in 2003.

He and his wife, Rebecca Samberg, established a scholarship fund that has supported more than 200 MIT scholars since its inception, many throughout their MIT undergraduate careers.

Michaela Jarvis, MIT News *correspondent*

Abridged and reprinted with permission of MIT News (news.mit.edu). Read the full article at bit.ly/mit-samberg.

Mario Molina (1943–2020)

At press time, we received notice that Mario Molina had passed away. Mario was a Nobel laureate, former MIT Energy Initiative External Advisory Board member, and MIT Institute Professor Emeritus. We value his contributions to MITEI over the years; he will be greatly missed. Read about his legacy at bit.ly/mit-molina.

Encouraging solar energy adoption in rural India

An investigation into household decision making

Nancy W. Stauffer, MITEI

IN BRIEF

An MIT study in rural India suggests that ongoing efforts supporting the adoption of "off-grid" energy sources such as solar-powered lanterns and microgrids can successfully bring people in remote areas basic energy services from renewable resources—without waiting for a state-run power grid to reach them. The researchers used an interview technique based on game-playing to help members of 22 households recall why and how they had acquired solar-based systems or joined a microgrid. Their responses showed that off-grid solar sources had enabled them to meet basic lighting and charging needs and in some cases even to run income-generating businesses from their homes. The researchers conclude that demonstrations by trusted nongovernmental organizations can inspire households to adopt solar power and help spread the use of renewable energy worldwide.

More than 73 million households in remote areas of the world get electricity not from a conventional power grid but rather from sources such as solar lanterns, solar home systems (SHSs) that can power several devices, and local solar-based microgrids. Such off-grid devices and systems provide life-changing services to people who are off centralized electricity grids, and they help spread the use of renewable energy. As a result, international aid organizations and nongovernmental organizations (NGOs) are working hard to encourage their adoption.

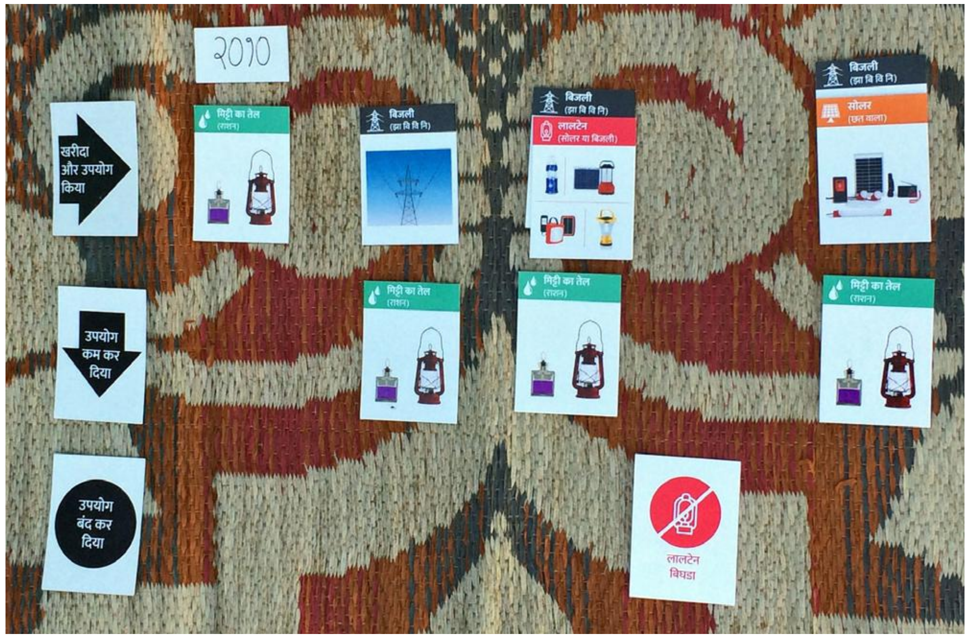
Facing page Many people in remote villages in India—including the one pictured here—use solar lanterns and other off-grid energy sources for basic lighting. To help bring such services to others, an MIT-led team has been investigating why and how households select and acquire their lighting sources. Photos: Ameya Athavankar

Above When interviewing a household, the researchers use cards representing various devices, the local microgrid, and the state-run electricity grid. Members of the household together recall the order in which they acquired their energy sources and lay down cards accordingly. At each decision point, the researchers ask why they made that choice.

To expedite the spread of solar technologies, such organizations need to understand the barriers and incentives for households to adopt them. Scholars have assumed that as household income increases, people will adopt newer, "higher-order" technologies and abandon older, "lower-order ones," such as those that burn fossil fuels. But there's clear evidence that in remote places people don't easily abandon the energy sources they have—including their kerosene lanterns.

What motivates people in remote communities to decide to buy and use a particular energy source? What encourages them to choose a certain solar lantern? And why do they then hang onto some of their older devices after acquiring new sources such as a microgrid or even access to the state-run electric grid?

Three years ago, David Hsu, an associate professor of urban and environmental planning, and then-graduate student Elise Harrington PhD '20, both of the Department of Urban Studies and Planning, decided to investigate those questions in remote villages in India. From preliminary work in the region, they knew that many households use a range of energy sources. If they were to figure out what had prompted a household to adopt and use particular technologies, they'd need to interview the whole decision-making group—a prospect they knew would be difficult. In the past, when Hsu and his colleagues knocked on doors to ask about interest in microgrid power, a crowd of villagers would quickly gather, the person with the highest status would respond, and everybody else would nod. For this study, he and Harrington needed to go into the home, determine what energy systems and appliances were present, and then get the family members to remember—together—how they had decided to purchase them and perhaps abandon previous systems.



Card-based protocol used in interviews The layout of cards shown here records what happened when people being interviewed in one household recalled making a series of decisions about their energy sources. "Primary sources" appear at the top of each column, "backup sources" are in the second row, and eliminated sources are in the third row. Each column represents the result of a decision that's been made. In this example, the household started with a kerosene lantern (green card). They next connected to the state-run grid (black) and retained their kerosene lantern for backup use. Then they added a solar lantern (red) as a second primary source, but it broke (crossed-out red card). Finally, they added a solar home system (orange) as their second primary source but retained their kerosene lantern for backup use. Photo: Ameya Athavankar

The first challenge would be to get in the door. "There are many different social norms that govern access to private spaces," says Harrington. "But as a woman, I was allowed into interior living spaces. So I got to see firsthand the appliances and lights and so on that were installed or in use." In addition, she had learned to speak some basic Hindi so she could introduce herself, refer to appliances, and ask basic questions.

The second challenge was to get the group to remember decisions made in the past and what had motivated them—a process that could be both tedious and confusing. For help, the researchers engaged Ameya Athavankar of twobythree, a company based in Mumbai, India, that specializes in creating techniques using elements of game-playing for applications ranging from building and product design to marketing research. Athavankar quickly became an integral member of the research team, working to explore and test possible game formats and field protocols, helping to communicate in both Hindi and the local dialect, and leading the interviews.

Game-playing reveals choices

The United Nations recognizes six steps, or "tiers," in the transition from having no electricity to being able to run high-power appliances. In their work, Hsu and Harrington decided to focus on the transition from no access to focused task lighting plus phone charging (tier 1), and then the move to general lighting, phone charging, and appliance use (tier 2). "Going from just kerosene to having electricity that provides you with basic lighting and charging can be a really transformative step for households," says Harrington.

In consultation with a local microgrid company and an NGO with a local office, the researchers selected three villages in the Gumla District of Jharkhand, India, for their study. Two of the villages—Bartoli and Neech Kobja—had access to the state-run electricity grid. The third village—Ramda Bhinjpur—had access to a private microgrid but not to the state grid. Within those three villages, the team selected a total of 22 households that represented a range of experience with solar technologies and fuels used for basic household lighting and charging.

The photo on page 6 shows the result of using the researchers' game-based protocol in one interview. In the game, colored playing cards represent five energy sources for lighting: a kerosene lantern, a solar lantern, an SHS, a microgrid, and the state grid. The layout of cards here shows the respondents' choices at a series of decision points, moving in time from left to right. Each column shows the result of one decision, with cards in the top row representing "primary sources," cards in the second row "backup sources," and cards in the third row sources that have been eliminated for lighting use.

In this interview, respondents started with a kerosene lantern (green card)—the initial lighting source in most households. Next they added a black card representing the state-run grid in the top position and moved the kerosene lantern down a row, indicating that they retained it in their household "stack" of energy sources but used it less. They then added a solar lantern (red), using it in tandem with the state grid such that both were primary sources. The solar lantern then broke—as indicated by the red card with the crossed-out image. Finally, they added a solar home system (orange) that they used along with the state grid, while retaining their kerosene lantern.

Purchase and use patterns

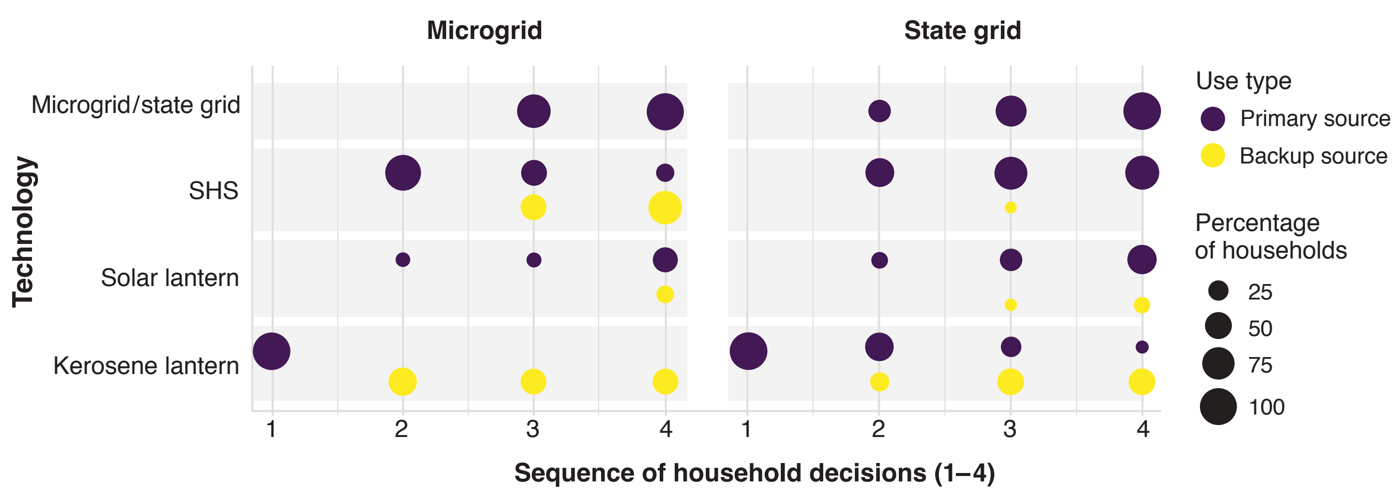
Following the same protocol, the researchers performed interviews at 22 households across the three villages. They then added up the sources cited as primary and as backup at each decision point across two groups: at microgrid households and at households connected to the state grid. Their results appear in the figure below.

The two groups show some marked differences in behavior, beginning with their move away from their kerosene lanterns. As the figure shows, the microgrid households moved kerosene lanterns to backup as soon as they had other options available, whereas the state grid group continued to use their kerosene lanterns, only gradually shifting them to a backup position.

Households in both groups adopted solar lanterns, and many continued to use them as a primary source even after being hooked up to a microgrid or the state grid. One reason cited was that solar lanterns can provide lighting for outdoor activities after dark. Perhaps more important, a government program was providing discounted solar lanterns through schools in all three villages.

SHSs were also adopted by both groups. Indeed, many in the microgrid group went directly to an SHS, essentially leapfrogging over the solar lantern option. Once the two groups got grid access, their treatment of their SHSs differed: The microgrid households soon moved much of their SHS use into a backup position, while the state grid households continued to use their SHS as a primary source.

The researchers stress that these interviews offer insight into household use patterns for solar power: Although the sample may be small, it provides rich qualitative data for understanding household decisions. And they did observe some interesting trends. For example, when households connected to a microgrid, they often shifted their existing sources to a backup position, using them on occasion to help defray the cost of the microgrid.



Energy sources and uses This figure shows the results of decisions made at four points in time by nine households on a microgrid (left panel) and 13 households on the state-run power grid (right panel). The size of each circle shows the percentage of households that chose that energy source. A purple circle indicates that a technology was used as a primary energy source; a yellow circle indicates that it was used as a backup.

In contrast, households that got access to the state-run grid frequently added both a solar lantern and an SHS, and continued to use them—even increasing their use over time. Moreover, they kept using their kerosene lanterns, only gradually moving them into a backup position. The state grid is notoriously unreliable, so people need to maintain good alternatives for use during blackouts.

Explaining the choices

To delve deeper into what influences technology choice, the researchers asked at each decision point why changes had been made. Using a second set of cards, they asked respondents about the possible importance of five factors: awareness, availability and access, capacity, unit pricing, and quality. (See the list on this page for further explanation.)

As the table on page 9 shows, the adoption of every energy technology—but especially the SHS and microgrid—was intended to increase system capacity to meet more end uses, including additional appliances. People cited pricing and payment options as influencing their decisions to acquire solar lanterns and SHSs. Decisions to connect to the state grid were totally dependent on access, whereas decisions to connect to a solar microgrid were more heavily influenced by awareness of the technology.

Notably, failures in the quality of higher-order sources often influenced the retention of lower-order sources. Fully 90% of respondents mentioned capacity as influencing their decision to retain their SHS, citing its ability to provide brighter light and greater coverage than other sources. Solar lanterns were retained for their portability and ability to provide better-quality light for studying and other indoor activities. Most households retained kerosene and solar lanterns as well as SHSs to provide coverage during state grid or microgrid outages.

Factors influencing household decisions to adopt, retain, or eliminate energy sources

Awareness — knowledge of a product or service from experience, peer influence, dealer suggestion, an NGO program, or a government campaign

Availability and access — access to a product and to services, including maintenance and repairs

Capacity — ability of a system to meet household needs, for example, to run appliances, to improve lighting quality or portability, or to run previously purchased appliances

Unit pricing — affordability, financing

Quality — experiences with or information about quality standards, reliability, or performance failures

The researchers cite several responses as unexpected. For example, when purchasing an SHS, respondents were initially interested in financing—until they learned about the interest rate and the monthly payments. In general, respondents said that they preferred to make cash payments all at once because their household income varies with the season. Interestingly, other areas of the world with growing off-grid solar markets often have strong programs of pay-as-you-go financing for solar products.

Even more surprising to Harrington was finding that the people interviewed typically paid little attention to warranties or quality labels when making purchases. "There are important efforts in India, and internationally, that focus on setting technical quality standards and providing labeling and certification to communicate those quality standards to consumers," she says. "But we found that what matters to people is their personal relationship with a shop owner or with the person or organization that introduces them to a solar product."

Powering appliances

Finally, the researchers looked at what appliances and activities people supported with an SHS, microgrid, and grid. They grouped households into three categories by income and compared end uses across those three electricity sources.

For the high- and middle-income groups, an SHS permitted the use of high-watt devices such as fans, televisions, and laptop computers along with mobile phones and lights. Connection to either the state grid or a microgrid enabled those income groups to undertake income-generating enterprises such as operating a convenience store or running an electronics repair shop. That finding is notable because many aid organizations and microgrid operators emphasize the importance of enabling productive activities when providing electricity to underserved populations.

For the lowest income group, an SHS made possible the first move in electricity access—getting mobile phones and lights. But once on the state-run grid, even some of the most financially constrained households could run televisions and fans as well. "For all the discussion about the challenges with grid reliability and quality, you also see this amazing opportunity that the grid provides to those in our study with the lowest income," says Harrington.

	Adoption factors					Retention factors			
	Access	Awareness	Capacity	Pricing	Quality	Access	Capacity	Pricing	Quality
Kerosene lantern						41%	77%		36%
Solar lantern	18%	35%	41%	88%	6%	24%	59%		24%
SHS	25%	60%	70%	75%	20%	40%	90%	30%	55%
Microgrid		78%	67%						
Grid	100%		46%						

Factors that influenced adoption or retention of each technology
This table indicates the percentage of households that mentioned each factor as influential in their adoption (left panel) or retention (right panel) of each energy source. Not all households adopted every technology; only households that reported purchasing and using each source are included in the calculation.

Policy implications and plans

The researchers' findings demonstrate the value of introducing SHSs and solar lanterns to provide basic lighting and charging capability before the grid is available. In some cases, supporting adoption of those technologies is the most cost-effective approach to spreading electrification, at least in the short term.

The study also shows that people tend to buy solar devices and services in response to interactions with those whom they trust. In one case, a village decided to participate in a microgrid after an NGO well-known to the community organized a trip to see a microgrid in another village. More such efforts at consumer education and engagement may be needed to support off-grid solar.

Finally, the research confirms the value of the card-based interview technique for data collection and subsequent analysis. Taking a photograph of the laid-out cards at the end of each interview proved important to remembering and then analyzing the timeline and key factors influencing the decisions made at each step. "If we had just done interviews and transcriptions, I don't think we ever would have made sense of what people's decision process was," says Hsu. "People don't always remember the sequence or rationale for their energy adoption choices until you give them a way to record their experience."

Ameya Athavankar of twobythree (left) leads an interview with members of a household while Elise Harrington PhD '20 takes notes. At the end of the interview, the layout of the cards on the floor recorded the household's energy-related decisions over many years. Photo: David Hsu, MIT

The researchers also see another potential application of the technique. Setting up a microgrid to provide different levels of service to households in a village requires a high degree of collective decision making. Perhaps a version of their card-playing interview technique could support that decision making, ensuring that every household is heard and gets what it needs from the proposed microgrid.

NOTES

This research was supported by MIT's Tata Center for Technology and Design, which is part of the MIT Energy Initiative (MITEI).

