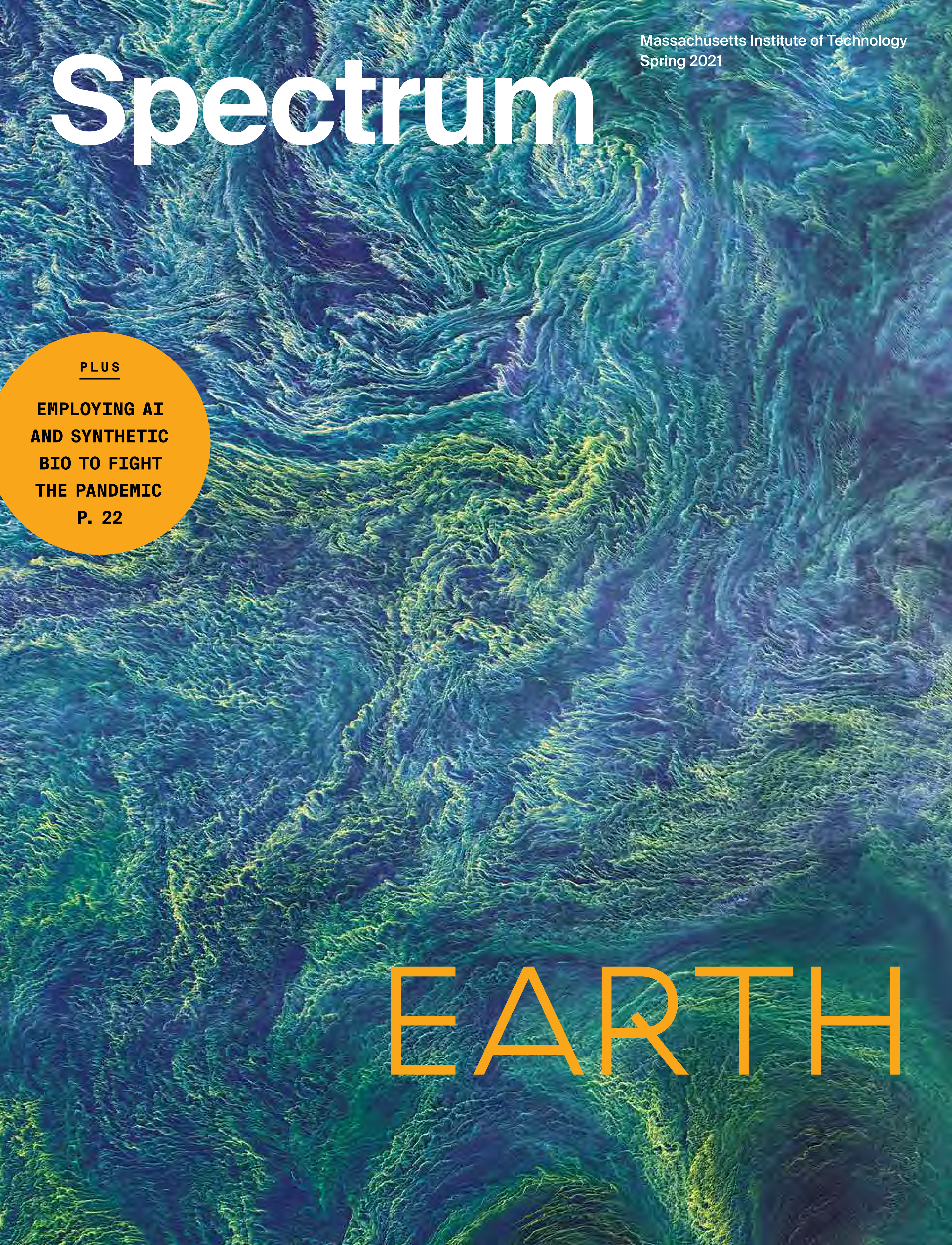
Massachusetts Institute of Technology
Spring 2021

Spectrum



PLUS

EMPLOYING AI AND SYNTHETIC BIO TO FIGHT THE PANDEMIC
P. 22

EARTH

From left: Kripa Varanasi, MIT professor of mechanical engineering; Karim Khalil PhD '18; and Maher Damak PhD '18 cofounded Infinite Cooling to capture and recycle vaporized water from thermoelectric power plants.

PHOTO: COURTESY OF INFINITE COOLING

(↗)
LOOKING FOR MORE?

Infinite Cooling is just one of many sustainability-focused companies with MIT roots. Read about them and find additional stories of MIT's extraordinary faculty, researchers, and students at work exclusively at

spectrum.mit.edu

Wide Angle

Subjects

SPECIAL SECTION
Earth

Breakthroughs and Insights

Inside the MIT Campaign for a Better World

FRONT COVER
Blooms of cynobacteria, a type of phytoplankton, swirl through the Baltic Sea in a false-color satellite image from 2015. Large blooms of cynobacteria can cause oxygen-depleted dead zones.

IMAGE: NASA EARTH OBSERVATORY

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Spring 2021

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The Office of Resource Development gratefully acknowledges the leadership of the MIT Corporation in the MIT Campaign for a Better World.

A Grand Global Challenge

Long before MIT issued its 2015 climate action plan, students, staff, and faculty across the Institute have focused on crucial aspects of mitigating the climate crisis by advancing science, innovation policy, and education. Given the scope of the climate emergency, however, it is clear that we need to do more—much more.

In that spirit, in July 2020, we initiated the ambitious research effort called the Climate Grand Challenges, and in January 2021, as a natural complement, we launched the MIT Climate and Sustainability Consortium (MCSC), an Institute-wide strategy with the potential to make all of MIT's climate efforts more effective. Just as the Climate Grand Challenges are accelerating research on climate science and solutions, MCSC aims to vastly accelerate the adoption of such solutions, at scale, and spanning industries around the world.

The consortium's member companies represent a range of industries, from construction to mining, transportation to textiles, real estate to pharmaceuticals. By convening major corporations that are striving to reach their own net-zero goals and by inspiring them to collaborate across sectors, we hope to test and deploy serious climate solutions on a global scale in time to make a real difference.

This issue of *Spectrum* highlights the remarkable range of MIT's climate expertise, which resides in all five schools and the college of computing. MIT researchers are leading the way in climate modeling, alternative energy, low-carbon materials, and energy storage. They are making climate a central concern in architecture and building technology, transportation, and food safety. They are out in the field, around the world, studying the carbon cycle in coastal environments and working to reduce air pollutants in megacities. They are bringing economic, political, and cultural research to bear on climate change by addressing its societal dimensions. Researchers are even exploring the best ways to motivate people to take action.

An MIT project in collaboration with the City of Cambridge brings home the stark reality of the climate threat. It focuses on mapping and modeling the MIT campus to prepare us for climate resiliency in the face of potential threats like flooding or extreme heat. It is sobering to confront these not as remote possibilities but as eventual developments that require practical plans.

As a campus, a community, a nation, and a planet, we are all vulnerable to the devastating effects of climate change. At MIT, we are meeting that challenge in the best can-do tradition, fearlessly pursuing facts with ingenuity and boldness.

Sincerely,

L. RAFAEL REIF

LEARN MORE
betterworld.mit.edu

"It is an honor to be the first head of house for MIT's newest undergraduate living community. With its terrific location, resources, and core values, the Vassar Street residence hall is emblematic of MIT's mind, hand, heart culture and will be a welcoming place for all MIT students."

Steven R. Hall '80, ScD '85
New Vassar head of house, professor of aeronautics and astronautics

Targeting LEED Platinum Certification

New Vassar Community Values

- OPENNESS
- WELL-BEING
- INCLUSIVENESS
- INTEGRITY
- COMMUNITY
- ADVENTURE
- COLLABORATION
- KINDNESS

170K
GROSS SQUARE FEET

This space was photographed in January 2021.

PHOTO: M. SCOTT BRAUER

5 FLOORS

450 UNDERGRADUATE STUDENTS

Community Building

Early this year on Vassar Street, next door to the Metropolitan Storage Warehouse building, the first undergraduate living community built at MIT since Simmons Hall in 2002 opened its doors to campus after three years of construction. But the community that would populate the space started taking shape well before New Vassar's opening.

Drawing on a longstanding MIT tradition of consulting many stakeholders in the residence hall development process, a Founders' Group of students, faculty, and staff was formed in October 2019 to provide input on the final elements of the building's furnishings and finishes, establish a governance system, and define the community's values. The group built upon years of student input solicited throughout the planning process.

"We've long said that residence halls are 'the other classroom' at MIT, where students can learn from each other and develop intellectually, personally, physically, and spiritually," says Suzy M. Nelson, MIT's vice president and dean for student life. "We're thrilled to see how the students of New Vassar are living those values."