In autumn 2020, Elise Harrington PhD '20 became an assistant professor at the University of Minnesota's Humphrey School of Public Affairs. David Hsu is an associate professor in MIT's Department of Urban Studies and Planning and a member of MITEI's Energy Minor Oversight Committee. Further information on this and related research can be found in:

E. Harrington, A. Athavankar, and D. Hsu. "Variation in rural household energy transitions for basic lighting in India." *Renewable and Sustainable Energy Reviews*, vol. 119, March 2020. Online: doi.org/10.1016/j.rser.2019.109568.

E. Harrington. *Intermediaries and Electrification: Dimensions of Trust and Consumer Education in Kenya's Off-Grid Solar Market*. PhD thesis, Department of Urban Studies and Planning, 2020. Online: dspace.mit.edu/handle/1721.1/127615.

China's transition to electric vehicles

Benefits will come, but at what cost?

Nancy W. Stauffer, MITEI

IN BRIEF

Recently, China imposed a mandate on automakers requiring that electric vehicles (EVs) make up 40% of all sales by 2030. According to a series of MIT analyses, this move will expand the production of EVs and EV batteries enough to bring down the worldwide cost of both. Within China, annual sales of all vehicles will drop temporarily and then resume growing. The market share of EVs will expand as mandated, but many models will remain more expensive than their gasoline-powered counterparts. Between 2021 and 2030, the transition cost to China's society could equal 0.1% of the nation's growing gross domestic product every year. In a follow-on study, the researchers are finding that the benefits of the mandated move to EVs—for air pollution, human health, climate change, and national security—may be large enough to offset the cost.

In recent decades, China's rapid economic growth has enabled more and more consumers to buy their own cars. The result has been improved mobility and the largest automotive market in the world—but also serious urban air pollution, high greenhouse gas emissions, and growing dependence on oil imports.

To counteract those troubling trends, the Chinese government has imposed policies to encourage the adoption of plug-in electric vehicles (EVs). Since buying an EV costs more than buying a conventional internal combustion engine (ICE) vehicle, in 2009 the government began

Above By 2030, fully 40% of all vehicles sold in China will be electric. That government-mandated target will bring cleaner air, improved public health, and more. But an MIT study has found that the cost to individual consumers and to the society as a whole will be substantial. Photo: Chuttersnap/Unsplash to provide generous subsidies for EV purchases. But the price differential and the number of buyers were both large, so paying for the subsidies became extremely costly for the government.

As a result, China's policy makers will phase out the subsidies by the end of 2020 and instead rely on a mandate imposed on car manufacturers. Simply stated, the mandate requires that a certain percent of all vehicles sold by a manufacturer each year must be battery-powered. To avoid financial penalties, every year manufacturers must earn a stipulated number of points, which are awarded for each EV produced based on a complex formula that takes into account range, energy efficiency, performance, and more. The requirements get tougher over time, with a goal of having EVs make up 40% of all car sales by 2030.

This move will have a huge impact on the worldwide manufacture of EVs, according to William H. Green, the Hoyt C. Hottel Professor in Chemical Engineering. "This is one of the strongest mandates for electric cars worldwide, and it's being imposed on the largest car market in the world," he says. "There will be a gigantic increase in the manufacture of EVs and in the production of batteries for them, driving down the cost of both globally."

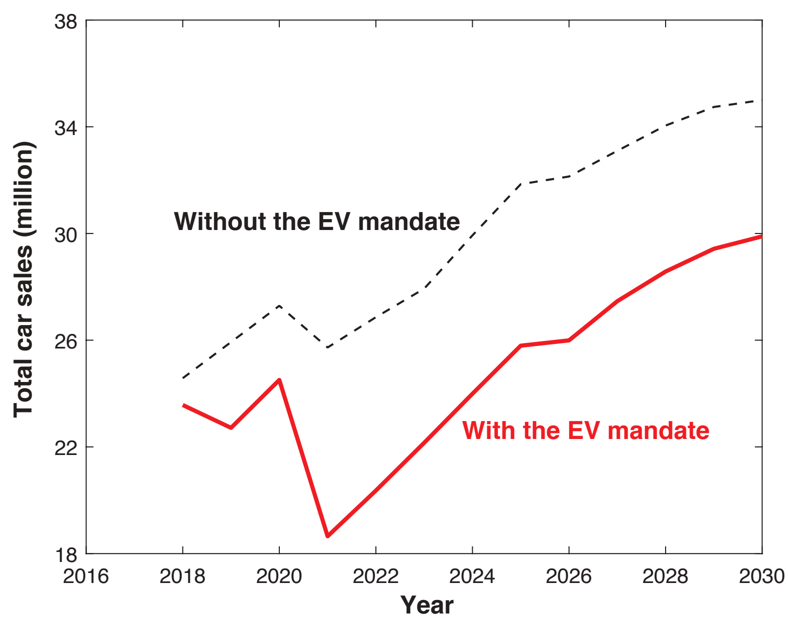
But what will be the impact of the mandate within China? The transition to EVs will bring many environmental and other benefits. But how much will it cost the nation? In 2016, chemical engineering colleagues Green and then-graduate student I-Yun Lisa Hsieh PhD '20 decided to find out. Their goal was to examine the mixed impacts of the mandate on all affected factors: battery prices, manufacturing costs, vehicle prices and sales, and the cost to the consumer of owning and operating a car. Based on their results, they could estimate the total societal cost of complying with the mandate in the coming decade.

Looking at battery prices

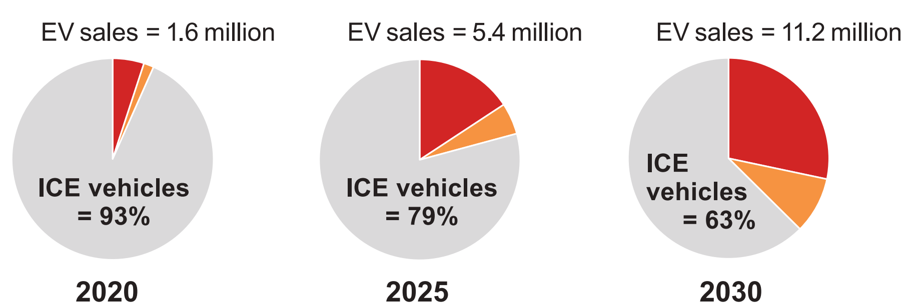
"The main reason why EVs are costly is that their batteries are expensive," says Green. In recent years, battery prices have dropped rapidly, largely due to the "learning effect": As production volumes increase, manufacturers find ways to improve efficiency, and costs go down. It's generally assumed that battery prices will continue to decrease as EVs take over more of the car market.

Using a new modeling approach, Green and Hsieh determined that learning effects will lower costs appreciably for battery production but not much for the mining and synthesis of critical battery materials. They concluded that the price of the most widely used EV battery technology—the lithium-ion nickel-manganese-cobalt battery—will indeed drop as more are manufactured. But the decline will slow as the price gets closer to the cost of the raw materials in it.

Using the resulting estimates of battery price, the researchers calculated the extra cost of manufacturing an EV over time and—assuming a standard markup for



Projected car sales in China without and with the electric vehicle (EV) mandate The black dashed curve shows projected car sales assuming no EV mandate. The decline in 2021 is due to new emissions and fuel economy standards adopted in 2020. The solid red curve shows projected car sales with the mandate. Total car sales drop in 2021 due to the elimination of EV subsidies and then grow again as consumer incomes rise.



Makeup of projected vehicle sales at three points in time on the red curve above These pie charts show the split in projected sales among the three vehicle types: ICE vehicles (gray), hybrid EVs (orange), and pure battery EVs (red). The total number of EVs sold is indicated for each year.

profit—determined the likely selling price for those cars. In previous work, the researchers had used a variety of data sources and analytical techniques to determine "affordability" for the Chinese population, in other words, the fraction of their income available to spend on buying a car. Based on those findings, they examined the expected impact on car sales in China between 2018 and 2030.

Their results are shown in the top figure on page 11. As a baseline for comparison, the researchers first assumed a "counter-factual" (not true-to-life) scenario—here, car sales without significant adoption of EVs, so without the new mandate. As the dashed black curve shows, under that assumption, annual projected car sales climb to more than 34 million by 2030. (The drop in 2021 is a response to higher prices due to new emissions and fuel economy standards in 2020.)

The solid red curve shows what happens when the subsidy on EV purchases is eliminated and the mandate is enacted in 2020. Total car sales shrink in 2021 after the subsidies are eliminated. But thereafter, the growing economy and rising incomes increase consumer purchasing power and drive up the demand for private car ownership. Annual sales are on average 20% lower than in the counterfactual scenario, but they're projected to reach about 30 million by 2030.

The pie charts on the bottom of page 11 show the breakdown in projected sales between ICE vehicles and battery EVs at three points in time. In 2020, EVs make up just 7% of the total (1.6 million vehicles). By 2025, that share is up to 21% (5.4 million). And by 2030, it's up to 37% (11.2 million)—close to the government's 40% target. Altogether, 66 million EVs are sold between 2020 and 2030.

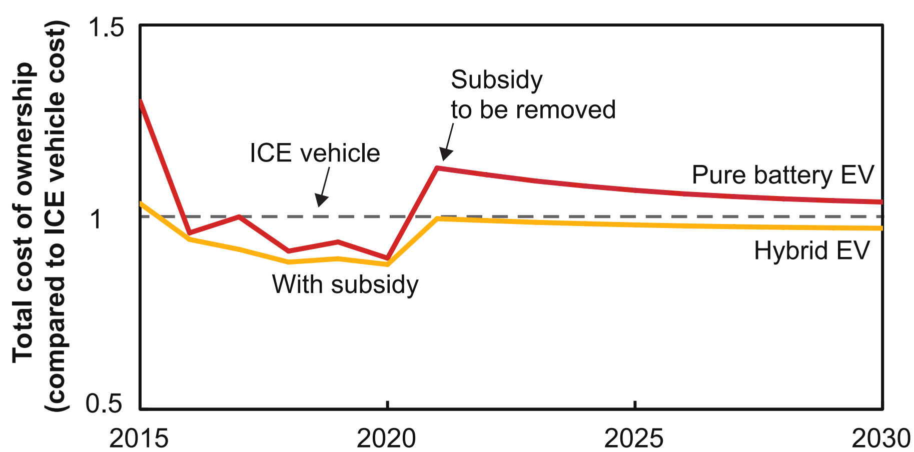
Two types of plug-in EVs are indicated by color: Red represents pure battery EVs, and orange represents hybrid EVs (which are powered by both batteries and gasoline). About twice as many pure battery EVs are sold than hybrid EVs, even though the former are more expensive due to the higher cost of their batteries. "The mandate includes a special preference for cars with a longer range, which means cars with large batteries," says Green. "So carmakers have a big incentive to manufacture the pure battery EVs and be awarded extra points under the mandate formula."

For the consumer, the added cost of owning an EV includes any difference in vehicle expenses over the whole lifetime of the car. To calculate that difference, the researchers quantified the "total cost of ownership," or TCO, including the purchase cost, fuel cost, and operating and maintenance costs (including insurance) of their two plug-in EVs and an ICE vehicle out to 2030. The figure below shows how the costs of the pure battery EV and the hybrid EV compare to the cost of an ICE vehicle. The horizontal rule at 1 indicates that the costs are the same, so "at parity."

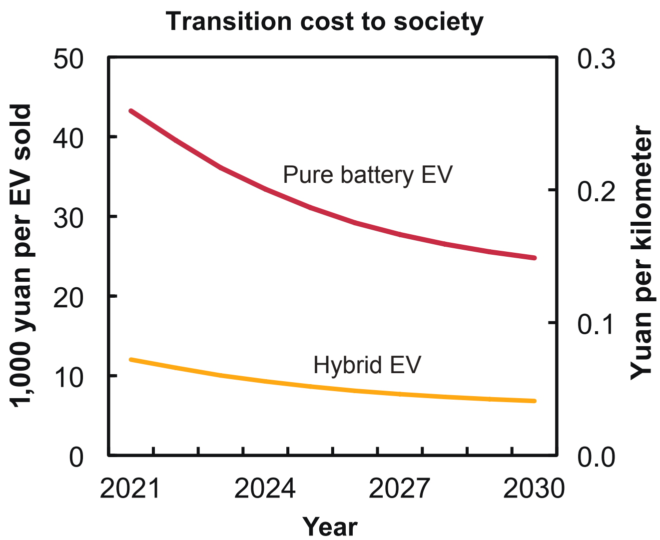
From 2016 to 2020, both types of EVs benefit from the electric vehicle subsidy, so the TCO of each is less than that of an ICE vehicle. Substantial cuts in the pure battery EV subsidy in 2017 and 2019 cause the two rises in that curve, and the total elimination of the subsidies causes a major uptick in both EV curves in 2020. TCO parity remains for the hybrid EV out to 2030, but parity isn't achieved for the pure battery EV even by 2030, though it gets closer due to the expected decline in battery prices.

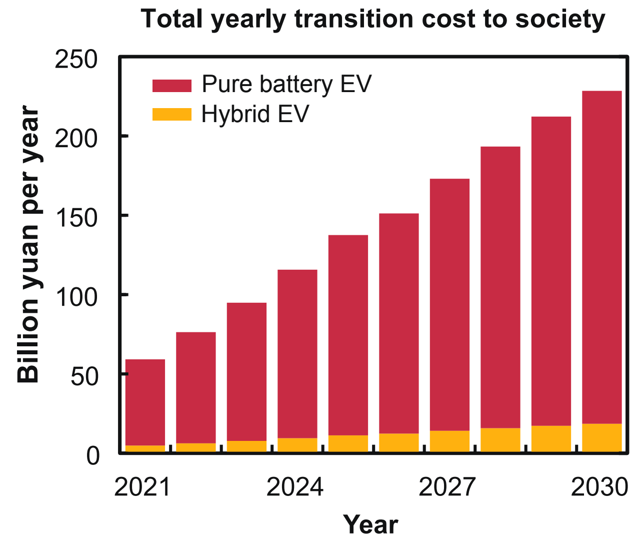
Cost to society

The next step for the researchers was to calculate the total cost to China of forcing the adoption of EVs. The basic approach is straightforward: The researchers take the extra TCO for each EV sold in each year, discount that cost to its present value, and multiply the resulting figure by the number of cars sold in that year. (They exclude taxes embedded in the purchase prices of the vehicle, of electricity and gasoline, and so on, as the society will have to pay other taxes to replace that lost revenue.)



Total cost in China of owning an EV compared to an ICE vehicle over the lifetime of the car Before 2020, owning either type of plug-in EV is less costly than owning an ICE vehicle due to the subsidy paid on EV purchases. After the subsidy is removed and the mandate imposed in 2020, owning a hybrid EV (orange curve) is comparable to owning an ICE vehicle. Owning a pure battery EV (red curve) is more expensive due to its high-cost batteries. Dropping battery prices reduces total ownership cost for both types of EVs, but the pure battery EV remains more expensive out to 2030.





Transition cost to society
Left: The per-vehicle incremental cost of owning and driving an EV decreases from 2021 to 2030. The cost declines more for pure battery EVs than for hybrid EVs, but the former remain more costly. **Right:** Each bar represents the total cost of transitioning to EVs in a single year. The red represents pure battery EVs and the orange, hybrid EVs. The total number of EVs sold in a year more than offsets any decrease in per-vehicle cost, so the incremental cost to society grows.

Their results appear above. The left-hand figure shows the incremental cost to society of each EV sold in a given year (left axis) and the extra cost per kilometer driven (right axis). The cost assumes that the vehicle has a lifetime of 12 years and is driven 12,500 kilometers each year. Again, the pure battery EV curve is higher than the hybrid EV curve, and both decline over time as battery costs decrease.

The right-hand figure combines that per-car cost to society with the number of cars sold, revealing the total extra cost incurred. Each bar represents a single year, and the red represents pure battery EVs, the orange, hybrid EVs. The chart shows that the number of EVs sold annually will increase faster than the cost per vehicle will drop, so the annual incremental cost to society will keep growing. And the cost is sizeable. On average, the transition to EVs forced by the mandate will cost 100 billion yuan per year from 2021 to 2030, which is about 2% of the nationwide expenditure in the transport sector every year.

During the 10 years from 2021 to 2030, the annual societal cost of the transition to almost 40% EVs is equivalent to about 0.1% of China's growing gross domestic product. "So the cost to society of forcing the sale of EVs in place of ICE vehicles is significant," says Hsieh. "People will have far less money in their pockets to spend on other purchases."

Other considerations

Green and Hsieh stress that the high societal cost of the forced EV adoption must be considered in light of the potential benefits to be gained. For example, switching from ICE vehicles to EVs will lower air pollution and associated health costs; reduce carbon dioxide emissions to help mitigate climate change; and reduce reliance on imported petroleum, enhancing the country's national energy security and balance of payments.

Hsieh is now working to quantify those benefits so that the team can perform a proper cost-benefit analysis of China's transition to EVs. Her initial results suggest that the monetized benefits are—like the costs—substantial. "The benefits appear to be the same order of magnitude as the costs," she says. "It's so close that we need to be careful to get the numbers right."

The researchers cite two other factors that may impact the cost side of the equation. In early 2018, six Chinese megacities with high air pollution began restricting the number of license plates issued for ICE vehicles and charging high fees for them. With their lower-cost, more-abundant "green car plates," EVs became cost-competitive, and sales soared. To protect Chinese carmakers, the national government recently announced that it plans to end those restrictions. The outcome and its impacts on EV sales remain uncertain.

The second caveat concerns how carmakers price their vehicles. The results reported here assume that prices are calculated as they are today: the cost of manufacturing the vehicle plus a certain percentage markup for profit. With the new mandate in place, automakers will need to change their pricing strategy so as to persuade enough buyers to purchase EVs to reach the required fraction. "We don't know what they're going to do, but one possibility is that they'll lower the price of their battery cars and raise the price of their gasoline cars," says Green. "That way, they can still make their profits while operating within the law." As an example, he cites how U.S. carmakers responded to Corporate Average Fuel Economy standards by adjusting the relative prices of their low- and high-efficiency vehicles.

While such a change in Chinese automakers' pricing strategy would lower the price of EVs, it would also push up average car prices overall, because the total car sales mix is dominated by ICE vehicles. "Some people in China who would otherwise be able to afford a cheap gasoline car now won't be able to afford it," says Hsieh. "They'll be priced out of the market."