Founders' Group member Ololade Abdulai '23 says the group embraced the idea of "something for everyone." The new residence's design—led by Michael Maltzan Architecture—features a yoga studio, small convenience store, music practice spaces, and workout rooms. It also has one of the largest and most visible makerspaces of any MIT residence and an outdoor maker yard where students can test their projects.

Supporting healthy eating was an important goal, says Emily Larson '21, also in the Founders' Group. Unique among MIT's student residences, the building's dining hall houses an array of cook-for-yourself stations stocked with blenders, pans, and coolers full of ingredients. Outside of the dining hall, there's also a full country kitchen so "students can have fun cooking together—once the pandemic has subsided," she says.

"The amenities allow students to feel more connected and help to solidify the relationship between the residence and the broader MIT community," Larson says.

The residence hall also has a distinctive open-plan design, which Abdulai hopes will eventually increase opportunities for serendipitous meetings and cross-disciplinary interactions, both academic and extracurricular. "Our goal was to create spaces where people share ideas and interests and see what comes from that dynamic," he says. "I'm really interested in seeing how the community evolves." —Joelle Carson

Economics and Well-Being

Class gives students frameworks to improve decision making

TITLE
14.13: Psychology and Economics

INSTRUCTOR
Frank Schilbach
Gary W. Loveman Career Development Associate Professor, Department of Economics

FROM THE CATALOG

Behavioral economics (aka psychology and economics) is a growing subfield that incorporates insights from psychology and other social sciences into economics. The broad goal of these efforts is to make economic models more realistic and to strengthen their predictive power by incorporating previously neglected features such as self-control issues, concern for others, or aversion to losses. This course covers recent advances in behavioral economics by reviewing some of the assumptions made in mainstream economic models and by discussing how human behavior systematically departs from these assumptions.

Chuan: "It's refreshing to have this field that addresses a lot of the issues related to the assumptions made in standard economic models, issues that definitely occurred to me when I first learned these models in earlier classes."

"If I can get students excited about economics while they're also using some of those insights to understand themselves better and make better decisions in their lives, that's really exciting," says Associate Professor Frank Schilbach.

THE CLASS

The first two-thirds of the class focuses on the ways in which behavioral economics can provide a more complete picture of human action than classical economics does.

"When people think about economics, they often think about money, finance, and the like. But a lot of economics, in fact, is about trying to better understand choices that have important economic and other consequences in people's lives," says Schilbach. "It's really much broader than finance and money. For many such choices, including finance, psychological factors are important, so we need to understand them better."

Students learn how behavioral economics takes assumptions made by traditional models and bolsters them with insights from other social sciences. These alternative models paint a clearer picture of how people make decisions with economic implications—from personal shopping to policy making.

"We talked about tax salience, for example, and how people's purchasing decisions change when the tax is incorporated into the price tag," says Grace Chuan '21. "These little things can inform policy making."

Students relax on campus in the fall. Participants in 14.13 are asked to think about how behavior impacts happiness.

PHOTO: GRETCHEN ERTL

Topics in the first two-thirds of the course include:

- **Time preferences**: Why do people choose between happiness in the present and in the future?
- Risk preferences: How do people make choices in the face of risk?
- **Social preferences**: How do people take others into account when making decisions?
- Beliefs: What information and beliefs do people use when making decisions?
- Non-standard decision making: How much do factors such as someone's socioeconomic circumstances or the way a choice is framed matter?

For example, Chen says, people often procrastinate unless they have "commitment devices," such as a deadline or a friend to hold them accountable.

This semester, the class discussed this topic in the context of adherence to Covid-19 safety guidelines.

In the final few weeks of the course, students explore how behavioral economics is applied to public policy and general well-being in society. For example, one lecture focuses on poverty through the lens of psychology—an area of research for Schilbach.

"I try to understand mental health in the context of poverty and the economic consequences of psychotherapy or any kind of mental health interventions and more broadly the relationship between economic and mental well-being," says Schilbach.

This work leads students into a unit on happiness and mental health in general, and how better mental well-being leads to better decision making and a happier life. "A lot of students at some point during their time at MIT struggle with mental health issues," says Schilbach. "The hope is that talking about these issues specifically might encourage some to seek help and try to improve their own mental health."

In the final lecture, students hear about how behavioral economics applies to gender, discrimination, and identity.

$$U_t = u_t + \beta \sum_{\tau = t+1}^{T} \delta^{\tau - t} u_\tau$$

THE ASSIGNMENTS

Most problem sets (PSETs) in 14.13 require students to work through the **quantitative aspects** of the alternative economic models covered in lectures. But in fall 2020, with classes online and Covid-19 cases surging, the instructors (this year, Schilbach was joined by Dmitry Taubinsky, assistant professor of economics at the University of California at Berkeley) also devised a PSET designed to bring a little brightness to the students' week. While covering social preferences and the idea that improving the well-being of others can lead to benefits for all, they asked students to perform a random act of kindness for someone in their lives.

One PSET asks students to investigate whether procrastination (of PSETs!) can be explained by quasi-hyperbolic preferences using the equation above.

"This problem set was a pedagogical way of trying to teach students about the underlying subject matter, but we were also trying to cheer them up or improve their well-being by helping them do something nice for someone," says Schilbach.

Before taking action, students were asked to rate how good it would make both them and the recipient feel. Afterward, they reflected on how well they had estimated the emotional impact of the activity. (Most of them had underestimated it, illustrating that people often don't fully comprehend the effect of their actions on others.)

"It was a very nice and really **wholesome problem set**," says Chuan. "It just reminded people of their humanity, especially in this very difficult time."

Chuan used the assignment to reconnect with an old friend.

In addition to problem sets, students also produce weekly memos relating class lectures to something that happened to them during that time. These reveal that many students are already applying what they've learned in 14.13.

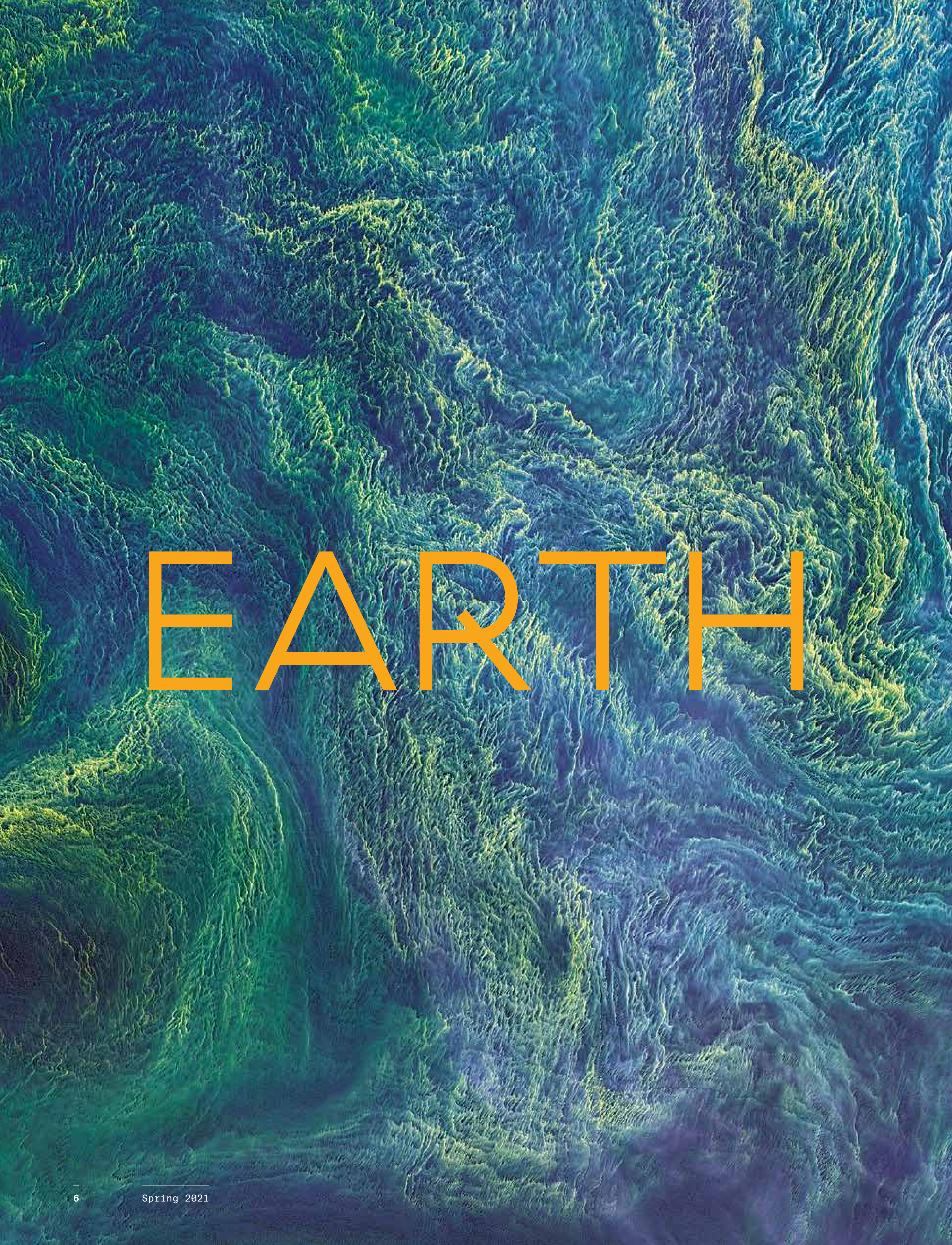
"I definitely think about time preferences when I'm procrastinating on my work or when I try to plan out my day now," Chuan says, referring to one of her favorite memos. "I think more ahead, like, 'Do I actually have the amount of time that I think I do, or am I being naïve?'"

And Fiona Chen '21, one of the fall 2020 teaching assistants, has incorporated behavioral economics into her work in student government. While weighing recommendations for grading policies during Covid-19, for example, she says she considered both the degree to which continuing the letter grading system would act as a commitment device to help students stay on track as well as more nuanced factors.

"Problems arising from Covid-19 have amplified mental health issues for many students, particularly low-income or minority students, which could hurt students' academic performance through negative effects on their attention or productivity. As a result, maintaining a regular grading scheme under Covid could reproduce many social inequities," she said.

Ultimately, Schilbach hopes students continue to use what they learn, not just in economics but as a guide to improve their decision making and increase happiness in their lives.

"If I had to say what I want students to take away," he says, "I would like them to be more deliberate and more thoughtful about the choices and decisions that they make and consider how that might improve their well-being." —Stephanie M. McPherson SM '11



EARTH

Climate change presents a challenge like no other, truly daunting in its complexity. At MIT, faculty, students, and staff are working to address the planet's mounting issues in ways both large and small. While some work to mitigate damage and construct a sustainable future, others seek to understand and influence the human behaviors at the heart of the problem. Together, they hope to protect Earth.

IMAGE: NASA EARTH OBSERVATORY

EARTH

The Big Picture

MIT experts outline issues, offer hope for climate action

Across the Institute, work is under way to understand and address Earth's changing climate and to mitigate the impacts of these changes on human populations. *Spectrum* asked three MIT faculty members who have engaged deeply with this work to provide insight into the challenges that lie ahead and suggest paths forward.


Chisholm


Emanuel


Solomon

Sallie (Penny) Chisholm is an Institute Professor with a joint appointment in the Department of Civil and Environmental Engineering and the Department of Biology. Her award-winning research explores the biology, ecology, and evolution of the marine phytoplankton, photosynthetic microbes that shape aquatic ecosystems.

Kerry A. Emanuel '76, PhD '78 is the Cecil and Ida Green Professor of Atmospheric Science in the Department of Earth, Atmospheric and Planetary Sciences (EAPS) and co-director of the Lorenz Center at MIT, an advanced climate research center. A prominent meteorologist and climate scientist, Emanuel is best known for his research on hurricanes and atmospheric convection.

Susan Solomon is the Lee and Geraldine Martin Professor of Environmental Studies in EAPS and a professor of chemistry. Solomon, who researches interactions between chemistry and climate, is renowned for her work advancing the understanding of the global ozone layer.

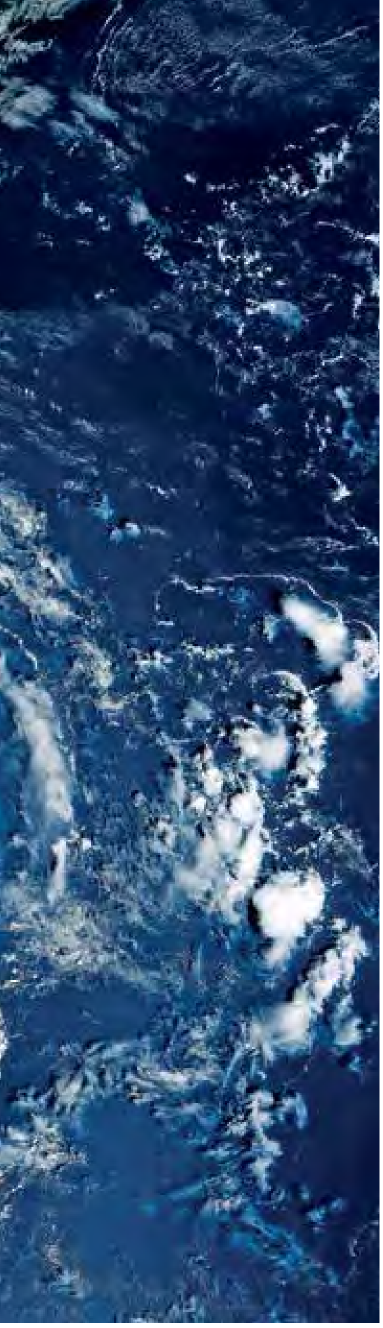
What are the biggest scientific challenges we face in addressing climate change?

SOLOMON: One of the biggest scientific challenges is understanding how much and how fast biological processes will be affected by a warmer world. For example, we need to better understand the drivers of wildfires in the North American West, the roles of ocean acidification and warming in damaging marine life, and how climate change will affect the spread of diseases. The coupling between biology and the physical and chemical system is well recognized as important, but a lot more needs to be done. Another key challenge is better understanding extreme events, because neither humans nor ecosystems have sufficient ability to deal with them.

EMANUEL: In my view, the greatest scientific challenge we face is quantifying the risks of climate change. We spend too much time calculating and talking about global mean temperature and sea level when in fact the most serious problems are bound to arise from extreme events, such as storms, droughts, and wildfires. There is much evidence that the risk of such events, which are also the main source of insurance payouts involving naturally occurring phenomena, has already evolved well beyond historical levels, rendering obsolete the financial basis of the global insurance and reinsurance markets. It is absolutely essential that science help the world come to grips with current levels of natural hazard risk and with how such risks are likely to evolve.

CHISHOLM: It appears to me that the biggest *immediate* challenge is in the social sciences. Broadly speaking, natural scientists know what causes global warming and what is needed to curb it. But until the public at large accepts that anthropogenic climate change is real and the consequences dramatic, it will be impossible to implement solutions.

PORTRAIT PHOTOS: COURTESY OF MIT DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING (CHISHOLM); HELEN HILL (EMANUEL); JUSTIN KNIGHT PHOTOGRAPHY (SOLOMON)



Climate change increases the risk of extreme events such as storms.

PHOTO: STOCKTREK IMAGES / GETTY IMAGES

How do we rise to this challenge and get the public to feel the urgency? I am reminded of the popularized wisdom of Baba Dioum, a Senegalese forester: "In the end, we will conserve only what we love; we will love only what we understand; and we will understand only what we are taught." I too like to think that if people understood how our planet functions as a living system and how the climate system is embedded in that system, it would help move the needle.

What are you working on that gives you hope for the future?

EMANUEL: I have been working on a method for downscaling tropical cyclones from climate models in a way that allows one easily to generate hundreds of thousands of storms in a given climate. The important step was applying a rigorous understanding of tropical cyclone physics to the problem so as to achieve maximum computational speed with minimum loss of fidelity. My work has already been applied to estimate flood risk for every single piece of private property in the United States. The hope is that this work will make the impact of climate change personal, and citizens will agitate for action.

SOLOMON: I've been doing a lot of work on fully understanding the sources and sinks of fluorochemicals, including chlorofluorocarbons and their substitutes, the hydrochlorofluorocarbons and hydrofluorocarbons. The fluorochemicals are potent greenhouse gases, so phasing them out has great benefits for climate. Some of my group's recent work has shown that there are "banks" of old chlorofluorocarbons (for example, in old building chillers or even home freezers) that are still leaking and contributing to global warming. What makes me hopeful is that there is now much more policy attention on what could be done to curb these emissions.

> "Until the public at large accepts that anthropogenic climate change is real and the consequences dramatic, it will be impossible to implement solutions," Chisholm says.