Green emphasizes the impact of the mandate on all carmakers worldwide. "I can't overstate how hugely important this is," he says. "As soon as the mandate came out, carmakers realized that electric vehicles had become a major market rather than a niche market on the side." And he believes that even without subsidies, the added expense of buying an EV won't be prohibitive for many car buyers—especially in light of the benefits they offer.

However, he does have a final concern. As more and more EVs are manufactured, global supplies of critical battery materials will become increasingly limited. At the same time, however, the supply of spent batteries will increase, creating an opportunity to recycle critical materials for use in new batteries and simultaneously prevent environmental threats from their disposal. The researchers recommend that policy makers "help to integrate the entire industry chain among automakers, battery producers, used-car dealers, and scrap companies in battery recycling systems to achieve a more sustainable society."

NOTES

This research was supported through the MIT Energy Initiative's Mobility of the Future study. William H. Green is co-director of MITEI's Mobility Systems Center. In autumn 2020, I-Yun Lisa Hsieh PhD '20 joined the faculty of the National Taiwan University as an assistant professor. More information about this research can be found in:

I-Y.L. Hsieh and W.H. Green. "Transition to electric vehicles in China: Implications for total cost of ownership and cost to society." *SAE International Journal of Sustainable Transportation, Energy, Environment, & Policy*, 2020. Online: doi.org/10.4271/13-01-02-0005.

I-Y.L. Hsieh, P.N. Kishimoto, and W.H. Green. "Incorporating multiple uncertainties into projections of Chinese private car sales and stock." *Transportation Research Record*, 2018. Online: doi.org/10.1177/0361198118791361.

I-Y.L. Hsieh, M.S. Pan, Y.-M. Chiang, and W.H. Green. "Learning only buys you so much: Practical limits on battery price reduction." *Applied Energy*, no. 239, pp. 218–224, 2019. Online: doi.org/10.1016/j.apenergy.2019.01.138.

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Building nuclear power plants
Why do costs exceed projections?

Nancy W. Stauffer, MITEI

IN BRIEF

An MIT team has revealed why, in the field of nuclear power, experience with a given technology doesn't always lower costs. When it comes to building a nuclear power plant in the United States—even of a well-known design—the total bill is often three times as high as expected. Using a new analytical approach, the researchers delved into the cost overrun from non-hardware-related activities such as engineering services and labor supervision. Tightening safety regulations were responsible for some of the cost increase, but declining labor productivity also played a significant role. Analyses of possible cost-reduction strategies show potential gains from technology development to reduce materials use and to automate some construction tasks. Cost overruns continue to be left out of nuclear industry projections and overlooked in the design process in the United States, but the researchers' approach could help solve those problems. Their new tool should prove valuable to design engineers, developers, and investors in any field with demanding and changeable regulatory and site-specific requirements.

Nuclear power is frequently cited as a critical component in the portfolio of technologies aimed at reducing greenhouse gas emissions. But rising construction costs and project delays have hampered efforts to expand nuclear capacity in the United States since the 1970s. At plants begun after 1970, the average cost of construction has typically been far higher than the initial cost estimate.

Nevertheless, the nuclear industry, government, and research agencies continue to forecast cost reductions in nuclear plant construction. A key assumption in such projections is that

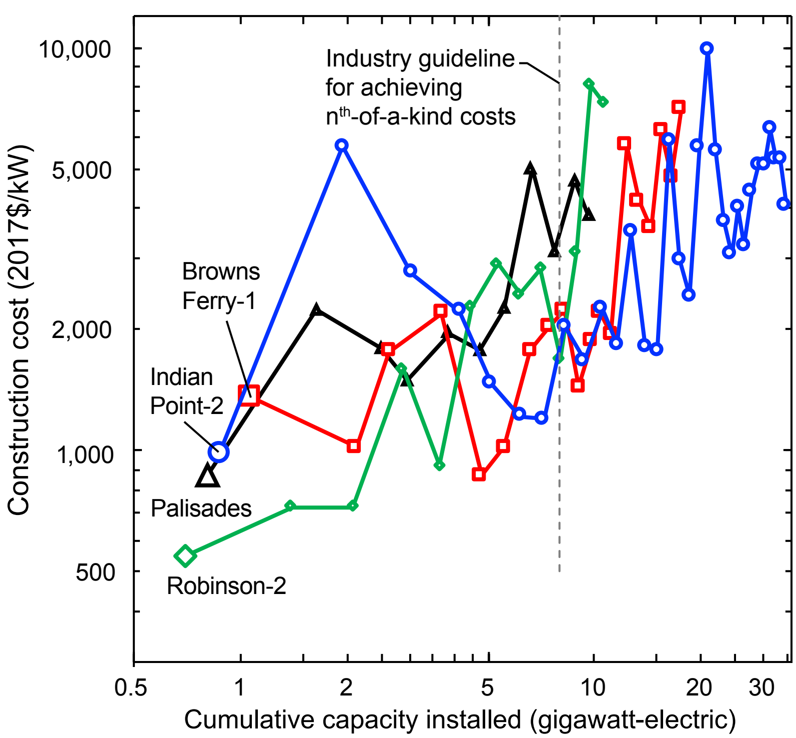
Above For decades, the cost of building a nuclear power plant in the United States has been far higher than projected—one factor that has limited the expansion of this carbon-free electricity source. MIT researchers have developed tools that industry personnel can use to improve their cost projections and to predict how design changes will affect overall costs. Photo courtesy of Georgia Power costs will decline as the industry gains experience with a given reactor design. "It's often included in models, with huge impacts on the outcomes of projected energy supply mixes," says Jessika E. Trancik, an associate professor of energy studies in the MIT Institute for Data, Systems, and Society (IDSS).

That expectation is based on an assumption typically expressed in terms of the "learning rate" for a given technology, which represents the percent cost reduction associated with a doubling of cumulative production. Nuclear industry cost-estimating guidelines as well as widely used climate models and global energy scenarios often rely on learning rates that significantly reduce costs as installed nuclear capacity increases. Yet empirical evidence shows that in the case of nuclear plants, learning rates are negative. Costs just keep rising.

To investigate, Trancik and her team—co-first authors Philip Eash-Gates SM '19 and IDSS postdoc Magdalena M. Klemun PhD '19; IDSS postdoc Gökşin Kavlak; former IDSS research scientist James McNerney; and TEPCO Professor of Nuclear Science and Engineering Jacopo Buongiorno—began by looking at industry data on the cost of construction (excluding financing costs) over five decades from 107 nuclear plants across the United States. They estimated a negative learning rate consistent with a doubling of construction costs with each doubling of cumulative U.S. capacity.

That result is based on average costs across nuclear plants of all types. One explanation is that the rise in average costs hides trends of decreasing costs in particular reactor designs. So the researchers examined the cost trajectories of four standard plant designs installed in the United States that reached a cumulative built capacity of 8 gigawatts-electric. Their results appear in the figure on this page. They found that construction costs for each of the four designs rose as more plants were built. In fact, the first one built was the least expensive in three of the four cases and was among the least expensive plants in the fourth.

"We've confirmed that costs have risen even for plants of the same design class," says Trancik. "That outcome defies engineering expectations." She notes that a common view is that more stringent safety regulations have increased the cost of nuclear power plant construction. But is that the full explanation, or are other factors at work as well?



U.S. nuclear plant construction costs for four standard plant designs A common assumption is that the "first-of-a-kind" plant will be the most expensive and that learning over time will begin to decrease the cost by the "nth-of-a-kind" plant. These curves show the costs (excluding financing) for individual plants of four designs that reached a cumulative built capacity of 8 gigawatts-electric (indicated by the vertical dashed line), a threshold at which industry cost guidelines expect plants to realize cost reductions. The first marker in each series shows the cost of the first plant that was built with that design.

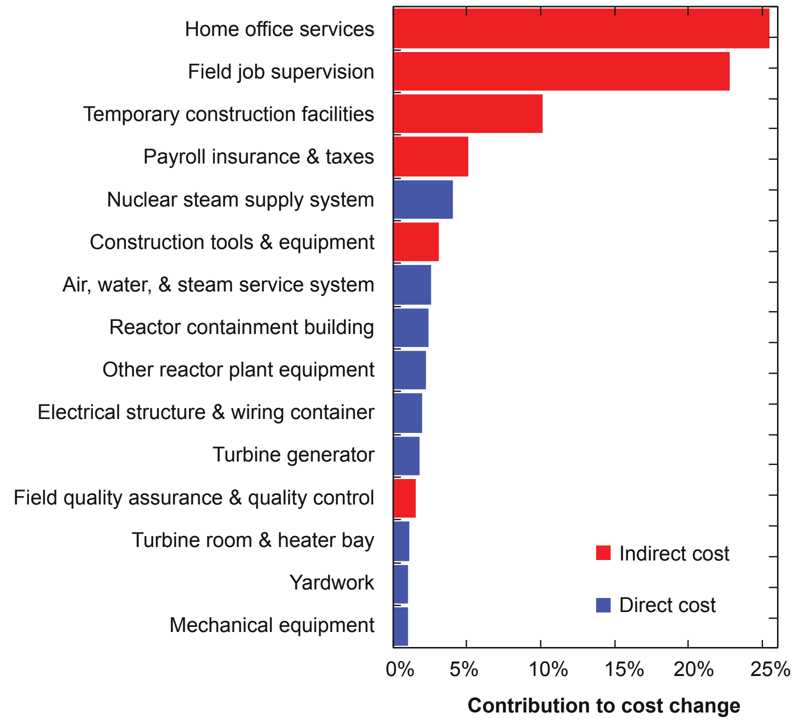
Source of increasing cost

To find out, the researchers examined cost data from 1976 to 1987 in the U.S. Department of Energy's Energy Economic Data Base. (After 1987 the DOE database was no longer updated.) They looked at the contributions to overall cost increases of 61 "cost accounts" representing individual plant components and the services needed to install them.

They found that the overall trend was an increase in costs. Many accounts contribute to the total cost escalation, so the researchers couldn't easily identify one source. But they could group the accounts into two categories: direct costs and indirect costs. Direct costs are costs of materials and labor needed for physical components such as reactor equipment and control and monitoring systems. Indirect costs are construction support activities such as engineering, administration, and construction supervision. The figure on the facing page shows their results.

The researchers concluded that between 1976 and 1987, indirect costs—those external to hardware—caused 72% of the cost increase. "Most aren't hardware-related but rather are what we call soft costs," says Trancik. "Examples include rising expenditures on engineering services, on-site job supervision, and temporary construction facilities."

To determine which aspects of the technology were most responsible for the rise in indirect expenses, they delved further into the DOE dataset and attributed the indirect expenses to the specific plant components that incurred them. The analysis revealed that three components were most influential in causing the indirect cost change: the nuclear steam supply system, the turbine generator, and the containment building. All three also contributed heavily to the direct cost increase.



Changes in nuclear plant costs, 1976 to 1987
This figure shows sources of cost change from 1976 to 1987, divided into indirect costs (red) and direct costs (blue). Direct costs relate to physical components and their installation, while indirect costs include support activities. Altogether, indirect costs made up 72% of the total change in cost during the period—yet most engineering models don't take into account such non-hardware-related factors.

A case study

For further insight, the researchers undertook a case study focusing on the containment building. This airtight, steel-and-concrete structure forms the outermost layer of a nuclear reactor and is designed to prevent the escape of radioactive materials as well as to protect the plant from aircraft impact, missile attack, and other threats. As such, it is one of the most expensive components and one with significant safety requirements.

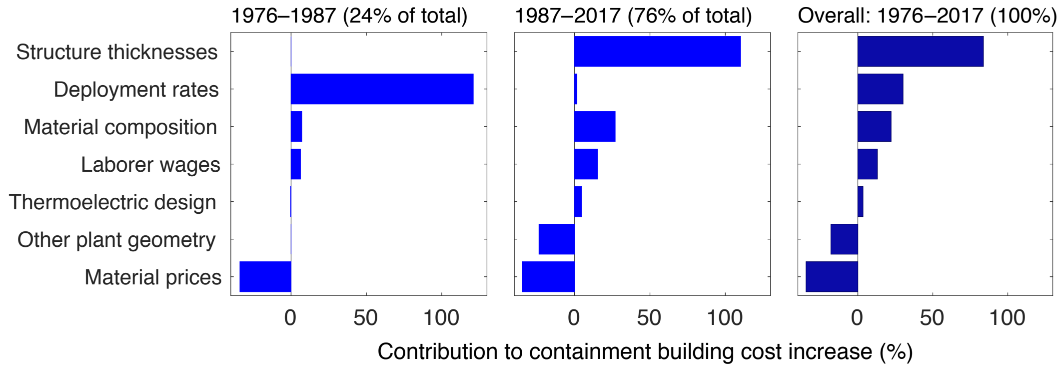
Based on historical and recent design drawings, the researchers extended their analysis from the 1976–1987 period to the year 2017. Data on indirect costs aren't available for 2017, so they focused on the direct cost of the containment building. Their goal was to break down cost changes into underlying engineering choices and productivity trends.

They began by developing a standard cost equation that could calculate the cost of the containment building based on a set of underlying variables—from wall thickness to laborer wages to the prices of materials. To track the effects of labor productivity trends on cost, they included variables representing steel and concrete "deployment rates," defined as the ratio of material volumes to the amount of labor (in person-hours) required to deploy them during construction.

A cost equation can be used to calculate how a change in one variable will affect overall cost. But when multiple variables are changing at the same time, adding up the individual impacts won't work because they interact. Trancik and her team therefore turned to a novel methodology they developed in 2018 to examine what caused the cost of solar photovoltaic modules to drop so much in recent decades. Based on their cost equation for the containment building and following their 2018 methodology, they derived a "cost change equation" that can quantify how a change in each variable contributes to the change in overall cost when the variables are all changing at once.

Their results, summarized in the right-hand panel of the figure on page 18, show that the major contributors to the rising cost of the containment building between 1976 and 2017 were changes in the thickness of the structure and in the materials deployment rates. Changes to other plant geometries and to prices of materials brought costs down but not enough to offset those increases.

As the left and center panels on page 18 show, the importance of those mechanisms changed over time. Between 1976 and 1987, the cost increase was caused primarily by declining deployment rates; in other words, productivity dropped. Between 1987 and 2017, the containment building was redesigned for passive cooling, reducing the need for operator intervention during emergencies. The new design required that the steel shell be approximately five times thicker in 2017 than it had been in 1987—a change that caused 80% of the cost increase over the 1976–2017 period.



Percentage contribution of variables to increases in containment building costs
These panels summarize types of variables that caused costs to increase between 1976 and 2017. In the first time period (left panel), the major contributor was a drop in the rate at which materials were deployed during construction. In the second period (middle panel), the containment building was redesigned for improved safety during possible emergencies, and the required increase in wall thickness pushed up costs. Overall, from 1976 to 2017 (right panel), the cost of a containment building more than doubled.

Overall, the researchers found that the cost of the reactor containment building more than doubled between 1976 and 2017. Most of that cost increase was due to increasing materials use and declining on-site labor productivity—not all of which could be clearly attributed to safety regulations. Labor productivity has been declining in the construction industry at large, but at nuclear plants it has dropped far more rapidly. "Material deployment rates at recent U.S. 'new builds' have been up to 13 times lower than those assumed by the industry for cost estimation purposes," says Trancik. "That disparity between projections and actual experience has contributed significantly to cost overruns."

Discussion so far has focused on what the researchers call "low-level mechanisms" of cost change—that is, cost change that arises from changes in the variables in their cost model, such as materials deployment rates and containment wall thickness. In many cases, those changes have been driven by "high-level mechanisms" such as human activities, strategies, regulations, and economies of scale.

The researchers identified four high-level mechanisms that could have driven the low-level changes. The first three are "R&D," which can lead to requirements for significant modifications to the containment building design and construction process; "process interference, safety," which includes the impacts of on-site safety-related personnel on the construction process; and "worsening despite doing," which refers to decreases in the performance of construction workers, possibly due to falling morale and other changes. The fourth mechanism—"other"—includes changes that originate outside the nuclear industry, such as wage or commodity price changes. Following their 2018 methodology, the team assigned each low-level cost increase to the high-level mechanism or set of mechanisms that caused it.

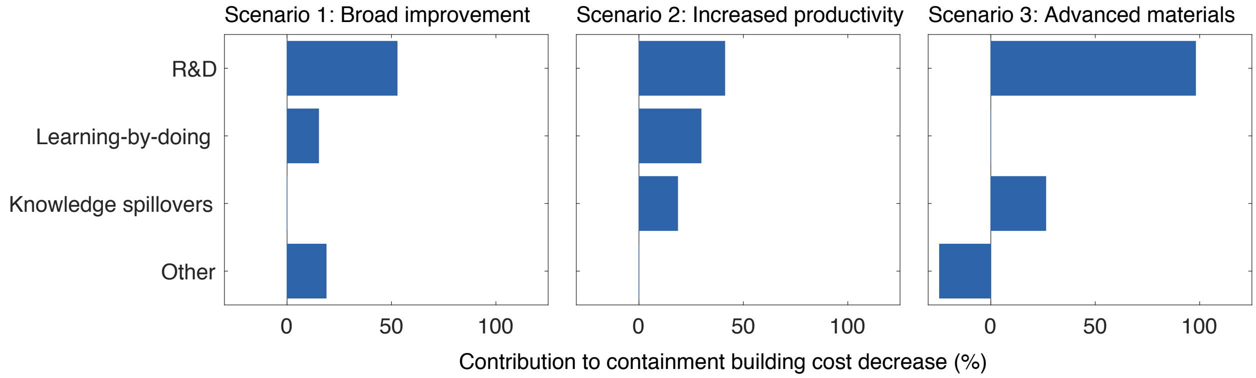
The analysis showed that R&D-related activities contributed roughly 30% to cost increases, and on-site procedural changes contributed roughly 70%. Safety-related mechanisms caused about half of the direct cost increase over the 1976 to 2017 period. If all the productivity decline were attributed to safety, then 90% of the overall cost increase could be linked to safety. But historical evidence points to the existence of construction management and worker morale issues that cannot be clearly linked to safety requirements.

Lessons for the future

The researchers next used their models in a prospective study of approaches that might help to reduce nuclear plant construction costs in the future. In particular, they examined whether the variables representing the low-level mechanisms at work in the past could be addressed through innovation. They looked at three scenarios, each of which assumes a set of changes to the variables in the cost model relative to their values in 2017.

In the first scenario, they assume that cost improvement occurs broadly. Specifically, all variables change by 20% in a cost-reducing direction. While they note that such across-the-board changes are meant to represent a hypothetical and not a realistic scenario, the analysis shows that reductions in the use of rebar (the steel bars in reinforced concrete) and in steelworker wages are most influential, together causing 40% of the overall reduction in direct costs.

In the second scenario, they assume that on-site productivity increases due to the adoption of advanced manufacturing and construction management techniques. Scenario 2 reduces costs by 34% relative



Decreases in containment building costs due to four high-level mechanisms under three innovation strategies Scenario 1 assumes a 20% improvement in all variables; Scenario 2 increases on-site material deployment rates by using advanced manufacturing and construction management techniques; and Scenario 3 involves use of advanced, high-strength construction materials. All three strategies would require significant R&D investment, but the importance of the other high-level mechanisms varies. For example, "learning-by-doing" is important in Scenario 2 because assumed improvements such as increased automation will require some on-site optimization of robot operation. In Scenario 3, the use of advanced materials is assumed to require changes in building design and workflows, but those changes can be planned off-site, so are assigned to R&D and "knowledge spillovers."

to estimated 2017 costs, primarily due to increased automation and improved management of construction activities, including automated concrete deployment and optimized rebar delivery. However, costs are still 30% above 1976 costs.

The third scenario focuses on advanced construction materials such as high-strength steel and ultra-high-performance concrete, which have been shown to reduce commodity use and improve on-site workflows. This scenario reduces cost by only 37% relative to 2017 levels, in part due to the high cost of the materials involved. And the cost is still higher than it was in 1976.

To figure out the high-level mechanisms that influenced those outcomes, the researchers again assigned the low-level mechanisms to high-level mechanisms, in this case including "learning-by-doing" as well as "knowledge spillovers," which accounts for the transfer of external innovations to the nuclear industry. As shown in the figure above, the importance of the mechanisms varies from scenario to scenario. But in all three, R&D would have to play a far more significant role in affecting costs than it has in the past.

Analysis of the scenarios suggests that technology development to reduce commodity usage and to automate construction could significantly reduce costs and increase resilience to changes in regulatory requirements and on-site conditions. But the results also demonstrate the challenges in any effort to reduce nuclear plant construction costs. The cost of materials is highly influential, yet it is one of the variables most constrained by safety standards, and—in general—materials-related cost reductions are limited by the large-scale dimensions and labor intensity of nuclear structures.

Nevertheless, there are reasons to be encouraged by the results of the analyses. They help explain the constant cost overruns in nuclear construction projects and also demonstrate new tools that engineers can use to predict how design changes will affect both hardware- and non-hardware-related costs in this and other technologies. In addition, the work has produced new insights into the process of technology development and innovation. "Using our approach, researchers can explore scenarios and new concepts, such as microreactors and small modular reactors," says Trancik. "And it may help in the engineering design of other technologies with demanding and changeable on-site construction and performance requirements." Finally, the new technique can help guide R&D investment to target areas that can deliver real-world cost reductions and further the development and deployment of various technologies, including nuclear power and others that can help in the transition to a low-carbon energy future.

NOTES

This research was supported by the David and Lucile Packard Foundation and the MIT Energy Initiative. Philip Eash-Gates SM '19 is now a senior associate at Synapse Energy Economics. James McNerney is a research associate in the Center for International Development at Harvard University. Further information about this research and the earlier study of photovoltaic technology can be found in:

P. Eash-Gates, M.M. Klemun, G. Kavlak, J. McNerney, J. Buongiorno, and J.E. Trancik. "Sources of cost overrun in nuclear power plant construction call for a new approach to engineering design." *Joule*, November 2020. Online: doi.org/10.1016/j.joule.2020.10.001.

G. Kavlak, J. McNerney, J.E. Trancik. "Evaluating the causes of cost reduction in photovoltaic modules." *Energy Policy*, vol. 123, pp. 700–710, 2018. Online: doi.org/10.1016/j.enpol.2018.08.015.

MIT Energy Initiative awards eight Seed Fund grants for early-stage energy research

Eight individuals and teams from MIT were recently awarded $150,000 grants through the MIT Energy Initiative (MITEI) Seed Fund Program to support promising novel energy research.

The highly competitive annual program received a total of 82 proposals from 88 researchers representing 17 departments, labs, and centers at MIT. The applications, which came from a range of disciplines, all aim to help advance a low-carbon energy system and address key climate challenges.

"The breadth of creative, interdisciplinary research proposals that we received truly reflects the Institute's increasing focus on curbing the effects of climate change," says MITEI Director Robert C. Armstrong, the Chevron Professor of Chemical Engineering. He noted that a large number of proposals focused on energy storage, signifying the central role that these technologies will play in deep decarbonization.

The winning projects will address topics ranging from hurricane-resilient smart grids and zero-emissions neighborhoods to new, low-cost batteries for grid-level energy storage.

Building hurricane-resilient smart grids

In 2017, Hurricane Maria left more than 1 million Puerto Ricans without power—many of whom did not have their electricity restored until months later. As stronger hurricanes become increasingly frequent, extreme weather is proving to be a critical and growing threat to electric power grids and energy infrastructure.

First-time Seed Fund awardees Kerry Emanuel and Saurabh Amin aim to develop a foundational design approach for building hurricane-resilient smart grids. They will combine their expertise in hurricane physics and power system control to develop new strategies that can greatly increase the resilience of power grids and allow for quicker restoration of service following disruptions.

"The goal is to reduce overall grid damage and avoid prolonged outages after storms by integrating strategic resource allocation and microgrid control strategies," says Emanuel, the Cecil and Ida Green Professor in the Department of Earth, Atmospheric and Planetary Sciences.

"Unlike a traditional centralized grid that depends on a reliable supply of bulk power, our design approach accounts for the uncertain failure rates of grid components due to hurricane winds and floods, and leverages the flexibility enabled by distributed energy resources such as reconfigurable microgrids, localized renewable energy, and storage devices," adds Amin, an associate professor in the Department of Civil and Environmental Engineering and a member of the Laboratory for Information and Decision Systems.

This interdisciplinary research holds promise for advancing the science of climate risk management and helping government agencies and energy utilities work together to develop flexible operational strategies in preparation for future storms.

Biological self-assembly to improve catalysis

According to Ariel Furst, an assistant professor in the Department of Chemical Engineering, 500 gigatons of carbon dioxide (CO_2) are expected to be produced from industrial processing and the burning of fossil fuels over the next five decades. An important way to reduce the carbon footprint of one of these main emitters—industrial processing—is to transform CO_2 into useful products.

The first step in this transformation process is to reduce CO_2 to carbon monoxide through a method such as

Electric power grids and energy infrastructure are becoming increasingly threatened as extreme weather events, such as hurricanes, occur with more frequency and strength. One of the eight novel energy research projects to recently win an MIT Energy Initiative Seed Fund award will address these challenges by developing an approach for building hurricane-resilient smart grids. Photo: Pixabay electrocatalysis. This reaction—in which a small-molecule catalyst interacts with an electrode—can often be imprecise and limited. With this in mind, Furst plans to use her Seed Fund grant to explore how the specific placement of the small-molecule catalysts affects catalytic efficiency in CO_2 reduction.

"We provide a unique perspective to this work by combining the inherent power of biology with these electrocatalytic transformations," says Furst, who is both a new MIT faculty member and a first-time Seed Fund grant winner.

She will use self-assembled nano-structures composed of deoxyribonucleic acids (DNA) to control the precise positioning of molecular catalysts on electrode surfaces. This research will allow her to evaluate spatial effects on catalytic efficiency, from which she can extrapolate design parameters that can be applied to other classes of catalysts in the future.

Rapid material design for solid-state batteries

Another first-time Seed Fund award team will use its grant to develop an automated synthetic process to speed up the discovery, design, and construction of new ceramic material components for solid-state lithium-ion batteries (SSBs), which have the potential to increase safety and energy efficiency as compared to more conventional liquid-electrolyte batteries.

One of the major challenges with implementing SSBs is the need for a high ceramic manufacturing temperature to make key components, resulting in an expensive, time-consuming synthesis that doesn't easily translate into industrially relevant manufacturing. Looking to overcome this obstacle, the team has identified the potential for a low-temperature process to synthesize the ceramic components.

The interdisciplinary team consists of a material ceramicist, Thomas Lord Associate Professor Jennifer Rupp of the Departments of Materials Science and Engineering (DMSE) and Electrical Engineering and Computer Science (EECS); an automation expert, Professor Wojciech Matusik of EECS; and a material informatics expert, Esther and Harold E. Edgerton Career Development Professor Elsa Olivetti of DMSE.

Leveraging its distinct expertise, the research team will work with students to couple machine learning techniques and automated synthesis to revise ceramic processing and enable rapid material screening, device design, and data analysis for performance engineering.

"This work has the potential to fundamentally alter the way research is conducted in the battery community," says Rupp. "The higher throughput pathway will allow more discoveries to be made in less time and will enable researchers to focus on altering battery design toward performance."

The MITEI Seed Fund Program has supported 185 early-stage energy research projects through a total of $24.9 million in grants since its establishment in 2008. This funding comes primarily from MITEI's founding and sustaining members, supplemented by gifts from generous donors.

Kelley Travers, MITEI

Recipients of MITEI Seed Fund grants, 2020

Building hurricane-resilient smart grids: Optimal resource allocation and microgrid operation
Kerry Emanuel
Department of Earth, Atmospheric and Planetary Sciences
Saurabh Amin
Department of Civil and Environmental Engineering

DNA nanostructure-immobilized electrocatalysts for improved CO_2 reduction efficiency
Ariel Furst
Department of Chemical Engineering

Enabling high-energy Li/Li-ion batteries through active interface repair
Betar Gallant
Department of Mechanical Engineering

Extremely low-cost aluminum-sulfur battery running below 100 degrees Celsius for grid-level energy storage
Donald Sadoway
Department of Materials Science and Engineering

Low-cost negative emissions from concentration swing absorption
Jeffrey Grossman
Department of Materials Science and Engineering

Rapid material discovery for solid-state batteries: Coupling low-cost processing with material screening and performance optimization using machine learning
Jennifer Rupp
Department of Materials Science and Engineering
Department of Electrical Engineering and Computer Science
Wojciech Matusik
Department of Electrical Engineering and Computer Science
Elsa Olivetti
Department of Materials Science and Engineering

Sorption-enhanced steam methane reforming with molten sorbents for clean hydrogen production
T. Alan Hatton
Department of Chemical Engineering

Toward zero-emissions neighborhoods: A novel building-grid optimization framework
Audun Botterud
Laboratory for Information and Decision Systems
Christoph Reinhart
Department of Architecture

Can industrial-scale green hydrogen be cost-competitive by 2030?

Hydrogen has the potential to play an important role in deep decarbonization efforts due to its versatility as an energy carrier and usability in different sectors such as industry, where there is limited potential for direct electrification and efforts to reduce emissions have been slow. But while hydrogen use itself creates no carbon emissions, its production can actually have a huge environmental impact, as over 95% is currently produced from fossil fuels.

Expanding decarbonization efforts across all energy sectors is contingent on producing energy carriers like hydrogen with zero or low lifecycle carbon dioxide (CO_2) emissions at a competitive cost. To that end, researchers at MIT and Harvard have published a new article in *Cell Reports Physical Science* that identifies 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. The system, which uses solar photovoltaic (PV)-electrolysis coupled with storage, has the potential to compete with conventional natural gas–based hydrogen including the cost of carbon capture and sequestration (CCS).

The potential of "green hydrogen"—hydrogen produced from renewable energy—is already gaining traction around the world. This is evidenced by new, promising project announcements for large-scale green hydrogen production, including a solar-powered electrolysis pilot in Florida and a green ammonia facility in the Kingdom of Saudi Arabia.

In the *Cell Reports* study, the researchers examine the levelized cost of a hypothetical standalone green hydrogen plant combining solar PV, electrolysis, and on-site storage to enable round-the-clock hydrogen production. Focusing on the techno-economic outlook for 2030, the researchers developed an optimization model to analyze the impacts of component cost projections, location, and system design factors on the cost of supplying green hydrogen 24/7 to industrial consumers. They also consider this as a limiting case for carbon emissions since it implicitly excludes grid-based fossil power generation. Because grid electricity might still be associated with emissions in 2030, particularly at times of low solar availability, this could appeal to industrial customers who want to limit their exposure to intra-day and intra-year electricity price volatility while still achieving near-zero-carbon hydrogen production.

"We wanted to develop a modeling approach that internalizes the cost of managing hour-to-hour variability of solar energy throughout the year in order to supply a demand that is likely to be continuous in nature," says Dharik Mallapragada, a research scientist at the MIT Energy Initiative (MITEI) and the study's lead author. "Our goal was to identify the cost of producing hydrogen at a steady rate from variable renewables that can be directly adopted by industrial customers who may not want to deal with the variability of the energy source that comes along with using green hydrogen."

When designing for a low-cost facility capable of supplying hydrogen continuously from a variable renewable energy source like solar, it is particularly important to carefully evaluate the sizing of individual plant components, as well as the type of energy storage used, since the cost of production would be dominated by capital costs. The researchers used their model to identify the least-cost system design while considering simulated plant operations over a full year at an hourly resolution, with high availability of hydrogen supply (95%). They also used the model to evaluate the prospect of solar-powered electrolytic hydrogen with costs at or below $2.5 per kilogram, which would allow it to be cost-competitive with hydrogen produced from natural gas with CCS.

"Over the course of our research, we've seen that the component sizing really depends on the resource availability at a particular location," says co-author Emre Gençer, a research scientist at MITEI. "In other techno-economic studies on green hydrogen, it is common practice to consider average solar resource availability throughout the year; but we show that it is important to consider intra-annual variations in solar availability. It leads to non-intuitive least-cost designs, such as overbuilding the solar array relative to the size of the electrolyzer."

Another key driver of system cost is the type of hydrogen storage available: pressure vessels versus geological storage (such as salt caverns or depleted oil and gas reservoirs). The cost of the storage system used also impacts the sizing, and therefore costs, of the other plant components because it affects how much hydrogen the plant will be able to produce and store economically. While geological storage proves to be the least expensive option and is key to lowering overall system costs, it is also limited in its geographical availability. The authors also considered the option of deploying battery storage as part of the system design, but found that across nearly all of the evaluated scenarios and locations, it was less economical than deploying hydrogen storage.

While adhering to hourly solar availability, production requirements, and component intertemporal operating constraints, the researchers examined the cost-optimal

Researchers consider the potential of solar photovoltaic–powered electrolysis to produce cost-competitive, industrial-scale quantities of green hydrogen by a 2030 timeframe. Photo: andreas160578/Pixabay

green hydrogen system design across nearly 1,500 locations spanning the continental United States. From these locations, they identified a number of sites close to existing industrial hydrogen demand that have the potential to produce economically viable green hydrogen at scale—though some of these are contingent on the assumed system cost projections for 2030 and availability of geological hydrogen storage.

"A decade ago, I would have ridiculed the possibility that solar hydrogen could take a meaningful bite out of the carbon budget, perhaps outcompeting natural gas with CCS," says contributing author David Keith, a professor in Harvard University's School of Engineering and Applied Sciences and Kennedy School of Government. "I was wrong. The drop in solar PV costs has been astounding, and now there is evidence that electrolysis cost can also drop quickly. Our analysis shows that reasonable extrapolation of current trends can make solar hydrogen produced in sunny places competitive with CCS hydrogen by the end of the decade."

In future work, the researchers plan to reassess promising sites to quantify the scale of green hydrogen that can be produced at these locations while accounting for land availability constraints and the feasibility of geological hydrogen storage. They would also like to expand the analysis to other regions outside the United States and evaluate the costs when integrating the use of wind resources in conjunction with solar for producing hydrogen and other hydrogen-derived energy carriers such as ammonia, which may be easier to handle and transport. While this study looked specifically at solar due to its wide availability and lower land area requirements as compared to wind, the outlook for green hydrogen may be more compelling when considering wind-based or wind-plus-solar-based electrolytic hydrogen production.

"Today, renewable energy resources represent the lowest cost option for delivering electricity in many markets around the world, and over the coming decade the competitiveness of this energy will only increase," says Francis O'Sullivan, the head of onshore strategy at Ørsted Onshore North America, who was director of research at MITEI when collaborating on this study. "Major energy-consuming sectors are now seeing an increasingly cost-effective pathway toward a lower-carbon future through the integration of renewables-derived green hydrogen into their value chains. I have no doubt that over the next five to ten years, renewables-derived electrolytic hydrogen will not just be able to outcompete hydrogen produced from fossil fuels with CCS, but in certain markets, green hydrogen will be able to directly compete on cost with natural gas-based hydrogen production even without considering the cost of carbon."

Kelley Travers, MITEI

NOTES

This research was supported by MITEI's Low-Carbon Energy Centers for Electric Power Systems and Carbon Capture, Utilization, and Storage. Many of the study's findings were presented by Mallapragada in a MITEI webinar on the role of hydrogen in future energy systems. To watch, please go to youtube.com/watch?v=l-0YcIOnrs8. Further information about the research can be found in:

D.S. Mallapragada, E. Gençer, P. Insinger, D.W. Keith, and F.M. O'Sullivan. "Can industrial-scale solar hydrogen supplied from commodity technologies be cost competitive by 2030?" *Cell Reports Physical Science* 1, 100174, September 23, 2020. Online: doi.org/10.1016/j.xcrp.2020.100174.

Mobility Systems Center funds new research, names new co-director

The Mobility Systems Center (MSC), one of the MIT Energy Initiative's Low-Carbon Energy Centers, is funding four new research projects that will allow for deeper insights into achieving a decarbonized transportation sector.