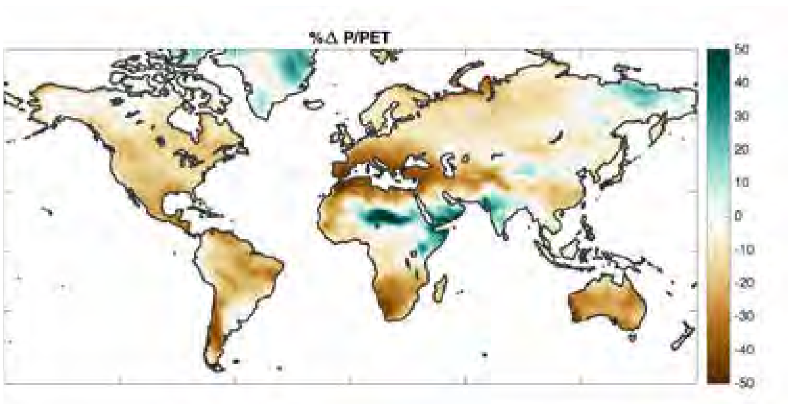
CHISHOLM: My lab does not work on climate science directly. We study marine phytoplankton, photosynthetic microbes at the base of aquatic food webs. Like plants on land, they use solar energy to draw CO_2 out of the atmosphere and fix it into the organic carbon, feeding the rest of life in the sea. This so-called "invisible pasture" is responsible for nearly half of the annual flow of CO_2 from the atmosphere into the global biosphere. More importantly, the planktonic food web functions as a biological pump, securing an enormous cache of CO_2 in the deep sea. Like so many other biospheric processes, this ecosystem service is something we take for granted. But if the oceans were not alive—if the pump did not function—CO_2 concentrations in the atmosphere would be dramatically higher.

But you asked what gives me hope. The short answer is: the wisdom and commitment of the younger generation to fight for their future. I frequently get emails from K–12 students, and recently a 14-year-old wrote to ask, "What's stopping us from mass adoption of 'CO_2 bioreactors' to offset carbon emissions? Cost? Efficiency? Another factor?" That a 14-year-old is thinking along these lines is just one small example of things that give me hope.

What role do you think MIT and other research universities have to play in addressing climate change?

SOLOMON: MIT and other research universities have fantastic potential to help move the needle. For one thing, we have relevant experts in the physics, chemistry, and biology related to climate change under one roof. We also have key experts in the engineering and policy aspects of climate change. In short, we have all the research expertise needed to make progress. The problem is that it's tough to get funding for interdisciplinary work via the traditional national funding mechanisms. Fortunately, that's slowly changing.

EMANUEL: Universities can play a crucial role in bringing the dangers of climate change right to the front doors of ordinary people by catalyzing a revolution in the risk-modeling industry. We need to produce a new stream of talent that has a deep understanding of the physics of weather hazards; of numerical modeling; and of risk, risk-affected industries and government entities, and the risk-modeling industry. Such talent could then be employed to bring physical modeling to bear on weather hazard risk assessment. At the moment, almost all global risk modeling is done by just two firms and is extrapolated from historical records that are grossly insufficient for estimating long-term risk.



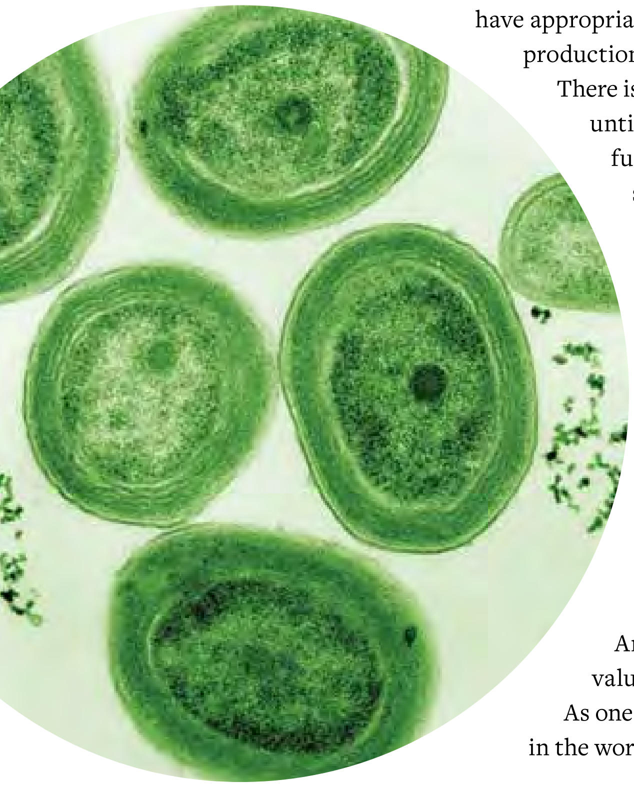
This image reveals how much more arid the world is expected to be by the end of the 21st century (browner areas are drier).

IMAGE: COURTESY OF SUSAN SOLOMON

Fortunately, the insurance and reinsurance industries are rapidly coming to understand the woeful state of risk modeling and are eager to catalyze change. They are ready and willing to help fund positions in universities (e.g., postdoctoral research positions) that would produce the stream of new talent that's badly needed to revolutionize the way we quantify and respond to climate risks.

CHISHOLM: Climate change, as well as most of the environmental challenges we face today, has emerged because we have accelerated dramatically the natural flows of energy and materials through the biosphere. The weight of human-made components on Earth now equals that of natural components, and we have appropriated roughly one-quarter of the Earth's net plant production—the foundation of life for all other species. There is little hope of making rational plans for our future until we begin to study the biosphere, and all the functions it mediates, with the same intensity as we study human biology.

So what role should MIT play? Our late colleague Henry Kendall, a Nobel laureate in physics, once advised me to "never make small plans," so here is my wish for MIT: Lead the equivalent of a Manhattan Project for the development of renewable energy and CO_2-removal technologies. Create a College of Biocomplexity to consolidate and greatly expand the environmental research and education that is scattered throughout the Institute. Ensure that all new campus construction is a showcase for energy efficiency and the use of sustainable materials. And finally, advance economic frameworks that assign value to ecosystem services in the world economy. As one of the premier education and research institutions in the world, we should be leading the way.



A microscopy image shows marine phytoplankton stained green. The photosynthetic microbes are at the base of aquatic food webs.

IMAGE: COURTESY OF THE CHISHOLM LAB

(↗)

Over the course of 12 months starting in October 2019, MIT presented a six-installment Climate Action Symposium series aimed at advancing our community's understanding of climate change and expanding our capacity to generate solutions.

WATCH THE VIDEOS AT
youtube.com/MITClimate

Institute Accelerates Climate Action

In July 2020, MIT launched the Climate Grand Challenges initiative to mobilize MIT researchers from every discipline to contribute their best and boldest ideas to the climate crisis. "The world's existing technologies and policies are not sufficient to respond to this emergency," says Associate Provost Richard Lester PhD '80, the Japan Steel Industry Professor of Nuclear Science and Engineering, who co-chairs the initiative with Vice President for Research Maria Zuber, the E. A. Griswold Professor of Geophysics. "With the entire MIT community focused on solutions, we could help move the needle on the world's climate response."

Taking up the charge, 385 researchers from throughout MIT submitted outlines for 94 potential projects. After evaluation by a committee of faculty leaders from MIT's five schools and the college of computing, 28 teams have been invited to submit white papers and will receive funding to develop their ideas further. By year's end, a small group of projects will be selected as multi-year Grand Challenge projects and launched with funding raised by the Institute.

While many at the Institute are already pursuing climate-related research, the Climate Grand Challenges initiative is intended to harness the best efforts of MIT's multidisciplinary research community toward solving a few of the toughest problems. "Climate problems and solutions often have to do with how people live and work," says Lester. "So researchers focused on science and technology will collaborate with colleagues who study economic, political, psychological, and ethical barriers to change. It's imperative to generate real-world, workable strategies."

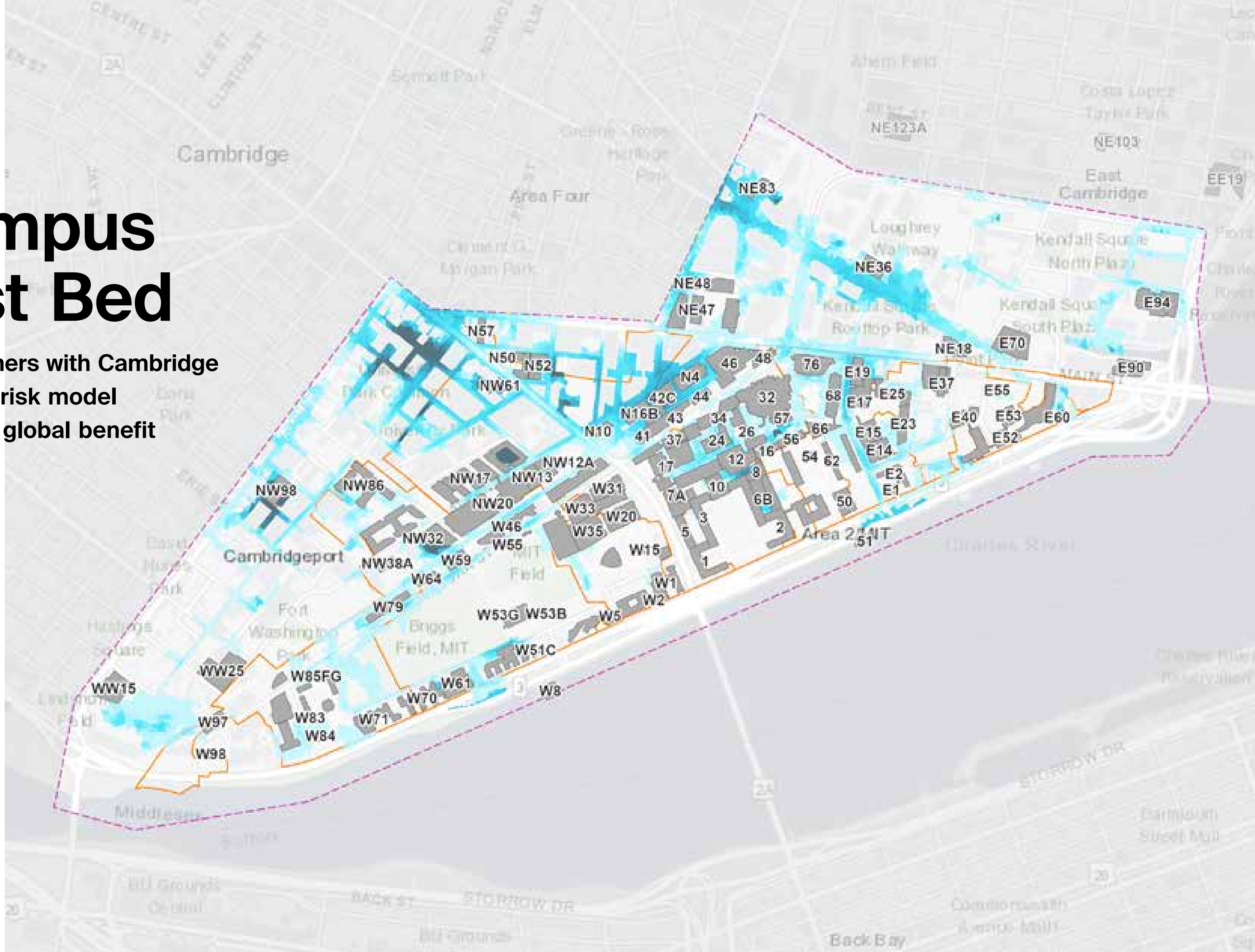
Zuber, recently named co-chair of the President's Council of Advisors on Science and Technology, agrees: "The whole of humanity needs these solutions, and that's why we have brought the whole of MIT together through the Climate Grand Challenges."

Just as Climate Grand Challenges is accelerating research on climate science and solutions, the recently launched MIT Climate and Sustainability Consortium (MCSC)—chaired by Anantha P. Chandrakasan, dean of the School of Engineering and the Vannevar Bush Professor of Electrical Engineering and Computer Science—aims to accelerate the adoption of such solutions, at scale and across industries.

Drawing from a broad range of industries, the MCSC will convene an alliance of influential corporations motivated to work with MIT, and with each other, to pilot and deploy the solutions necessary to reach their own ambitious decarbonization commitments. The goal: to vastly accelerate the implementation of large-scale, real-world solutions, across many sectors, to help meet the global climate emergency. —Christine Thielman

Campus Test Bed

MIT partners with Cambridge on flood-risk model for local, global benefit



MIT's large-scale efforts to promote sustainability and mitigate the effects of climate change are well known. But while thinking globally, MIT is also acting locally, working to make its own campus more resilient.

"We don't presume to have all the answers here," says Brian Goldberg, assistant director of the MIT Office of Sustainability (MITOS). "But we intend to draw on knowledge from around the world to solve problems here on campus. And then we intend to send those solutions back out into the world."

Founded in 2013 and part of the Executive Vice President and Treasurer's Office, MITOS uses the MIT campus as a test bed and incubator for strategies Goldberg and his colleagues hope will help meet the challenges posed by our changing planet. "One thing we do is try to downscale some of the work the Institute is doing across the globe to help understand and tackle the risks we face right here," he explains.

While the campus is a primary focus for MITOS, it hardly exists in a vacuum. MIT is situated in a city, on a river, near a harbor. The campus is vulnerable to regional events, including severe rains and flash floods, and to such global trends as soaring temperatures and rising seas. To accurately assess campus risks and provide planning parameters, MITOS has established a series of strategic partnerships, including one with the City of Cambridge. "A flood in Cambridgeport can affect MIT," Goldberg says. "And a flood on the MIT campus can affect city neighborhoods."

In 2017, Cambridge considered current conditions and projected climate changes and issued a flood risk assessment that charted flood risk for 90% of the city. The missing 10%—the unmapped part of Cambridge—was the MIT campus. "MIT was an open gray area on that model," says Kenneth Strzepek '75, SM '77, PhD '80, a climate impact specialist and MITOS faculty fellow. "The campus had four major outlets to the Charles River that weren't in the city model. That meant both the campus and the city were unable to fully assess their risk."

Mapping drainage system

Working with the city and with researchers at the MIT Center for Global Change Science, the MIT Department of Facilities, and local engineering consultants, MIT conducted a thorough survey of its drainage systems, mapping every drainpipe, catchment, and manhole. With those data, a campus flood-risk model was built that was then integrated into the Cambridge city model. "Now both parties can use the same model for their mutual good," says Strzepek. "We can better decide where and how to build, whether to raise structures or put valuable machinery on roofs. It's the result of a marvelous collaboration between MIT and Cambridge."

While exemplary, this partnership might be difficult to replicate elsewhere, since few areas have comparable expertise or resources. That's why MITOS is developing an affordable model that small schools and municipalities worldwide can use to assess their own flood risk, an example of the MITOS strategy to acquire local knowledge and share it with the world.

"In our small, urban, climate-resiliency lab, we built a complex flood-risk model," says Goldberg. "Now we're working with climate scientists and campus facility staff to develop a modeling approach that can help predict the likelihood, duration, and impact of heat and rain events for the MIT campus, and we are using the best available science to guide our work."

—Ken Shulman

MIT's Climate Resiliency Dashboard reveals potential risk to the campus from flooding.

IMAGE: COURTESY OF MIT OFFICE OF SUSTAINABILITY

Climate Landscape

New insights and game-changing technologies are urgently needed to ensure humankind's future. That's why the work at MIT matters so much. Here's a look at just a few of the scores of ways MIT's engineers are addressing the urgent challenges of climate change and sustainability.

(↗)

EXPLORE MORE

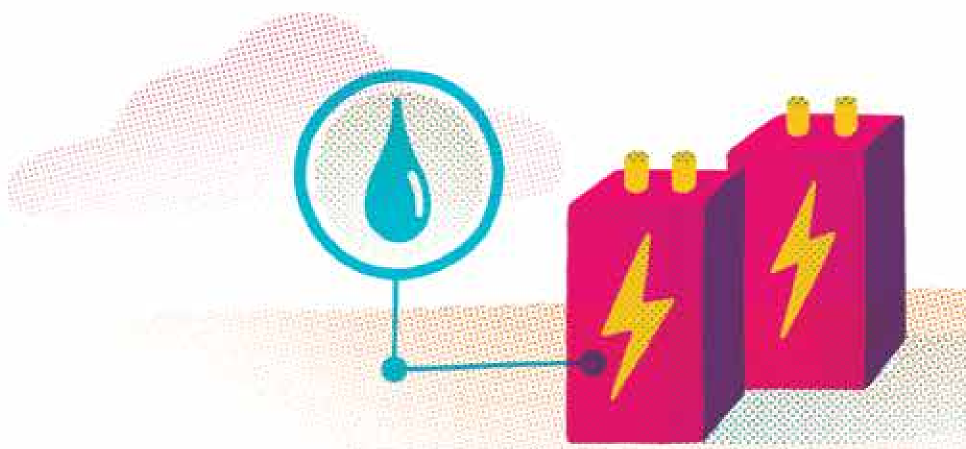
FOR A DEEPER DIVE INTO THESE PROJECTS, VISIT
spectrum.mit.edu/climate-landscape