"Based on input from our Mobility Systems Center members, we have selected an excellent and diverse set of projects to initiate this summer," says Randall Field, the center's executive director. "The awarded projects will address a variety of pressing topics, including the impacts of Covid-19 on urban mobility, strategies for electric vehicle charging networks, and infrastructure and economics for hydrogen-fueled transportation." The projects are spearheaded by faculty and researchers from across the Institute, with experts in several fields, including economics, urban planning, and energy systems.

In addition to pursuing new avenues of research, the MSC welcomed Jinhua Zhao as co-director. Zhao serves alongside William H. Green, the Hoyt C. Hottel Professor in Chemical Engineering. Zhao is an associate professor in the Department of Urban Studies and Planning and director of the JTL Urban Mobility Lab. He will succeed Sanjay Sarma, the vice president for Open Learning and the Fred Fort Flowers (1941) and Daniel Fort Flowers (1941) Professor of Mechanical Engineering.

"Jinhua already has a strong relationship with mobility research at MITEI, having been a major contributor to MITEI's Mobility of the Future study and serving as a principal investigator for MSC projects. He will provide excellent leadership to the center," says MITEI Director Robert C. Armstrong, the Chevron Professor of Chemical Engineering. "We also thank Sanjay for his valuable leadership during the MSC's inaugural year and look forward to collaborating with him in his role as vice president for Open Learning—an area that is vitally important in MIT's response to research and education in the Covid-19 era."

The impacts of Covid-19 on urban mobility

In a remarkably short amount of time, the Covid-19 pandemic has transformed all aspects of life, including how, when, and why people travel. The center's new co-director, Zhao, will also lead one of the MSC's new projects to identify how Covid-19 has impacted use of, preferences toward, and energy consumption of different modes of urban transportation, including driving, walking, cycling, and—most dramatically—ride-sharing services and public transit.

Zhao describes four primary objectives for the project. The first is to quantify large-scale behavioral and preference changes in response to the pandemic, tracking how these change from the beginning of the outbreak through the medium-term recovery period. Next, the project will break down these changes by sociodemographic group, with a particular emphasis on low-income and marginalized communities. The project will then use the insights gained to posit how changes to infrastructure, equipment, and policies could help shape travel recovery to be more sustainable and equitable. Finally, Zhao and his research team will translate the behavioral changes into energy consumption and carbon dioxide emissions estimates.

"We make two distinctions: first, between impacts on amount of travel (for example, number of trips) and impacts on type of travel (e.g., mixture of different travel modes); and second, between temporary shocks and longer-term structural changes," says Zhao. "Even when the coronavirus is no longer a threat to public health, we expect to see lasting effects on activity, destination, and mode preferences. These changes, in turn, affect energy consumption and emissions from the transportation sector."

MITEI's Mobility Systems Center has selected four new low-carbon transportation research projects to add to its growing portfolio. Photo: Benjamin Cruz/Pexels

The economics of electric vehicle charging

In the transition toward a low-carbon transportation system, refueling infrastructure is crucial for the viability of any alternative fuel vehicle. Jing Li, an assistant professor in the MIT Sloan School of Management, aims to develop a model of consumer vehicle and travel choices based on data regarding travel patterns, electric vehicle (EV) charging demand, and EV adoption.

Li's research team will implement a two-pronged approach. First, team members will quantify the value that each charging location provides to the rest of the refueling network, which may be greater than that location's individual profitability due to network spillovers. Second, they will simulate the profits of EV charging networks and the adoption rates of EVs using different pricing and location strategies.

"We hypothesize that some charging locations may not be privately profitable but would be socially valuable. If so, then a charging network may increase profits by subsidizing entry at 'missing' locations that are underprovided by the market," she says. If the theory proves correct, this research could be valuable in making EVs accessible to broader portions of the population.

Hydrogen mobility systems

Hydrogen-based transportation and other energy services have long been discussed, but what role will they play in a clean energy transition? Jessika Trancik, an associate professor of energy studies in the Institute for Data, Systems, and Society, will examine and identify cost-reducing and emissions-saving mechanisms for hydrogen-fueled mobility services. She plans to analyze production and distribution scenarios, evolving technology costs, and the lifecycle greenhouse gas emissions of hydrogen-based mobility systems, considering both travel activity patterns and fluctuations in the primary energy supply for hydrogen production.

"Modeling the mechanisms through which the design of hydrogen-based mobility systems can achieve lower costs and emissions can help inform the development of future infrastructure," says Trancik. "Models and theory to inform this development can have a significant impact on whether or not hydrogen-based systems succeed in contributing measurably to the decarbonization of the transportation sector."

The goals for the project are threefold: quantifying the emissions and costs of hydrogen production and storage pathways, with a focus on the potential use of excess renewable energy; modeling costs and requirements of the distribution and refueling infrastructure for different forms of transportation, from personal vehicles to long-haul trucking, based on existing and projected demand; and modeling the costs and emissions associated with the use of hydrogen-fueled mobility services.

Analysis of forms of hydrogen for use in transportation

MITEI Research Scientist Emre Gençer will lead a team including Yang Shao-Horn, the W.M. Keck Professor of Energy in the Department of Materials Science and Engineering, and Dharik Mallapragada, a MITEI research scientist, to assess the alternative forms of hydrogen that could serve the transportation sector. This project will develop an end-to-end techno-economic and greenhouse gas emissions analysis of hydrogen-based energy supply chains for road transportation.

The analysis will focus on two classes of supply chains: pure hydrogen (transported as a compressed gas or cryogenic liquid) and cyclic supply chains (based on liquid organic hydrogen carriers for powering on-road transportation). The low energy density of gaseous hydrogen is currently a barrier to the large-scale deployment of hydrogen-based transportation; liquid carriers are a potential solution in enabling an energy-dense means for storing and delivering hydrogen fuel. The scope of the analysis will include the generation, storage, distribution, and use of hydrogen, as well as the carrier molecules that are used in the supply chain. Additionally, the researchers will estimate the economic and environmental performance of various technology options across the entire supply chain.

"Hydrogen has long been discussed as a fuel of the future," says Shao-Horn. "As the energy transition progresses, opportunities for carbon-free fuels will only grow throughout the energy sector. Thorough analyses of hydrogen-based technologies are vital for providing information necessary to a greener transportation and energy system."

Broadening MITEI's mobility research portfolio

The mobility sector needs a multi-pronged approach to mitigate its increasing environmental impact. The four new projects will complement the MSC's current portfolio of research projects, which includes an evaluation of operational designs for highly responsive, urban, last-mile delivery services; a techno-economic assessment of options surrounding long-haul road freight; an investigation of trade-offs between data privacy and performance in shared mobility services; and an examination of mobility-as-a-service and its implications for private car ownership in U.S. cities.

"The pressures to adapt our transportation systems have never been greater with the Covid-19 crisis and increasing environmental concerns. While new technologies, business models, and governmental policies present opportunities to advance, research is needed to understand how they interact with one another and help to shape our mobility patterns," says Field. "We are very excited to have such a strong breadth of projects to contribute multidisciplinary insights into the evolution of a cleaner, more sustainable mobility future."

Turner Jackson, MITEI correspondent

RESEARCH NEWS

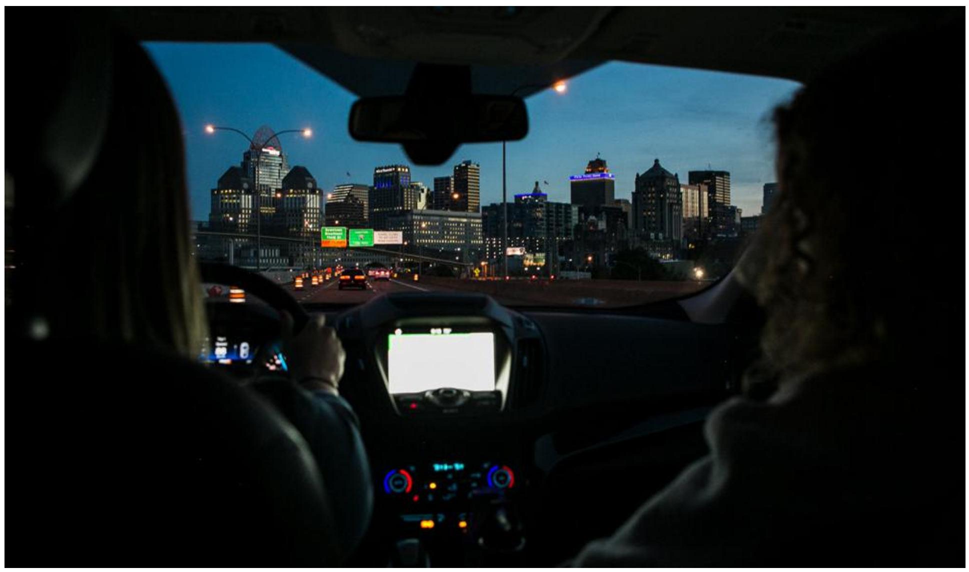
3 Questions: The price of privacy in ride-sharing app performance

Ride-sharing applications such as Uber and Lyft collect information about a user's location to improve service and efficiency, but as data breaches and misuse become more frequent, the exposure of user data is of increasing concern. M. Elena Renda, a visiting research scientist in MIT's JTL Urban Mobility Lab; Francesca Martelli, a researcher at the National Research Council in Pisa, Italy; and Jinhua Zhao, the director of the JTL Urban Mobility Lab, discuss findings from their new article in the *Journal of Urban Technology* about the impacts of different degrees of locational privacy protection on the quality of ride-sharing, or "mobility-sharing," services. Zhao is also director of the MIT Mobility Initiative, co-director of the MIT Energy Initiative's (MITEI) Mobility Systems Center, and an associate professor of urban studies and planning. This research was supported by the Mobility Systems Center, one of MITEI's Low-Carbon Energy Centers.

Q What does your research tell us about the trade-offs in protecting a user's locational privacy and the performance of ride-sharing applications?

A By providing mobility-sharing applications with both spatial and temporal data on their activities, users could reveal personal habits, preferences, and behaviors. Masking location data in order to avoid the identification of users in case of data leakage, misusage, and/or security breaches increases user privacy. However, the loss of information can decrease data utility and lead to poorer quality of service, or lower efficiency, in a location-based system.

Our research focuses on mobility-sharing applications that hold promise for improving the efficiency of transportation and reducing vehicle miles traveled (VMT). In our study, we ask: How would location privacy-preserving techniques affect the performance of such applications, and more importantly, the aspects that most impact passengers, such as waiting time, VMT, and so on? The study compares different methods for masking data and different levels of location data anonymization, and provides useful insights into the trade-off between user privacy and the performance of mobility-sharing applications.



Masking location data helps avoid the identification of users in case of a security breach, but this loss of information can also lead to poorer quality of service in a location-based ride-sharing app. Photo: Wendy Wei/Pexels

We specifically analyzed the case of carpooling between home and work, which is the largest contributor to traffic congestion and air pollution. The analyses allow a careful quantification of the effects of different privacy-preservation techniques on total saved mileage, showing that better savings can be obtained if users agree to trade convenience for privacy—more in terms of travel time than waiting time. For instance, by masking locations within a 200-meter radius, the total saved mileage decreases on average by 15% over the optimal solution with exact location information, while travel time for users increases by five minutes on average. Thus, by compromising on convenience, it is possible to preserve privacy while only minimally impacting total traveled mileage. This observation might be especially useful for city authorities and policy makers seeking a good compromise between their citizen's individual right to privacy and the societal need to reduce VMT and energy consumption. For instance, introducing more flexibility in working hours could facilitate the above compromise in urban contexts.

Q How does the cost of privacy affect a mobility-sharing system's carbon footprint?

A In our study, we compared the number of shared miles that would be obtained by optimally matching trips using exact location information with those obtained through increasingly anonymized data. We found that the higher the level of privacy that is granted to users, the fewer the shared miles: The percentage of shared miles decreases from 10% with minimal privacy preservation, up to 60% with the stricter privacy preservation policies. The values in between depend not only on the levels of location data anonymization considered, but also on the amount of discomfort we are giving to users (for example, longer riding and waiting times). In a nutshell, the cost of privacy in terms of increased carbon footprint might be very high, and it should be carefully balanced with city-level and societal-level sustainability targets.

Q What next steps are you considering for your research, and how does your research support the decarbonization of the transportation sector?

A Currently, users grant whole-data ownership and rights to these application companies, since otherwise they would not be able to use their services. If this scenario changes (for example, in response to new regulations), companies might start offering users benefits and rewards (for example, lower cost, higher priority, or higher score) to nudge them to fully or partially opt out from a "privacy option." This would allow the system to fully access their location data or reduce the level of privacy users were initially granted. If the user could set a desired level of privacy or decide not to require any privacy at all, this would lead to different levels of data privacy within the same privacy-preserving system. Performing tests on the sensitivity of the system efficiency and quality of service with respect to the percentage of riders requesting privacy controls and the geographical distribution of those riders could be an interesting research direction to investigate.

Furthermore, the extent to which data privacy is perceived as a concern by shared mobility users is still largely unknown. Would users accept rewards and benefits from the companies to totally or partially relinquish their privacy rights?

Recently, another major factor potentially disrupting the shared mobility market has appeared and spread worldwide: the Covid-19 pandemic. How could this impact shared mobility? What if people keep social distancing in the long term and drastically change their mobility patterns? What if citizens worldwide adopt the view that owning a car and driving alone (or at most, with family members) is the safest way for their health to move within and among cities, to the detriment of shared mobility modes, such as carpooling, ride-hailing, ride-sharing, or car-sharing? Failing to anticipate and address these worst-case scenarios could lead to rising traffic and congestion, which in turn will harm the environment and public health. Our plan is to investigate to what extent people are willing to use smart mobility systems post-Covid-19, and to what extent health concerns and location data privacy could be an issue.

Kelley Travers, MITEI

NOTES

For information on this research, please see the following:

F. Martelli, M.E. Renda, and J. Zhao. "The price of privacy control in mobility sharing." *Journal of Urban Technology*, 17 September 2020. Online: doi.org/10.1080/10630732.2020.1794712.

Meet the research scientists behind MITEI's Electric Power Systems Center

Pablo Duenas-Martinez and Dharik Mallapragada first met on opposite sides of a sponsored research project through the MIT Energy Initiative (MITEI). They worked together to define a project to study the long-term evolution of the electricity sector in India and the impacts of technological and policy drivers. Duenas-Martinez guided the research direction on MITEI's end, and Mallapragada provided input from an industry perspective.

Mallapragada, who earned his PhD in chemical engineering from Purdue University, had been working in the energy and petrochemical sector for about five years at two different companies when he came to a realization.

"As I took on a bunch of different roles at the companies, I came to realize the connections between the applied research I was pursuing and the policy implications in the context of decarbonizing energy systems, but somehow the framing of the problems I was investigating didn't sit right with me," he says. He came to MIT because he wanted to think about the issue in broader terms. "The main challenge in my mind is to address economy-wide decarbonization while simultaneously expanding access to energy. It is not just the end state, but the entire trajectory of this transition that matters. I think everybody recognizes what the end goal is. But there are no real clear pathways that have been identified, and I've been eager to contribute toward addressing the gaps in this area of energy research."

At MITEI, Mallapragada utilizes his engineering training and industry background while learning about all the other elements that are necessary to be able to address the grand challenge of decarbonization, which he describes

Dharik Mallapragada, a research scientist at MITEI, speaks about hydrogen at MITEI's 2019 Annual Research Conference, which was focused on driving deep decarbonization. Photos: Kelley Travers, MITEI

as "really very multidisciplinary in terms of scope and applications."

Mallapragada joined fellow Research Scientists Duenas-Martinez and Karen Tapia-Ahumada at the Electric Power Systems (EPS) Center, one of MITEI's Low-Carbon Energy Centers. The center unites MIT researchers, faculty, and students to accelerate the transition to a clean electric power sector. The center's mission is threefold:

- to examine the impacts of emerging technologies, business models, regulatory frameworks, and policy dynamics;
- to investigate solutions ranging from developing new analytical tools for improved decision making in the industry to vetting breakthrough technologies;
- to serve as a convening entity to engage industry and policy makers and provide thought leadership through rigorous analysis of the clean energy transition.

Steering EPS Center projects

Mallapragada, Duenas-Martinez, and Tapia-Ahumada all bring a wealth of experience to their roles as the researchers who shape the direction of EPS Center projects. Mallapragada, the newest addition to the team, credits his previous work in the energy industry and personal experience working with academia on sponsored projects with helping him to "hit the ground running" at MITEI, in terms of engaging with research sponsors and guiding projects.

"Oftentimes, research scientists become conduits for communication within an organization. Our research helps people from different sides of the business engage with each other in new ways," says Mallapragada. "Our role is not just to do the research, but actually to persuade people to think about problems and challenges in new ways, using evidence generated from modeling and analysis."

Duenas-Martinez is no stranger to helping people in different sectors—from power and gas utilities to government and regulatory agencies—think outside the box to improve energy systems around the world.

He grew up in Madrid, Spain, where he obtained his bachelor's degree in industrial engineering, a master's in electric power systems, and a doctorate in electrical engineering at Comillas Pontifical University. He first came into contact with MIT during his PhD work in 2012, before joining MITEI as a postdoc in 2014. "I also received a bachelor's in economics from a distance learning university two years ago," he says.

A number of his projects touch on the impacts of natural gas on the electric power system, but his work has started moving in a different direction. "Lately I've been working on the security of energy supply and researching the distribution side and all the changes that are happening in the electric power system," says Duenas-Martinez.

Tapia-Ahumada, an electrical engineer, joined MITEI as a postdoc in 2011 and became a research scientist in 2014, but she has been at MIT for far longer. Like Mallapragada and Duenas-Martinez, her journey to MITEI spans years and continents. She grew up in Chile and came to MIT in 2003 after living and working in Argentina following her graduation from the Pontifical Catholic University of Chile.

While her husband pursued his MBA, Tapia-Ahumada was accepted into MIT's Technology and Policy Program, where she completed her graduate degree and continued on to earn her PhD in engineering systems.

"I did both my master's and PhD while I was having my kids—so I finished everything all at once," she says. Tapia-Ahumada completed postdoc work at MIT and finally landed at MITEI as a research scientist. "It has been a long and a rewarding road for me here at MIT," she says.

Tapia-Ahumada's research interests include the operation and planning of electric power systems, renewable energy generation, distributed energy resources, and the market and regulatory structures required to support the development of sustainable energy systems.

Roles at MITEI

Mallapragada, Duenas-Martinez, and Tapia-Ahumada manage separate projects and teams within the EPS Center's portfolio, but they utilize their different backgrounds to work toward the common goal of implementing widespread electricity access while decarbonizing the electric power sector.

Karen Tapia-Ahumada, a research scientist and digital learning fellow at MITEI, presents at MITEI's 2019 Annual Research Conference.

They each define their role slightly differently.

"In some ways, I play the role of a principal investigator on a research project, while also being fairly hands-on with the research—not only doing some of it, but also defining what the research objectives are and then working with students to meet the research goals," says Mallapragada. He notes that he primarily works with graduate students from MIT's Technology and Policy Program.

Duenas-Martinez concurs with Mallapragada, adding that establishing and managing the human capital for a project is a major part of sponsored research projects. "Sometimes we work together with a postdoc or a student—and sometimes, as in the cases of both Karen and me, we have even *been* the postdoc or the student on the project," he says.

Of equal importance, he says, is working with international students. Students from around the world often contact MITEI research scientists about topics of interest, and MITEI will invite them to come work on a project to help enrich the EPS Center's work with outside ideas.

They also work with "UROPs"—students who receive funding through MIT's vast Undergraduate Research Opportunities Program, which connects students with faculty to work on new or established research projects. "My experience with UROP students has always been great," says Duenas-Martinez. "They are motivated and very, very smart."

Tapia-Ahumada explains that they are all very hands-on when it comes to helping students succeed. "We [research scientists] are all developing particular modeling tools, so we know the details of the tools, and then when we bring on students, we are starting from scratch. They need the extra push from us at the beginning to learn how to set up and run the models, and then, once they are up to speed, we supervise their research throughout the course of the project," she explains.

The three research scientists also regularly serve as advisors for master's theses, and work with postdocs to help them figure out where they'd like to end up post-MITEI.

The EPS Center researchers do not work in fixed groups on every project. In fact, Mallapragada feels fortunate to have been part of quite a few different teams working on MITEI projects. "I've been able to build my own network that spans across MIT, rather than having a team that I work with on a day-to-day basis. I'm kind of like a puzzle piece that fits in wherever I'm needed," he says.

Tapia-Ahumada observes that research scientists act as a link between professors and particular projects. "Sometimes the professors provide the high-level ideas, and then we are there to help work out the smaller details of the project," she notes.

Mallapragada says MITEI research scientists help faculty by providing greater context to and perspective on the fundamental research that may be happening within academic departments. "We don't necessarily operate within the realm of technology development or fundamental science research ourselves, but we help faculty contextualize the work they are doing and make it appealing to an industrial sponsor, who may not otherwise be thinking about these issues from a long-term perspective. That is something that has an appeal not only within the electric power systems sector, but also across all the end-use sectors," he says. "We fit into the technology development pipeline as a contact center for defining what topics need to be focused on by industry, policy makers, and academia in order to accelerate the sustainable energy transition."

Research highlights and planned trajectories

Of the many projects they've participated in at MITEI, a few remain highlights. Duenas-Martinez counts MITEI's 2016 Utility of the Future study as a particular favorite. The study addressed the technology, policy, and business models that are shaping the evolution of the delivery of electricity services.

"We were on the cutting edge of knowledge. We were doing some really deep analysis of what's going to happen in the next few years, with all the transformation that is happening in the electric power systems," says Duenas-Martinez. "This was a consortium project, which was something very new for me. We had 10 companies involved and also an expert advisory board, so there were long discussions with large groups about very hot topics at the time, and it was a great learning experience because I was new. It was so rewarding."

One of Tapia-Ahumada's favorite projects focused on Iceland. "It was fascinating because of the topic itself. Iceland's energy is almost 100% renewable, so it was very interesting to learn about some of the challenges they are facing in order to ensure the long-term security of electricity supply in an economic manner while preserving environmental goals." She also enjoyed having the opportunity to work with both Duenas-Martinez and colleagues from Comillas Pontifical University in Spain. "It was an international group of people working on a very relevant topic," she says.

Tapia-Ahumada, along with Ignacio Pérez-Arriaga, a visiting professor from Comillas Pontifical University, also worked on a MITEI Seed Fund project with Mei Yuan, a research scientist at the Joint Program on the Science and Policy of Global Change. They developed an integrated framework that combined electricity and economic modeling with policy analysis of carbon cap-and-trade, renewable portfolio standards, and other energy and climate mechanisms used in the United States. Tapia-Ahumada says she found the project rewarding because it allowed the researchers to decide how to expand their modeling tools and determine which scenarios to analyze.

Mallapragada came on board with MITEI as part of a sponsored research project looking into the factors likely to impact the delivered cost of electricity in future low-carbon grids and the role for emerging technologies like battery energy storage. He considers it to be a highlight of his time at MITEI. "The fairly broad project scope meant that I had significant autonomy in terms of refining the research questions and approach, and it led us to identify some interesting insights on the long-term value of battery energy storage in power systems," he says. He plans to continue pursuing research on the role that hydrogen will play in the future clean energy system—a question that has been of increasing importance during his time at MITEI. "I've seen a clear, increasing emphasis on opportunities for clean hydrogen, and I've been fortunate to get involved with a few projects, some of which have been published, but others for which the results will be coming along within the next year or so."

Pablo Duenas-Martinez, a research scientist at MITEI, is focused on the long-term outlook for energy systems and how to provide reliable and affordable electricity to all. Photo: Adelaida Nogales

According to Duenas-Martinez, the majority of the changes happening in the electric power sector are happening at the consumer level. He plans to explore how the adoption of new technologies and distributed resources is going to impact the power system in general. "I want to know how energy communities will migrate to new technologies and how consumer empowerment and choice enter into the equation. What will the future of our electric power system look like?" he asks.

"The work that we are doing at MITEI is very wide in scope, and our focus on the electric power system also encompasses electrification, which involves other sectors of the economy," adds Tapia-Ahumada. "We are thinking hard about how to expand our research scope to incorporate other sectors, such as energy-intensive heating and transportation."

She aims to better understand the economic signals that consumers receive and the effects of electricity retail prices. "We are exploring how the retail price of electricity could be set to result in an efficient economic response—and how on-site energy generation will affect electricity consumption."

Tapia-Ahumada adds that she thinks of herself as a bridge between research methodology and real-world applications. "We have many methodologies, but then we need to find the right sort of abstraction in order for us to develop appropriate tools that can produce meaningful results, and then find ways to communicate those findings to nontechnical audiences so they can understand the potential applications and various pathways."

In addition to being a research scientist, Tapia-Ahumada is MITEI's digital learning fellow, a new role at MITEI that means she is responsible for helping develop and implement MITEI's online course curriculum.

Energy access and communications challenges

The three also offer insights into what they consider to be the most important challenges to solve in the energy space. While decarbonization is certainly an urgent issue, the team also considers expanded energy access and the accessible, effective communication of research findings to be other major obstacles to overcome.

Duenas-Martinez says he remains focused on the long-term outlook for energy systems and on other critical problems, including how to provide reliable and affordable electricity to those who are still without power. "We still have about one billion people without access to good electricity. This is one topic that MITEI is focused on: We are working with the Universal Energy Access Lab to facilitate energy access to those around the globe," says Duenas-Martinez. "We have been developing tools and we are in close contact with multilateral organizations, and governments and authorities from different countries to try to make this transformation possible."

Another major barrier to the clean energy transition is the lack of a common language within academia. "I have different styles for working with electrical engineers versus economists. It's very challenging to find a common language so that multidisciplinary teams can understand each other," says Tapia-Ahumada.

In addition, it's hard to get the research into the hands of those who can do something with it and effect real change, such as policy makers and the general public. "How do we communicate with lay people and policy makers in order for them to understand the need for decarbonization, where we are trying to go, and what we are trying to accomplish?" she asks.

Duenas-Martinez adds that he is always taken aback by how hard it is to explain what is going on in the energy world to the general public and to combat preconceived notions and pervasive misinformation: "There are many hot topics, starting with decarbonization and local air pollution, where people already have pieces of information—but it's not always the correct information, and it has surprised me how difficult it is to explain the reality and help them to see the fuller energy picture."

Mallapragada, too, is focused on engaging with academia, industry, policy makers, and the public in a meaningful way. "There's an increasing demand from society for science to be relevant to social issues and making that connection—so what may not have been part of the job description of a scientist previously is now a significant part of our role. It's not just about doing good research and publishing papers, but there is the added responsibility to take the extra step to communicate the findings effectively and in a nuanced way," says Mallapragada.

Working the clean energy transition

Finding the balance between solving energy problems and being realistic about the best paths forward can also be a challenge.

"At the end of the day, I want to be a constructive contributor in solving climate and energy challenges. And sometimes the constructive contributor has to be the one to say, 'Hey, we don't have all the answers, and we need to pump the brakes. Otherwise, we might end up going down a path that we may not like down the road,'" says Mallapragada.

"We know that 2050 is the target that everyone has in mind for reaching our decarbonization goals," adds Tapia-Ahumada. "If we are to make a successful energy transition, electricity prices will be key. We'll keep working on our simulation tools. They are not going to be the final answer, but they will identify the various pathways that the energy or electricity sector may take. This information is going to be useful for regulators, utilities, and other stakeholders working on the transition."

As the world continues to work toward a sustainable energy future, Duenas-Martinez says MITEI researchers will offer a set of solutions that could help move us down the path, but not dictate the path itself.

"We are not here to say what should be done. We are more here just to provide food for thought," says Duenas-Martinez. "We are doing the analysis, we are testing different scenarios, we are innovating and developing lots of solutions. We don't know which solution is the best one, but we are doing the best we can to try to improve our future by providing industry and policy makers with the tools to solve our energy challenges."

Kathryn Luu, MITEI

To read the full article, including the researchers' discussion of how they're continuing their work during the pandemic, visit bit.ly/mitei-eps.

Energy interns share remote summer research experiences

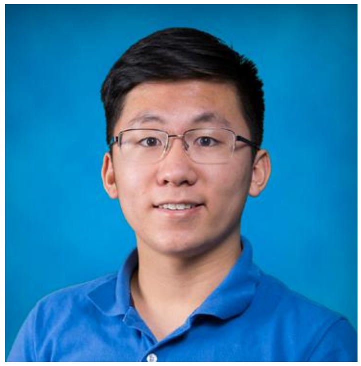
A newsletter series spearheaded by Kelly Wu '22, a chemical engineering major, allowed MIT students and recent alums who participated in summer energy internships to share their experiences working on diverse clean energy projects across academia, national labs, industry, and more.

Each week, the 10 participants in the series answered a set of questions tied to a weekly theme, such as how MIT courses translated to their internship projects. In addition, every newsletter featured a longer "blog post" entry from one student that offered their thoughts on the energy space and why they are excited to be part of it.

"We are at a turning point in energy, where the decisions we make now will have lasting impacts on our energy mix for decades into the future," writes Wu in her blog post. "There is no denying that severe consequences from climate change will come if we do not rapidly reduce the amount of carbon dioxide we emit as a society…Whether it is the policies we pass, the technologies we research, or the companies we invest or work in, our decisions now across all sectors of energy will determine the extent of climate change we leave for our future generations to grapple with."

Here are a few excerpts from the "Summer Energy Experiences" newsletter series. Read the complete series at bit.ly/energy-exp-2020.

During summer 2020, chemical engineering major Kelly Wu '22 interned at ExxonMobil and organized a newsletter that connected the summer energy interns and highlighted clean energy opportunities.



Anthony Cheng SB '20
Major: Materials Science and Engineering
Summer position: Eloranta Fellow, MIT Peter J. Eloranta Summer Fellowship

Q Describe your summer project.

A I aimed to answer the questions: What significant technical and business innovations have been made in the industrial sector to achieve decarbonization? What are modern change-makers doing nowadays, and how can they learn from the past? Through a series of interview-style podcasts and long-form radio pieces, I bring to light both human and technical elements that go into the cleantech innovator's journey, weaving a story of progress and change in the industrial sector. Listen to my podcast at bit.ly/acheng89.

Q Why did you choose to do something in the energy field this summer?

A The global climate crisis is real and looming, and humans are not doing enough to prevent catastrophic changes. Of critical importance to the issue of deep decarbonization is the industrial sector. Industrial processes account for about one fourth of global GDP and employment, along with roughly one fourth of the world's emissions. I wanted to spend the summer trying to better understand this sector.

Q What has been the most surprising fact you've learned within the energy space you're working in?

Just how significantly China's rapid industrialization in the 2000s has affected global emissions. China now produces 70% of the world's cement and 50% of its steel, at much higher emissions per quantity than western industry. If the developing world—especially India—develops at the same pace, it's going to be impossible to keep industrial emissions from exploding, much less having them decrease.

Q What is one impression you've had about how your group thinks about energy as a whole?

A All the folks I've talked to recognize that the industrial decarbonization process is very important if we are to reach net-zero carbon emissions. Unfortunately, they also generally agree that much more scholarship as well as resources are needed to create innovation in the sector, which is currently not being deployed at enough scale.

Q If you could learn an entire MIT course in one day right now for either your project or in general, which one would you choose, and why?

A That course would definitely be 14.44 Energy Economics, taught by Christopher Knittel, a professor of applied economics in the MIT Sloan School of Management. I'm very sad I couldn't participate in this class, as it was at the same time as Valerie Karplus' 14.47/15.219 Global Energy: Politics, Markets, and Policy. I plan to pursue a PhD that will undoubtedly involve economics, so I'm sad I missed out.

Heidi Li '22
Major: Materials Science and Engineering
Summer position: Research assistant, the Roosevelt Project
(Joint Harvard-MIT project)

Q Describe your summer project.

A I worked on the Roosevelt Project, which looks at ways to decarbonize Pennsylvania, one of the highest natural gas- and coal-producing states. Pennsylvania is charting a path to decrease and ultimately remove carbon emissions, which requires evaluating economic, social, and technological impacts. I'm looking at the dynamics among industry, emissions, and GDP to understand how decarbonization would impact workers and the economy.

Q Why did you choose to do something in the energy field this summer?

I'm really interested in energy and policy and understanding the economical ways of decarbonizing. Energy is a very diverse field, and I'm interested in the climate aspect of it. I think decarbonization is something that is talked about a lot, but I never knew how nuanced the problem was and how difficult it is to answer. I'm hoping that through this research project, I can glean a better perspective on ways to address this problem. I want to understand how energy is produced, distributed, and used—specifically, where is the highest potential for decarbonization?

Q What has been the most surprising fact you've learned within the energy space you're working in?

A Decarbonization is a highly nuanced issue—and unfortunately, highly politicized…Having a sustainable energy future is dependent on a diverse energy mix, but one that is also accompanied by economic drive (positive cash flows, profitable assets for companies, etc.) and effective policy design. Battling climate change and maintaining environmental stewardship must come from both parties. Policies cannot be introduced and repealed depending on the party that takes office.

Q What is one impression you've had about how your group thinks about energy as a whole?

A It's a very numbers-driven project, so we've looked into emissions, employment, and GDP data to ultimately determine which labor group would be hit hardest, given different sets of policies. It's mostly looking at the byproducts of energy—the emissions and economic gain—rather than the infrastructure and technology or processes, which is what I was used to before.

Q How did you apply what you've learned at MIT to your summer experience?

A My energy policy class [has helped me to understand] how policy will affect a region's GDP or social makeup. Also, learning about the different energy technologies has been helpful in trying to figure out where to put solar, for example, and how people can be incentivized to invest in it.

These excerpts were reprinted with permission of Kelly Wu, Anthony Cheng, and Heidi Li.

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Anthony Cheng: Wendy Lu
Heidi Li: Courtesy of Heidi Li

Energy Studies Minor graduates, June 2020

Michelle Bai
Economics; Political Science

Anthony Cheng
Materials Science and Engineering

Claire Halloran
Materials Science and Engineering

Henry Hanlon
Mechanical Engineering

Luke Harnett
Mechanical Engineering

Shannon Hwang
Electrical Engineering and Computer Science

Jacob Miske
Nuclear Science and Engineering; Engineering

Valerie Muldoon
Mechanical Engineering

Ignacio Ortega
Economics

Jonathan Sampson
Mechanical Engineering

Lisa Tang
Mechanical Engineering

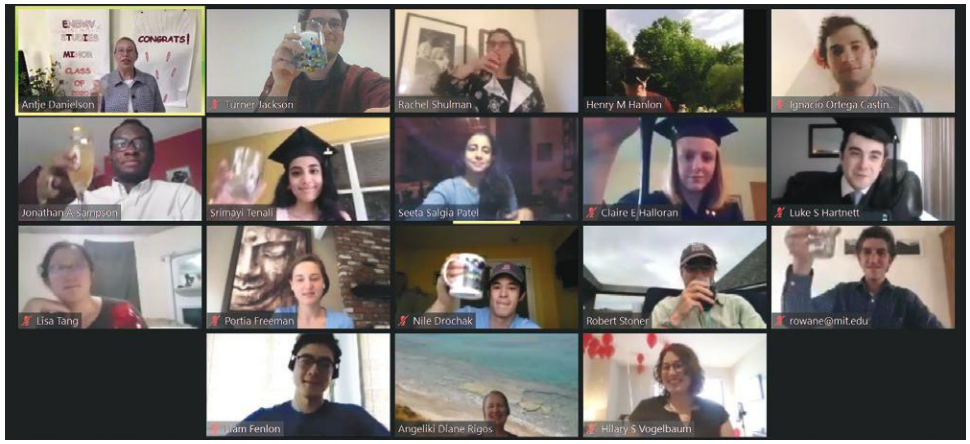
Srimayi Tenali
Mechanical Engineering

Seeta Salgia Patel
Materials Science and Engineering

MITEI hosts a virtual toast for 2020 Energy Studies Minor graduates

Covid-19-era physical distancing meant that MITEI's celebration of this year's Energy Studies Minor (ESM) graduates looked a little different. Following MIT's virtual Commencement ceremony, the 13 newly minted alumni gathered on Zoom for a toast to their achievements.