Air Transportation

Using gas turbines in airplanes to generate electrical power for electric motors and running resulting emissions from the engines through a catalyst to remove air pollutants. Key researcher: Steven Barrett, Professor of Aeronautics and Astronautics

Circular Economy

Illuminating the importance of identifying the grade and source of paper used in recycling to evaluate the environmental effects of substituting primary materials with recycled materials. Key researcher: Elsa Olivetti PhD '07, Esther and Harold E. Edgerton Associate Professor of Materials Science and Engineering



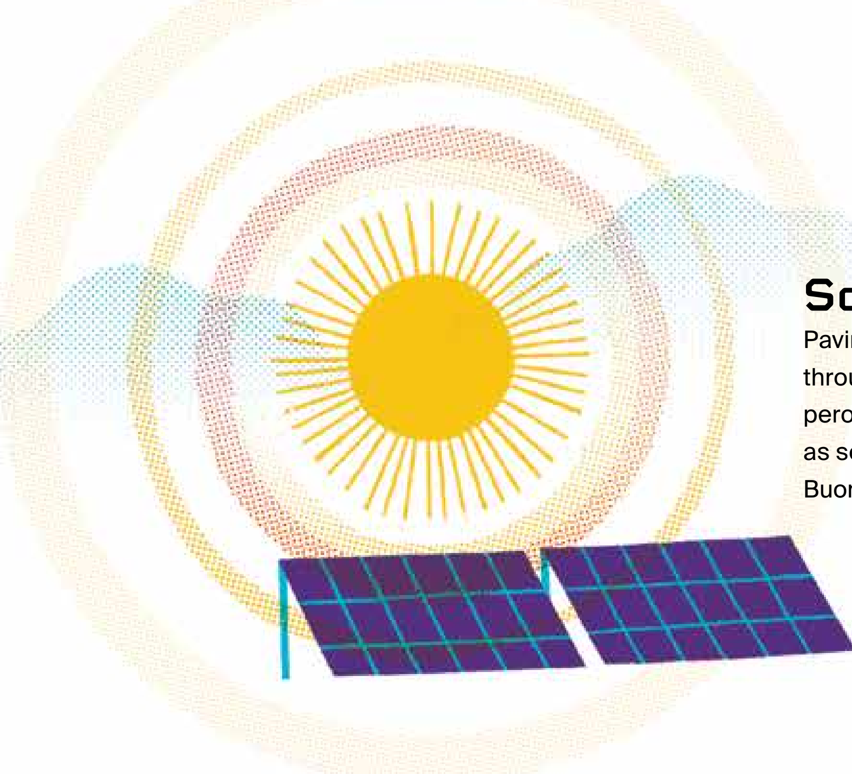
Sustainable Energy Storage

Designing a battery capable of storing renewable energy by splitting water into hydrogen and oxygen; the hydrogen becomes an energy carrier and can be stored for later use in a fuel cell. Key researcher: Yang Shao-Horn, Professor of Mechanical Engineering

Carbon Capture

Removing carbon dioxide from the air by passing it through a stack of charged electrochemical plates, a far more efficient system than most current carbon-capture technologies. Key researcher: T. Alan Hatton, Ralph Landau Professor of Chemical Engineering

Illustration: James Weinberg



Solar

Paving the way to new, more efficient solar cells through a streamlined system for screening perovskites (a broad class of materials) for use as semiconductors. Key researcher: Tonio Buonassisi, Professor of Mechanical Engineering

Food

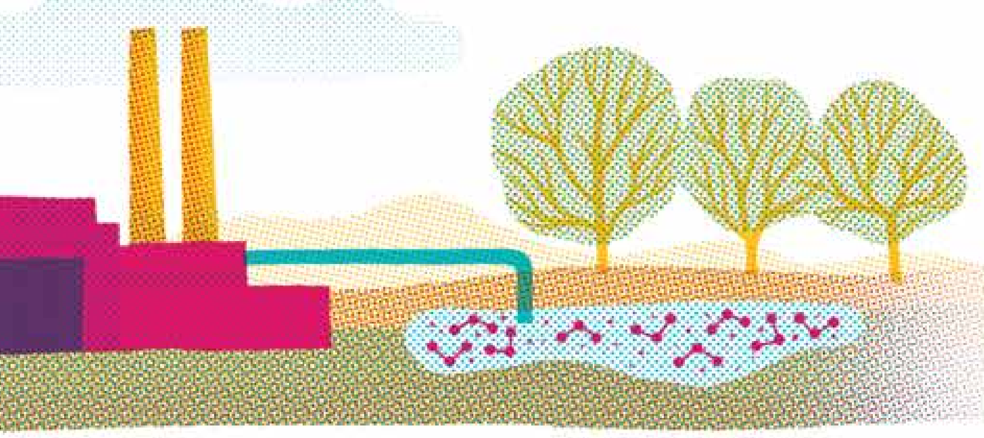
Developing new varieties of sustainable polymers that could provide all the food safety and preservation properties of plastics while being fully compostable. Key researcher: Bradley D. Olsen ’03, Professor of Chemical Engineering

Low-Carbon Energy

Building portable microreactors that can operate independently from the electric grid. These small fission reactors could power a vast array of activities across all sectors of the economy. Key researcher: Jacopo Buongiorno PhD ’01, TEPCO Professor of Nuclear Science and Engineering

Water

Creating low-cost, low-power drip irrigation systems to impact the lives of smallholder and marginal farmers worldwide and to help protect the global supply of fresh water. Key researcher: Amos Winter SM ’05, PhD ’11, Associate Professor of Mechanical Engineering



Carbon Sequestration

Studying the physics of multiphase flow in porous media, with applications to a variety of energy-driven geophysical problems including carbon sequestration, methane hydrates, and petroleum recovery. Key researcher: Ruben Juanes, Professor of Civil and Environmental Engineering

Climate Futures

CliMA collaboration aims to reinvent Earth system modeling

Climate issues are politically polarized in the United States, but that's not the only reason it's been difficult to curb global warming, says Raffaele Ferrari, the Cecil and Ida Green Professor of Oceanography in MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS). "Uncertainties in our climate forecasts are so great, we often can't guarantee that taking a particular action will have the desired result."

This is one reason Ferrari teamed up with fellow EAPS professor of oceanography and climate science John Marshall, along with other MIT colleagues, on an ambitious venture called the Climate Modeling Alliance (CliMA). Launched in 2018 in collaboration with researchers at Caltech, the NASA Jet Propulsion Laboratory, and the Naval Postgraduate School, CliMA is utilizing recent progress in computational science to develop an Earth system model that can predict droughts, heat waves, and rainfall with unprecedented precision.

"We agreed to start from scratch rather than building upon existing climate models, some of which dated back to the 1960s and '70s," Ferrari says. "To do something really new, we had to engage the computer science community," capitalizing on advances in programming languages, computer architectures, and artificial intelligence techniques.

Clouds and eddies

The team has also brought new science into its models, working to incorporate small-scale climate features and processes that most predecessors could not accurately represent. "Large-scale and small-scale processes are always interacting" in the oceans and atmosphere, Ferrari explains, which is why small-scale turbulent processes are crucial to the new model. "Everyone involved in CliMA agrees that they contribute to the greatest uncertainties in projections."

For example, the amount of heat and carbon taken up by the oceans, a key factor in climate models, is strongly influenced by "turbulent eddies," circular swirls, or vortices, of water 100 kilometers in diameter. In the atmosphere, small convective eddies arise when surface air, laden with moisture, is heated by the sun and lofts upward. Clouds, which form when this water vapor condenses, reflect sunlight and absorb infrared radiation from the Earth's surface, significantly affecting climate. They're another small-scale feature that CliMA researchers are determined to include in their model.

"We're not trying to represent every little cloud and eddy," Marshall says. "But we know the laws that govern such small-scale turbulence. If we can train our parameterizations (or approximations) on highly resolved sub-models of them, we believe we can enhance the fidelity of our global climate models."

The goal of this exercise, Ferrari says, "is to be able to predict something in the future for which we don't have data. That will require a new way of doing machine learning that learns from the data continually coming in and also takes into account the laws of physics and thermodynamics."

MIT computing power

Fortunately, MIT has an abundance of computer science expertise that CliMA is using to meet this goal. For starters, the project elected to use Julia, a dynamic programming language invented at MIT that's designed for scientific computing. "It was a bold choice," admits Valentin Churavy SM '19, a CliMA team member and doctoral student in the Department of Electrical Engineering and Computer Science, "because Julia hadn't been used on such a big science project before. But the language part of this effort has worked out well."