The attendees logged on from around the globe—from Florida to India—to reminisce about late-night study sessions in MIT's Undergraduate Energy Commons, discuss their plans for the future, and thank faculty and MITEI's education team for their support.



After Commencement, the 13 Energy Studies Minor graduates gathered on Zoom to celebrate their achievements, reminisce about their MIT experiences, and thank members of MITEI's education team for their support. Image courtesy of Turner Jackson

"We did it, we're done!" exclaimed Claire Halloran, a materials science and engineering graduate. "A lot of us ESMs are focused on the climate crisis—one of the most difficult challenges. But we also just finished something that's really hard—graduating from MIT. Just like that was a collaborative effort, none of us has to face the climate crisis alone. We need to be bold, imaginative, and daring, which I know we all are."

This sentiment was echoed by Halloran's classmates. While the future is as uncertain as ever, these rising energy leaders are bringing their skills, motivation, and collaborative spirit to the fight against climate change.

"I've seen a lot of you in a lot of different classes, in the energy lounge, and at various energy-related activities—long nights sitting in lounges and talking about all our energy feelings—and I've loved every minute of it," said graduate Hilary Vogelbaum, who also majored in materials science and engineering and focused her coursework in energy and business. "I couldn't imagine MIT without my energy family."

MIT's tight-knit energy community certainly seems like a family to all those involved. From the many energy-related clubs, classes, groups, and events, energy students gain much more from their time at the Institute than just technical skills.

"I wanted to thank Rachel [Shulman] for all the hard work that she's done over the past three years to make sure that all of us have really good experiences, where we can learn a lot and benefit from the MIT energy community," said Halloran. "I also wanted to thank all of my classmates, because it's just been such an honor and so much fun to go through MIT with classmates and friends who are as brilliant as all of you."

The close energy community also continues to inspire and inform the work done on behalf of students by MITEI's education team. "I'm really going to miss all of you so much," said Shulman, who is MITEI's undergraduate academic coordinator. "You have all worked immensely hard, and [we at] MITEI are so proud of you all."

Although ending their time at MIT, energy students from the class of 2020 are moving on to pursue careers and further studies in the fields of energy, environment, and beyond. Srimayi Tenali, who majored in mechanical engineering, has been awarded a Fulbright Fellowship to pursue a master's in sustainability in Australia. Halloran will pursue an MSc in energy systems and a master's in public policy at Oxford University as a Rhodes Scholar. And Anthony Cheng, who majored in materials science and engineering, conducted research into decarbonization of the industrial sector during the summer through the Eloranta Fellowship, with plans to pursue a PhD on the topic in the near future.

The MIT energy community at large—undergrads and grad students, clubs, professors, and beyond—is already missing this graduating class, but their impact and contributions to the clean energy sector will be felt for years to come.

Turner Jackson, MITEI correspondent

Weekly calls keep students connected to the Institute during a pandemic

When the MIT campus is alive, it nearly sings with innovation and excitement. Students sustain one another with activities ranging from building in makerspaces to psetting (doing problem sets) in residence halls to playing pick-up soccer games on the fields. But how can they remain connected during a pandemic, where physical distancing is the new normal? What can replace the informal chats with faculty members after class? Throw in remote learning, and the Infinite Corridor seems infinitely far away.

MIT's Student Success Coaching program paired students with volunteer "coaches," who checked in with them once a week through the end of the spring semester to see how they were transitioning to online learning and, more generally, how they were doing during the beginning of the Covid-19 crisis. Image courtesy of MIT's student success coaches/MIT News Office

Enter the MIT Student Success Coaching program, a new initiative that kept students "connected to the Infinite" during remote learning in spring 2020. The program, launched by the Division of Student Life (DSL) and the Office of the Vice Chancellor (OVC), matched students with volunteer "coaches," or staff or faculty members from several areas of the Institute. In many cases, the coaches were already known to students through their "day jobs" as athletic coaches, support professionals, or faculty members.

Coaches were assigned anywhere from one to 20 undergraduate students with whom they connected once a week through the end of the spring semester—checking to see how they were transitioning to online learning and, more generally, how they were doing during the Covid-19 crisis. Participating students received weekly check-ins conducted over Zoom, FaceTime, or even via phone or email.

The program emerged in response to a request from Suzy Nelson, vice president and dean for student life; Ian Waitz, vice chancellor for undergraduate and graduate education; and Krishna Rajagopal, dean for digital learning. The program's co-chairs were Lauren Pouchak, director of special projects in the OVC; Gustavo Burkett, senior associate dean for diversity and community involvement in DSL; and Elizabeth Cogliano Young, associate dean and director of first-year advising programs in OVC.

In the spring, there were more than 500 volunteer coaches matched with approximately 4,400 undergraduate students, according to Cogliano Young. The program was also open to MIT's graduate students but it served a smaller number "since many graduate students may already have regular meetings with advisors," Pouchak says. The team worked to identify coaching programs for graduate students.

Listening is number one

One of the co-chairs' first tasks was developing a training for the volunteers. They turned to colleagues across the Institute, including Rajagopal, who spoke at the first, hour-long, virtual training session. At that session, he emphasized that the coaches are not meant to replace academic advisors or the professionals who work for Student Support Services and GradSupport.

"The number one thing to do is to listen, listen, and listen," Rajagopal said.

Susanna Barry, senior program manager at MIT Medical, also spoke at the training, and she encouraged coaches to empower students to solve their own problems. A Slack group was formed where coaches could interact with one another and the program co-chairs could share what they were hearing from students, brainstorm approaches to addressing challenges, and develop new ideas for strengthening student connections to the Institute in the early days of the pandemic.

Pouchak said the Slack channel feedback meant that issues that "bubbled up" could be addressed in real time. For instance, many students reported having trouble sleeping and managing their time while off campus. Working with Barry, the co-chairs and a group of "super coaches" (staff who have particular expertise and experience and work to support students on a daily basis) produced Zoom workshops on topics such as sleep and time management, which included tips such as "don't hit the snooze button" and "try to get some sunlight before noon every day."

Rachel Shulman, undergraduate academic coordinator for the MIT Energy Initiative, who was matched with 18 undergraduate students, was eager to share insights with her fellow coaches. She says after initial conversations with several students, she noticed that many were finding it hard to stay focused.

"Everyone is distracted, and everyone is having trouble focusing on their lectures, and some are putting pressure on themselves to do as well as they were doing before," Shulman said this spring, when students were still adjusting to online learning. She noted that while some of her students reported doing well with the transition to virtual learning, they still appreciated hearing from someone at MIT.

Shulman says she reminded students that the weekly coaching sessions could be whatever students wanted them to be.

"I've told them that if they have specific goals, I can try to help them figure out how to achieve them, or I can connect them with resources. I had one student ask me about the career fair, and it was so great because there's a Slack channel for the MIT coaches…and I was able to Slack one of them while I was on a Zoom call with the student [so I could answer the student's question]," Shulman says.

Rachel Shulman, undergraduate academic coordinator at MITEI, volunteered for the MIT Student Success Coaching program, a new initiative that kept students connected to the Institute while navigating remote learning. Photo: Mira Whiting Photography

Luke Hartnett '20, a senior in mechanical engineering and an energy studies minor, was skeptical of the coaching initiative at first. But, after his first conversation with his coach, he realized that he appreciated the extra support—especially after his 90-year-old grandmother was diagnosed with Covid-19.

"[My coach] was very helpful in talking me through how to deal with school… and planning out the rest of the semester. Everyone is dealing with something, so I think it's nice that MIT thought of this unique way to support students," Hartnett says.

Junior Alex Encinas, another mechanical engineering major and energy studies minor, says he has found time management a struggle at his home in Houston, Texas. He committed to following the same schedule that he would have had if he were on campus, even though he had the option of watching his lecture recordings at any time. He says he adjusted well to the new routine, but while speaking with his coach, "things started flowing out that I didn't even know were bothering me…and we just talked through them. It was calming for me." …

One MIT

One unexpected benefit from the weekly check-ins: Coaches reported that the communication inspired them to forge new connections with colleagues. Shulman formed a virtual knitting group on the Student Success Team Slack channel, and about a dozen people attended the first two sessions.

"In addition to the advantages to the students, the coaches have found community with one another, which has become a tremendous resource," says program co-chair Burkett. "In my opinion, the program has become a real-life example of the idea of 'One MIT.'"

Amy MacMillan Bankson, MIT Sloan School of Management

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MIT Energy Conference goes virtual

For the past 14 years, the MIT Energy Conference—a two-day event organized by energy students—has united students, faculty, researchers, and industry representatives from around the world to discuss cutting-edge developments in energy.

The 2020 MIT Energy Conference organizers. Thomas "Trey" Wilder (pictured bottom row, fourth from left), an MBA candidate at the MIT Sloan School of Management, spearheaded the organization of this year's conference, which transitioned to a virtual event in less than a month. Image courtesy of Trey Wilder

Under the supervision of Thomas "Trey" Wilder, an MBA candidate at the MIT Sloan School of Management, and a large team of student event organizers from the MIT Energy Club, the final pieces for the 2020 conference were falling into place by early March—and then the Covid-19 pandemic hit the United States. As the Institute canceled in-person events to reduce the spread of the virus, much of the planning that had gone into hosting the conference in its initial format was upended.

The Energy Conference team had less than a month to move the entire event—scheduled for April 2–3—online.

During the conference's opening remarks, Wilder recounted the month leading up to the event. "Coincidently, the same day that we received the official notice that all campus events were canceled, we had a general body Energy Club meeting," says Wilder. "All the leaders looked at each other in disbelief—seeing a lot of the work that we had put in for almost a year now seemingly go down the drain. We decided that night to retain whatever value we could from this event."

The team immediately started contacting vendors and canceling orders, issuing refunds to guests, and informing panelists and speakers about the conference's new format.

"One of the biggest issues was getting buy-in from the speakers. Everyone was new to this virtual world back at the end of March. Our speakers didn't know what this was going to look like, and many backed out," says Wilder. The team worked hard to find new speakers; the last one was brought on just 12 hours before the event.

Another challenge posed by taking the conference virtual was learning the ins and outs of running a webinar on Zoom, a videoconferencing platform, in a remarkably short timeframe. "With the webinar, there are so many functions that the host controls that really affect the outcome of the event," Wilder says. "The speakers didn't quite know how to operate Zoom either."

In spite of such challenges, this year's coordinating team managed to pull off an informative and timely conference that reached a much larger audience than those in years past. This was the first year the conference was offered for free online, which enabled more than 3,500 people globally to tune in—a marked increase from the 500 attendees planned for the original, in-person event.

Over the course of two days, panelists and speakers discussed a wide range of energy topics, including electric vehicles, energy policy, and the future of utilities. The three keynote speakers were Daniel M. Kammen, a professor of energy and chair of the Goldman School of Public Policy at the University of California, Berkeley; Rachel Kyte, dean of the Fletcher School of Law and Diplomacy at Tufts University; and John Deutch, emeritus Institute Professor of Chemistry at MIT.

Many speakers modified their presentations to address Covid-19 and how it relates to energy and the environment. For example, Kammen discussed what those who are working to address the climate emergency can learn from the Covid-19 pandemic. He emphasized the importance of individual actions for both the climate crisis and Covid-19; how global supply chains are vulnerable in a crowded, denuded planet; and how there is no substitute for thorough research and education when tackling such complex issues.

Wilder credits the team of dedicated, hardworking energy students as the most important contributors to the conference's success. A couple of notable examples include Joe Connelly, an MBA candidate, and Leah Ellis, a materials science and engineering postdoc, who together managed the Zoom operations during the conference. They ensured that the panels and presentations flowed seamlessly, Wilder says.

Anna Sheppard, another MBA candidate, live-tweeted throughout the conference, managed the YouTube stream, and responded to emails during the event, with assistance from Michael Cheng, a graduate student in the Technology and Policy Program.

Wilder says MBA candidate Pervez Agwan "was the Swiss army knife of the group"; he worked on everything from marketing to tickets to operations—and, because he also had a final exam on the first day of the conference, even pulled an all-nighter to ensure that the event would run smoothly.

"What I loved most about this team was that they were extremely humble and happy to do the dirty work," Wilder says. "Everyone was content to put their head down and grind to make this event great. They did not desire praise or accolades and are therefore worthy of both."

Turner Jackson, MITEI correspondent

Energy Fellows, 2020–2021

The Society of Energy Fellows at MIT welcomed 35 new members in fall 2020. Their fellowships were made possible through the generous support of five MITEI Member companies.

Chevron

Robert Andrais
System Design and Management

Gloria Bahl Chambi
System Design and Management

Abhishek Bose
Technology and Policy Program

Louis Catalan
System Design and Management

Christian Dowell
System Design and Management

Matthew Hernandez
System Design and Management

Chadwick Holmes
System Design and Management

Matthew Kieke
System Design and Management

Hemant Kumar
System Design and Management

Alessandro Lucioli
System Design and Management

Elia Machado
System Design and Management

Alessandro Lucioli
System Design and Management

Monthep Parimontonsakul
System Design and Management

Allison Polly
System Design and Management

Kelsey Prestidge
System Design and Management

Zachary Schiffer
Chemical Engineering

Bagdat Toleubay
System Design and Management

John Ward
System Design and Management

Surge Yemets
System Design and Management

Commonwealth Fusion Systems

Richard Ibekwe
Nuclear Science and Engineering
Assignment in Plasma Science and Fusion Center

Theodore Mouratidis
Nuclear Science and Engineering
Assignment in Plasma Science and Fusion Center

Erica Salazar
Nuclear Science and Engineering
Assignment in Plasma Science and Fusion Center

Eni S.p.A.

Sarah Ferry, PhD
Nuclear Science and Engineering
Assignment in Plasma Science and Fusion Center

David Fischer, PhD
Nuclear Science and Engineering
Assignment in Plasma Science and Fusion Center

Michael Wigram
Nuclear Science and Engineering

ExxonMobil

Katherine Greco
Chemical Engineering

Onyu Jung
Chemistry

Bobak Kiani
Mechanical Engineering

Dongha Kim
Materials Science and Engineering

Shalmalee Pandit
Biological Engineering

Basuhi Ravi
Materials Science and Engineering

Daniel Schwalbe Koda
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Yuntong Zhu
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Total

Armi Tiihonen, PhD
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Fellows as of October 1, 2020

InEnTec: Climate goals expand impact of waste-processing MIT spin-off

Anyone who has ever hesitated in front of a trash bin knows the problem: It's hard to determine what can be recycled. Consider the average chip bag. It's got film plastic, metal, dyes, food residue; it's complicated. Today's recycling doesn't handle complexity well, so the typical chip bag is destined for the landfill.

Landfills take up space, of course, but there is a much more serious problem associated with them—one that was underscored for Daniel R. Cohn, currently an MIT Energy Initiative (MITEI) research scientist, when he was the executive director of MITEI's Future of Natural Gas study (bit.ly/natural-gas-study). That problem is greenhouse gas emissions.

"About 130 million tons of waste per year go into landfills in the U.S., and that produces at least 130 million tons of CO_2-equivalent emissions," Cohn says, noting that most of these emissions come in the form of methane, a naturally occurring gas that is much worse for the climate than carbon dioxide (CO_2).

For Cohn, working on the MITEI study made it clear that the time was ripe for InEnTec—a company he cofounded—to expand its business. Spun out of MIT in 1995, InEnTec uses a process called plasma gasification to turn any kind of trash—even biological, radioactive, and other hazardous waste—into valuable chemical products and clean fuels. (The company's name originally stood for Integrated Environmental Technologies.)

The process is more expensive than throwing trash in a landfill, however, and climate change considerations weren't a major driver of investment 25 years ago. "Back in the early '90s, global warming was more of an academic pursuit," says InEnTec president, CEO, and co-founder Jeffrey E. Surma, adding that many people at the time didn't even believe in the phenomenon.

As a result, for many years the company concentrated on providing niche services to heavy industries and governments with serious toxic waste problems. Now, however, Surma says the company is expanding with projects that include plastics recycling and low-cost distributed hydrogen fuel production—using advanced versions of their core technologies to keep waste out of landfills and greenhouse gases out of the air.

"People today understand that decarbonization of our energy and industrial system has to occur," says Surma. Diverting 1 ton of municipal solid waste from landfills is equivalent—"at a minimum"—to preventing 1 ton of CO_2 from reaching the atmosphere, he notes. "It's very significant."

This InEnTec plant in Oregon will receive feedstock materials such as medical and industrial waste and—using InEnTec's plasma gasification process—will convert them into high-purity hydrogen for use in industry and fuel cell vehicles. Photo: Jeffrey E. Surma, InEnTec

Roots at MIT

The story of InEnTec begins at the MIT Plasma Science and Fusion Center (PSFC) in the early 1990s. Cohn, who was then head of the Plasma Technology Division at the PSFC, wanted to identify new ways to use technologies being developed for nuclear fusion. "Fusion is very long-term, so I wondered if we could find something that would be useful for societal benefit more near-term," he says. "We decided to look into an environmental application."

He teamed up with Surma, who was working on nuclear waste cleanup at the Pacific Northwest National Laboratory (PNNL), and they obtained U.S. Department of Energy funding to build and operate an experimental waste treatment furnace facility at MIT using plasma—a superheated, highly ionized gas. Plasma is at the core of fusion research, which aims to replicate the energy-producing powers of the sun, which is essentially a ball of plasma. MIT provided the critical, large-scale space and facilities support for building the plasma furnace.

After the MIT project ended, Cohn and Surma teamed up with an engineer from GE, Charles H. Titus, to combine the plasma technology with a joule-heating melter, a device Surma had been developing to trap hazardous wastes in molten glass. They filed for patents, and with business help from a fourth cofounder, Larry Dinkin, InEnTec was born; a facility was established in Richland, Washington, near PNNL.