Ferrari agrees: "The Julia gamble has really paid off."

The majority of existing climate models run on Fortran, a programming language created in the late 1950s that is unfamiliar to most people under 30. "I'm glad I can finally stop using my grandfather's programming language," says Ali Ramadhan, an EAPS doctoral student on the CliMA team.

That's fitting, Marshall says, because CliMA is all about the future. Limitations in existing models have, for decades, led to inaccuracies in climate projections. "We need new approaches, and CliMA is offering a new route forward that should keep us going for decades to come."
—Steve Nadis

Steve Nadis is a 1997–98 MIT Knight Science Journalism Fellow.

Phytoplankton swirls reveal underlying currents, eddies, and flows in the ocean. Small-scale turbulent processes like these are crucial to the new climate model.

IMAGE: NASA EARTH OBSERVATORY

Keeping It Cool

Doctoral student helps architects design buildings to suit the climate and save energy

Arsano

Humans have long used sophisticated heating and air-conditioning technology to adapt to any climate in the world, but at what cost?

Alpha Arsano SM '17 asked herself that question as she watched more and more skyscrapers rise up in her hometown, the Ethiopian capital Addis Ababa. "They were mimicking the kinds of buildings found in Dubai and other countries," she says. Building techniques such as earthen walls, natural airflow, and insulation, used for centuries to complement Addis Ababa's temperate climate, were being abandoned in favor of massive, glass-walled buildings that relied on mechanical systems for climate control. "If I showed you a picture of one of these high-rise buildings, you wouldn't be able to tell where in the world it was from."

Then a student at the Ethiopian Institute of Architecture, Arsano began investigating how buildings might become more environmentally sustainable by taking advantage of passive strategies to save energy, including orienting buildings to take advantage of light and air flows and circulating natural air rather than using air conditioning. Her journey took her to a fellowship with a green engineering company in Germany and eventually to MIT, where she is pursuing a doctorate in architecture and building technology at the School of Architecture and Planning.

"Passive strategies cannot be a hundred percent of the solution all of the time," Arsano allows. However, integrating such strategies with active heating and air conditioning in so-called hybrid systems can dramatically reduce energy consumption and fossil fuel emissions. "The proposal is to find a middle ground."

Free online tool

Most architects today design buildings that are "climate-agnostic," Arsano says, producing essentially the same structure for snowy Boston, temperate Addis Ababa, or heat-baked Dubai. Together with her advisor, building technology professor Christoph Reinhart, Arsano has created a new online tool called ClimaPlus to help architects reverse that trend.

Loaded with climate information from more than 2,000 locations worldwide, the tool allows users to explore data related to temperature, air flow, and solar radiation and experiment with different construction techniques to optimize energy usage. "The architect, engineer, and climate scientist can all come together to customize a solution for a particular location," Arsano says.

For example, an architect can use trial and error to rotate the orientation of a building, add insulation, change the outside glazing material, and make other virtual adjustments to see the resulting effect on expected energy use. The tool can also help builders save money by translating that energy usage into cost, Arsano says. "An architect sitting in the United States doing a project in Australia or South Africa can use this to get a general, intuitive sense of a location they've never been to, in order to choose what kind of a system can work best."

Currently free online, the tool is also being used in a course Reinhart teaches on environmental building technologies and in a massive open online course sponsored by the MIT Energy Initiative that is available on MITx. "They can use this tool in their education, and then when they go into the field, they have much more experience in what might work for different circumstances," Arsano says.

Whether or not she returns to work in Africa, Arsano says she hopes the ClimaPlus tool helps architects create buildings more suitable to the continent's climate. Like many parts of the world, Africa is facing massive urban population growth alongside temperature increases due to the effects of climate change, creating a negative feedback loop of more people needing more buildings, which generates more emissions that drive temperatures higher.

"There's an expectation that buildings have air conditioning in every location, and of course, that has an adverse effect on climate," she says. "Now is the time to rethink how to address these challenges." —Michael Blanding

PORTRAIT PHOTO: ERIN EVE

As the Ethiopian capital of Addis Ababa grew, centuries-old building techniques such as earthen walls and natural airflow were abandoned.

PHOTO: J. COUNTESS / GETTY IMAGES

Why Care About Climate Change?

John Sterman helps people experience impacts of action and inaction

Research* has shown that most people care about climate change. The hard part is getting them to fight it. Why? Even as temperatures climb and natural disasters rage, the phenomenon seems overwhelmingly complex, distant, and abstract, says John D. Sterman PhD '84, the Jay W. Forrester Professor of Management and faculty co-director of the MIT Sloan School of Management Sustainability Initiative.

"A lot of people still hold a mental model that says, 'Let's wait and see how badly climate change is going to hurt us before acting,'" he notes. "Folks think it's like putting the kettle on the stove to boil water. They think you can wait until you hear the whistle to take the kettle off the flame."

But climate change isn't like your tea kettle. Every effort to "turn down the heat" takes time, from implementing climate-friendly policies to seeing declines in greenhouse gas (GHG) emissions.

We can't wait for the kettle to boil over, Sterman says. By the time the damage is clear enough to motivate strong action, it will be too late. That's why Sterman and colleagues have developed interactive climate policy simulation models grounded in peer-reviewed science; each lets people experience firsthand how various decisions affect the fate of humanity. Created by the MIT Sloan Sustainability Initiative together with the nonprofit think tank Climate Interactive, the simulations are frequently used in role-playing games and workshops for policy makers, leaders in business and civil society, educators, and laypeople.

C-ROADS (Climate Rapid Overview and Decision Support), launched in 2009, focuses on how changing national and regional emissions affects climate outcomes. En-ROADS (Energy Rapid Overview and Decision Support), released in 2019, explores what actions and policies can cut emissions quickly and deeply enough to limit global warming and climate change.

People can use both models, which are freely available online, to experiment with different policies and see immediate results. Through the MIT Climate Pathways Project, Sterman along with fellow MIT alumni Michael Sonnenfeldt SB '77, SM '78, the Sustainability Initiative's Bethany Patten EMBA '13, Drew Jones SM '97, and Ben Wolkon MBA '16 have facilitated interactive En-ROADS briefings with senior policy makers and negotiators around the world, including dozens of US senators, members of the House of Representatives, governors and other elected officials. To date, more than 100,000 people in over 90 countries have used the simulations.

The power of simulation

The success of both simulators is rooted in psychology, Sterman says. "People learn best from experiment and experience," but experiments are often impossible, he notes. "Today, whether it's learning to fly an aircraft, perform surgery, or tackle climate change, experience comes too late. In such settings, people learn best in simulations."

Simulations are especially important because evidence alone rarely changes human behavior, Sterman adds. Explaining research-based facts and then assuming policy will change—what Sterman describes as the "deficit model" of science communication—is futile, he warns. The deficit model says the public suffers from a deficit of understanding that only experts can fill. But while science and evidence are essential, Sterman notes, with a hint of irony, "Research shows that showing people research doesn't work." The Covid-19 crisis provides a clear example: scientists caution against large gatherings and urge mask wearing, but adherence has tragically fallen short.

In contrast, hands-on simulations allow people to come to their own conclusions by experimenting with scenarios they choose and receiving instant feedback about the likely consequences.

Both simulations are easy to use. In En-ROADS, for example, users swipe sliders to try different policies, such as pricing carbon pollution, slashing deforestation, or promoting energy-efficient buildings and transportation. Players build scenarios and immediately see the likely effects on energy demand, production, and prices; GHG emissions; global warming; sea level rise; and other factors. Users can also change a wide variety of assumptions, from future population growth

*Sources include the Yale Program on Climate Change Communication.

ILLUSTRATION: NIKI HINKLE

“People learn best from experiment and experience,” Sterman says.

to the timeline for retiring coal plants, and see what happens.

President Joe Biden has identified climate change as a priority in his administration, and more nations and businesses have pledged to become carbon-neutral by mid-century. “These changes are great news,” Sterman says, but he emphasizes that “pledges aren’t policies.” Real change, he stresses, requires broad bipartisan support for legislation, regulations, and incentives strong enough to boost energy efficiency, deploy renewables faster, and build a vibrant economy while cutting GHG emissions and keeping the remaining fossil carbon in the ground.

En-ROADS is designed to help people discover which actions work well and which do not, and it reveals how policies interact (try En-ROADS yourself at en-roads.org).