InEnTec's technology, which the team developed and tested for years before opening the company's first commercial-scale production facility in 2008, "allows waste to come into a chamber and be exposed to extreme temperatures—a controlled bolt of lightning of over 10,000 degrees Celsius," Surma explains. "When waste material enters that zone, it breaks down into its elements."

Depending on the size of the unit, InEnTec processors can handle from 25 to 150 tons of waste a day—waste that might otherwise be landfilled or even incinerated, Cohn points out. For example, in a project now under way in California, the company will produce ethanol using agricultural biomass waste that would typically have been burned and thus would have both generated CO_2 and contributed to air pollution in the Central Valley, he says.

Supporting the hydrogen economy

Unlike incineration, which releases contaminants into the air, InEnTec's process traps hazardous elements in molten glass while producing a useful feedstock fuel called synthesis gas, or "syngas," which can be transformed into such fuels as ethanol, methanol, and hydrogen. "It's an extremely clean process," Surma says.

Hydrogen is a key product focus for InEnTec, which hopes to produce inexpensive, fuel cell–grade hydrogen at sites across the country—work that could support the expanded use of electric vehicles powered by hydrogen fuel cells. "We see this as an enormous opportunity," Surma says.

While 99% of hydrogen today is produced from fossil fuels, InEnTec can generate hydrogen from any waste product. And its plants have a small footprint—typically 0.5 to 2 acres—allowing hydrogen to be produced almost anywhere. "You're reducing the distance waste has to travel and converting it into a virtually zero-carbon fuel," Surma adds, explaining that the InEnTec process itself produces no direct emissions.

Already InEnTec has built a plant in Oregon that will make fuel cell–grade hydrogen for the Northwest market from waste material and biomass. The plant has the potential to make 1,500 kilograms of hydrogen a day, roughly enough to fuel 2,500 cars for the average daily commute.

"We can generate hydrogen at very low cost, which is what's needed to compete with gasoline," Surma says.

Recycling plastic

Another initiative at InEnTec zeroes in on plastics recycling, which faces the kind of complexity illustrated by the chip bag. Different grades of plastic have different chemical compositions and cannot simply be melted down together to make new plastic—which is why less than 10% of plastic waste in the United States today is recycled, Cohn says.

InEnTec solves this problem with what it calls "molecular recycling." "We've partnered with chemical companies pursuing plastic circularity [making new plastics from old plastics], because our technology allows us to get back to molecules, the virgin form of plastics," Surma explains.

Recently, InEnTec teamed up with a major car-shredding company to process its plastic waste. "We can recycle the materials back into molecules that can be feedstock for new dashboards, seats, et cetera," Surma says, noting that 40% to 45% of the material in the waste generated from recycling vehicles today is plastic. "We think this will be a very significant part of our business going forward."

InEnTec's technology is also being used to recycle plastic for environmental cleanup. Notably, a small unit is being deployed on a boat to process ocean plastics. That project will likely require subsidies, Surma concedes, since InEnTec's business model depends on waste disposal payments. However, it illustrates the range of projects InEnTec can address, and it shows that—in both large and small ways—InEnTec is keeping waste out of landfills.

"We initially put a lot of effort into medical and hazardous waste because we got more money for disposing of those," says Cohn, but he emphasizes that the team has always had broader ambitions. "We're just arriving now at the point of getting more customers who believe that an environmentally superior product has more value. It's taken a long time to get to this point."

Kathryn M. O'Neill, MITEI correspondent

3 Questions: Dr. Fatih Birol on global energy markets and climate trends

As part of the MIT Energy Initiative's distinguished colloquium series, Dr. Fatih Birol, the executive director of the International Energy Agency (IEA), recently shared his perspective on trajectories in global energy markets and climate trends post-Covid-19 and discussed emerging developments that make him optimistic about how quickly the world may shift to cleaner energy and achieve international decarbonization goals. Here, Birol speaks with MITEI about key takeaways from his talk.

Q How has the Covid-19 pandemic impacted global energy markets?

A Covid-19 has already delivered the biggest shock to global energy markets since the Great Depression. Global energy demand is set to decline by 6%, which is many times greater than the fall during the 2009 financial crisis. Oil has been hardest hit, with demand set to fall by 8.4 million barrels per day, year-on-year, based on a resurgence of Covid-19 cases, local lockdown measures, and weak aviation. Natural gas and coal have also seen strong declines, and, while renewables have been more resilient, they, too, are under pressure.

The crisis is still with us, so it's too early to draw any definitive conclusions about the long-term implications for energy and climate trends. The extent to which governments prioritize clean energy in their economic recovery plans will make a huge difference. The IEA's *Sustainable Recovery Plan*, which we released in June, shows how smart policies and targeted investments can boost economic growth, create jobs, and put global greenhouse gas emissions into decline.

Q What trends in technology, policy, and economics have the most potential to curb climate change and ensure universal energy access?

A Five recent emerging developments are making me increasingly optimistic about how quickly the world may shift to cleaner energy and achieve the kind of structural declines in greenhouse gas emissions that are needed to achieve international climate and sustainable energy goals.

The first is the way solar is leading renewables to new heights—it has now become the least expensive option in many economies, and new projects are springing up fast all over the world. Solar also has huge potential to help increase access to energy, especially in Africa, where hundreds of millions of people still lack basic access to electricity.

The massive easing of monetary policy by central banks in response to the pandemic means that wind, solar, and electric vehicles should benefit from ultra-low interest rates for an extended period in some regions of the world. We need to find ways for all countries to access this cheaper capital.

At the same time, more governments are throwing their weight behind clean energy technologies, which was made clear by the number of Energy Ministers (40!) from nations around the world who took part in the IEA Clean Energy Transitions Summit in July.

More companies are stepping up their ambitions, from major oil firms committing to transform themselves into lower-carbon businesses to leading tech companies putting increasing resources into renewables and energy storage.

Dr. Fatih Birol, executive director of the International Energy Agency. Photo courtesy of IEA

Lastly, I see encouraging momentum in innovation, which will be essential for scaling up the clean energy technologies we need—like hydrogen and carbon capture—quickly enough to make a difference.

Q What are the greatest challenges to the clean energy transition, and how can we overcome them?

A Getting more countries and companies on board with the promising trends I just mentioned will be vital. Greater efforts need to be devoted to supporting fair, inclusive clean energy futures for all parts of the world.

One figure highlights the scale of the challenge in the energy industry: The oil companies that have pledged to achieve net-zero carbon emissions produce less than 10% of the global oil output. There's a lot of work to be done there.

We also have to make sure clean energy transitions don't leave anyone behind. As I mentioned, energy poverty is still a huge issue in Africa—we need innovative solutions to address this problem, especially since many African economies are now struggling financially, with some even facing full-blown debt crises, as a result of the global recession.

Perhaps the biggest technological challenge we face is tackling emissions from existing infrastructure—the vast fleets of inefficient coal plants, steel mills, and cement factories. These are mostly young assets in emerging Asia and could continue operating for decades more. Without addressing their emissions, we will have no chance of meeting our climate and energy goals. Our recent report, *Energy Technology Perspectives 2020*, takes a deep dive into this challenge and maps out the clean energy technologies that can overcome it. Innovation will be vital, and governments will need to play a decisive role.

Kathryn Luu, MITEI

Watch the recording of Dr. Birol's talk at bit.ly/miteibirol. Visit iea.org to learn more about the International Energy Agency and to access its flagship reports *Sustainable Recovery Plan* and *Energy Technology Perspectives 2020* as well as materials from the IEA's Clean Energy Transitions Summit.

Revamped MIT Climate Portal aims to inform and empower the public

Stepping up its ongoing efforts to inform and empower the public on the issue of climate change, on October 1, 2020, MIT announced a dramatic overhaul of the MIT Climate Portal, climate.mit.edu, which provides timely, science-based information about the causes and consequences of climate change—and what can be done to address it.

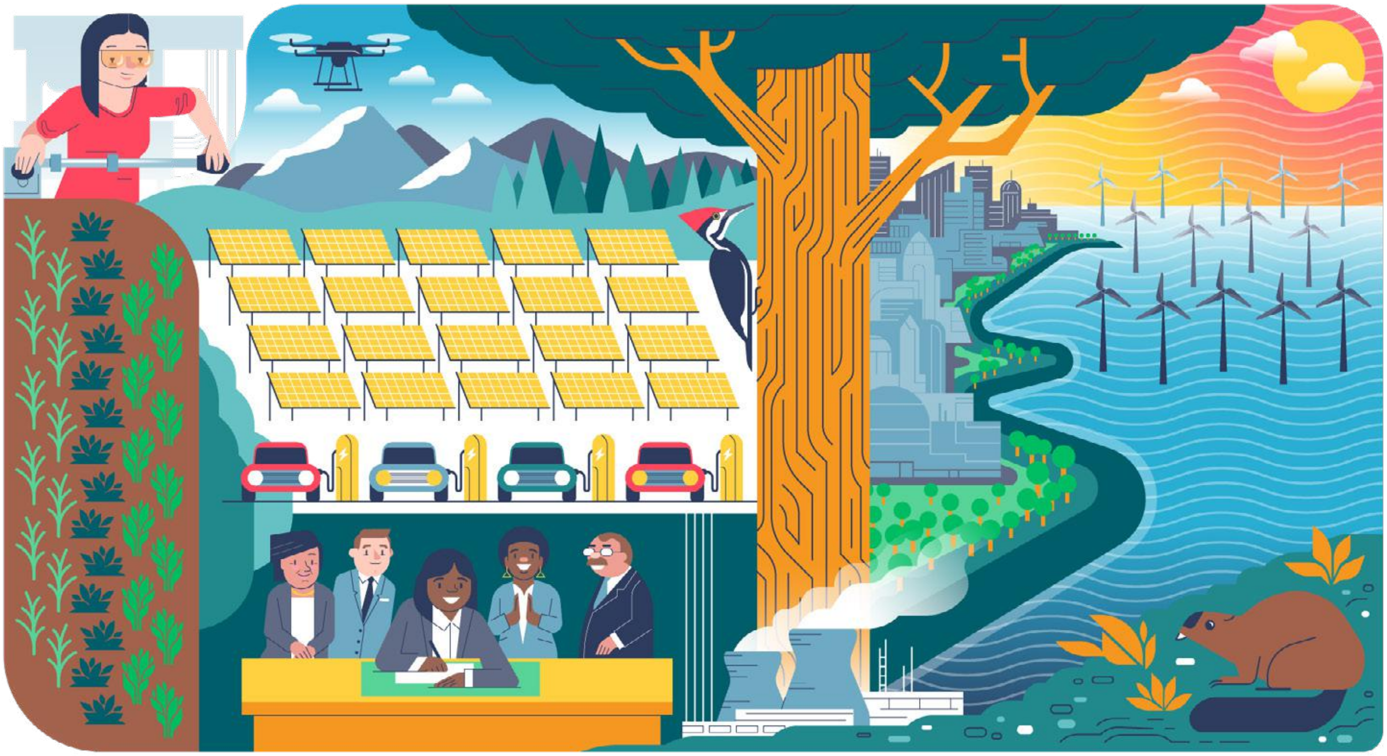
"From vast wildfires to an unusually active hurricane season, we are already getting a glimpse of what our climate-changed future looks like," says Maria T. Zuber, MIT's vice president for research. "With this website, we aim to communicate in rigorous but accessible ways what the science tells us: Yes, human-caused climate change is an urgent, serious problem; and yes, we can do something about it. Addressing climate change is an institutional priority, and this kind of public engagement is one way we hope to accelerate solutions."

Survey research shows that increasing numbers of people, both in the United States and around the world, are concerned about climate change. But in the U.S., research also shows that members of the public rarely hear about or discuss the issue. Researchers at the Yale Program on Climate Change Communication and the George Mason University Center for Climate Change Communication have suggested that there might exist a climate change "spiral of silence," in which "even people who care about the issue shy away from discussing it because they so infrequently hear other people talking about it."

MIT's efforts at public engagement on climate change are intended to help break this "spiral"—encouraging people to discuss climate change while also providing them with resources to discuss it in a way informed by the latest science and research. These engagement efforts are part of a commitment the Institute made in its 2015 Plan for Action on Climate Change "to offer the public a trusted source of climate change information, to engage leaders and citizens in the effort for solutions, and to use MIT's expertise in online education to dramatically expand our reach."

"We often talk about reaching people whom we call the 'climate curious'—people who want to learn more about what climate change means for them and their communities and, of course, what they can do about it," says John Fernández, the director of the MIT Environmental Solutions Initiative and a professor in the Department of Architecture. "Our goal is for this website to become a dependable resource for people across the U.S. and all over the world, so that they can have effective conversations about the urgency of the climate problem and our ability, even now, to reduce the grave risks it presents."

Managed by the MIT Environmental Solutions Initiative, the MIT Climate Portal features a range of content, including a comprehensive climate change primer and climate-related news from all corners of the Institute. New features launched [on October 1] include brief "explainers," written by faculty and scientists at MIT, that provide high-level overviews of important topics like wildfires, carbon pricing, renewable energy, and ocean acidification. Also new to the website is an "Ask MIT Climate" feature, where members of the public can get answers to their own questions about climate change. (If you have a question about climate change that you would like the MIT Climate Portal to answer, email climate@mit.edu.)



A graphic from the revamped MIT Climate Portal illustrates the section of the website, What Can Be Done About Climate Change?
Image courtesy of Rick Pinchera/MIT Climate Portal

The site also offers a clearinghouse of everything climate-related happening at MIT, from events to course offerings, to keep interested students, alumni, parents, faculty, and staff members up to date. Just as importantly, it creates a digital meeting place for members of the MIT community to share their latest work on climate change. Faculty, students, and staff across the Institute for years have made significant contributions to improving public understanding of and engagement with climate change, with tools like the climate simulators created by the MIT Sloan Sustainability Initiative; the Climate CoLab platform; and a number of public events, contests, and educational materials. The site will make these resources accessible in one place.

In addition to the MIT Climate Portal, MIT had previously launched two other digital resources for the public: an online, Webby Award-winning interactive primer on climate change, and a podcast series, TILclimate (short for "Today I Learned: Climate"). Both of these resources are accessible through the portal.

By enlisting MIT students in editorial aspects of the new website, the project is also proving to be a valuable hands-on educational tool. For example, for the "Ask MIT Climate" feature, students take questions about climate change submitted by users and then, under the guidance of MIT faculty members, research the answers and write responses.

"We see this as a powerful learning opportunity, a way for MIT students to strengthen their content knowledge about climate change, energy, and sustainability, but also to improve their ability to effectively communicate complex science and engineering topics to diverse audiences, a critical skill that will serve them well after they leave MIT," says Fernández.

The new website is not static: New content will be developed and added over time, and all departments, labs, and centers at MIT that work on climate change are invited to contribute to it. Members of the MIT community who want to learn more about getting involved, or who have ideas for subjects to cover, are encouraged to contact the Climate Portal team.

Environmental Solutions Initiative

MIT Energy Initiative Members

MITEI Founding and Sustaining Members

MITEI's Founding and Sustaining Members support "flagship" energy research programs and projects at MIT to advance energy technologies to benefit their businesses and society. They also provide seed funding for early-stage innovative research projects and support named Energy Fellows at MIT. To date, members have made possible 185 seed grant projects across the campus as well as fellowships for more than 500 graduate students and postdoctoral fellows in 20 MIT departments and divisions.

MITEI Founding Members

MITEI Sustaining Members

MITEI Startup Members

MITEI's Startup Member category is designed to help energy startups clear technology hurdles and advance toward commercialization by accessing the talent and facilities at MIT.

MITEI Associate Members

MITEI's Associate Members support a range of MIT research consortia, education programs, and outreach activities together with multiple stakeholders from industry, government, and academia. In general, these efforts focus on near-term policy issues, market design questions, and the impact of emerging technologies on the broader energy system.

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MITEI Affiliates

MITEI Affiliates are individual donors and foundations that support MITEI's energy- and climate-related activities across the Institute. Specific programs include the Undergraduate Research Opportunities Program, supplemental seed funding for early-stage innovative research projects, the MIT Energy Conference, the MIT Tata Center for Technology and Design, and the MIT Climate CoLab.

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Members as of September 15, 2020

AWARDS

MITEI-affiliated faculty inducted into AAAS for 2020

Six MIT faculty members are among more than 250 leaders from academia, business, public affairs, the humanities, and the arts elected to the American Academy of Arts and Sciences, the academy announced on April 23, 2020.

Two of the new academy members are affiliated with the MIT Energy Initiative (MITEI): MITEI Director Robert C. Armstrong, the Chevron Professor in Chemical Engineering, and Catherine L. Drennan, professor of biology and chemistry.

One of the nation's most prestigious honorary societies, the academy is also a leading center for independent policy research. Members contribute to academy publications, as well as studies of science and technology policy, energy and global security, social policy and American institutions, the humanities and culture, and education.

"The members of the class of 2020 have excelled in laboratories and lecture halls, they have amazed on concert stages and in surgical suites, and they have led in board rooms and courtrooms," said academy President David W. Oxtoby. "With today's election announcement, these new members are united by a place in history and by an opportunity to shape the future through the academy's work to advance the public good."

To see the full list of MIT inductees and get more details, go to bit.ly/aaas2020.

MIT News Office

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Work to develop hurricane-resilient smart grids is among eight MITEI Seed Fund projects awarded in 2020

The increasing frequency and strength of hurricanes and other weather events pose a growing threat to traditional centralized electric power grids. In a project launched with MIT Energy Initiative (MITEI) seed funding, MIT experts in hurricane physics and power system control are developing new grid designs that will have increased resilience during extreme weather events and permit quicker restoration of service following disruptions. Other winners of 2020 Seed Fund grants are focusing on biological self-assembly for improved catalysis, rapid materials design for solid-state lithium-ion batteries, building-grid optimization for zero-emissions neighborhoods, and more. Since 2008, the MITEI Seed Fund Program has supported 185 early-stage energy research projects with grants totaling about $24.9 million. Read more about the 2020 winners on page 20. Photo: Pixabay