Complex dynamic systems often generate counterintuitive behavior, explains Sterman, who is director of the MIT Systems Dynamics Group and a leading authority on system dynamics, a methodology that examines complex systems and their myriad interactions. He is also the author of *Business Dynamics*, the key textbook in the field. Intuitively appealing actions often fail or even worsen the problems they were intended to solve, because the best points of leverage are far removed from where the pain emerges, he says. (For example, traffic congestion often leads to building more roads, but new roads increase the attractiveness of driving, soon worsening congestion.) System dynamics provides a way of looking at such issues not by providing answers, but by helping people change their mental models, as Sterman puts it.

Interactive simulators like En-ROADS work, Sterman says, because they give users autonomy to design and test their own climate solutions. People can subsidize nuclear power or promote renewables, put a price on carbon pollution or ban coal power.

Sterman and colleagues use C-ROADS and En-ROADS for facilitated group-learning experiences such as the Climate Action Simulation. In this game, participants play the roles of delegates to an emergency UN climate summit, and they negotiate policies to limit warming to the goals set out in the 2016 Paris Agreement. Each “stakeholder” has a different agenda, and together they represent a range of interests, from clean-tech to the fossil-fuel industry, from Indigenous peoples to superpowers. Evaluations based on a sample of more than 2,000 participants from diverse nations, ages, and backgrounds found the experience not only boosted participants’ knowledge about climate change and what can be done to limit it, but more importantly, generated strong emotional responses, Sterman says.

According to Sterman, those emotions are critical. “Motivating people to act isn’t just about information. The evaluative studies showed it’s that emotional engagement that drives people’s desire to learn more and to take action.”

Notably, the experience is effective with people across the political spectrum: “liberals and conservatives, environmentalists and business people. That’s important,” he says, “because everyone is needed.”

“We are rigorously nonpartisan,” Sterman explains. “Participants try the policies they want to explore, learning for themselves about the economic, health, and national security threats of climate change—and, even more importantly, what we can do to build a safe, healthy, and prosperous world.”

Beyond denial and despair

That’s the real benefit to the simulators: they offer a way forward. “Climate communication is too often passive, complex, and overwhelming, leading many to denial or despair,” he says. Building sustainable scenarios in C-ROADS and En-ROADS fosters what Sterman calls “grounded hope,” hope rooted in science.

“Hope isn’t naïve optimism—the belief that some technological breakthrough will save us, without the need for us to change,” Sterman concludes. “Hope is the belief that what we do matters, that, although there’s no time to waste, it’s not too late. It’s the belief that working together, we can create a better world.”

—Kara Baskin

The En-ROADS online dashboard allows anyone to experiment with ways to limit future global warming.

IMAGE: CLIMATEINTERACTIVE.ORG

Chemistry Cleanup

Desirée Plata devises new methods for decontaminating air, water

For Desirée Plata PhD '09, the decision to become an environmental chemist was inspired not only by an interest in science but also by her personal experience with the health effects of environmental contamination. Growing up in Maine, Plata noticed a spike in disease among people in a neighboring town, including members of her family. Later she learned the illnesses were linked to water contamination caused by years of improper industrial waste disposal.

"It's not just an abstract idea that something that we make in industry could someday cause an undesirable health impact. It's a real manifestation that a lot of people around the country are living with," Plata says. "To me, having a clean environment is a basic freedom." Now the Gilbert W. Winslow Career Development Associate Professor of Civil and Environmental Engineering at MIT, Plata—who describes herself as "famously broad" in her research—is using her knowledge of environmental chemistry to protect the environment and make industrial processes more sustainable.

One of Plata's ongoing projects focuses on methane, a greenhouse gas up to 86 times more potent than CO_2 that is having a major impact on climate. Plata and her team are building a system that uses catalysts to capture ambient methane from the atmosphere and convert it into CO_2.

While creating more CO_2 may seem counterproductive, the process is chemically simpler than alternatives (such as making methanol fuel) and has major environmental benefits, Plata explains. "If you could convert about half of the atmosphere's methane into carbon dioxide, you could save about 16 percent of the near-term warming, which buys us a little more time to respond and adapt to the changing climate," Plata says.

Plata is also exploring groundwater contamination caused by hydraulic fracturing for natural gas extraction. To date, she and her team have collected nearly 500 groundwater samples that they are testing for toxic chemicals that evade traditional water treatment. They are also using sustainable nanomaterials to develop technologies that can purify water after it reaches homes.

"When thinking about sustainability, it's always best to intervene early, but we have a lot of established technologies where there has already been some environmental damage or the infrastructure is too hard to move," Plata says. "In those cases, you really need treatment technologies."

Keeping pace with innovation

A broader focus of Plata's lab is accelerating the pace of discovery in environmental chemistry by leveraging technologies such as robotics and machine learning. The aim, she says, is to build experimental systems that enable more efficient environmental assessment of chemicals. "Innovation will probably always outpace environmental assessment, so we can't really do the assessment chemical by chemical," Plata says. "We have to be faster and smarter."

Plata first experienced MIT while pursuing her PhD in chemical oceanography in the MIT-Woods Hole Oceanographic Institution Joint Program in Oceanography/Applied Ocean Science and Engineering, where she worked on developing more sustainable carbon nanotubes. She later joined the faculty at MIT, driven by her desire to make the practice of innovation more sustainable. "MIT is a really unique place in the world; there's a lot of innovation going on," she says.

Plata especially appreciates the Institute's strong connection to industry, which she has experienced in many ways, including through MIT's Industrial Liaison Program. In the program, Plata uses her expertise to work with companies on making their industrial processes more sustainable.

As part of Plata's commitment to teaching innovators how to incorporate sustainability into their designs, she also mentors young engineers at MIT. "I want to make sure that students are armed with the right skills to not just invent great products and technologies, but to do it in a way that doesn't cause environmental damage," Plata says.

—Catherine Caruso SM '16


Plata

PHOTO: LILLIE PAQUETTE

A Breath of Fresh Air

Major new J-PAL initiative targets impact at the nexus of climate and poverty

Once home to master silk weavers, the Indian city of Surat now churns out millions of meters of fabric a year. Textile plants in west-central India drive the local economy and help meet the national demand for peacock-hued fabrics. They also pollute the air and water in a region afflicted by poverty.

For almost a decade, economist Nicholas Ryan PhD '12 has been traveling to Surat in the state of Gujarat to tackle a thorny problem: since India ramped up industrialization to improve its citizens' standard of living, it has found itself with 13 of the world's 20 most polluted cities.

Many of Surat's 4.5 million residents are poor, packed densely into housing that lacks adequate sanitation and sewerage. In 2014, *The Guardian* reported that rapid urban development and global warming put Surat at risk for recurrent flooding and higher temperatures. Surat's air quality was also deteriorating from industrial pollution, which generates substantial carbon emissions.

Ryan, an assistant professor of economics at Yale University who is affiliated with MIT's Abdul Latif Jameel Poverty Action Lab (J-PAL), has joined collaborators at Yale and the University of Chicago in working with the environmental regulator in Gujarat to find better ways to bring down pollution that disproportionately impacts the poor. His latest work is being supported by J-PAL's King Climate Action Initiative (K-CAI), a large-scale, long-term effort launched last year with major funding from King Philanthropies that focuses on solving problems at the nexus of climate change and global poverty.

Last year, more than 300 factories in Surat were issued permits that required them to cap their emissions at set levels. Plants that used pollution controls to reduce emissions below permitted levels could then sell their extra allowances to plants that found stringent controls to be more costly.

Such cap-and-trade strategies are used successfully in Europe and the United States, but they are new to India. Testing how such interventions work in countries wrestling with poverty is the motivation behind K-CAI's scale-up of the emissions trading pilot.

"We are in dire need of action when it comes to climate change and poverty reduction, but there is a lack of evidence to help guide effective policies in this space," said J-PAL Global Executive Director Iqbal Dhaliwal. "By testing interventions in the real world and building long-term partnerships with policy makers to scale effective solutions, K-CAI will help ensure climate research creates meaningful change."

Supporting sustainable growth

As a graduate student working under Esther Duflo PhD '99, the Abdul Latif Jameel Professor of Poverty Alleviation and Development Economics at MIT and co-director of J-PAL, Ryan jumped at the chance to explore the real-world effects of economic policy on industrial pollution in India. "It's a super-hard problem," Ryan said. "There are tens of thousands of factories spread all over, and for the regulator, there is little good information on where pollution is coming from."

When he first traveled to Gujarat, he found existing regulatory tools were not always effective: despite stringent reporting rules, auditors routinely understated plant emission levels. Ryan and his collaborators, including members of J-PAL's South Asia office, helped implement reforms that made emissions reporting more transparent and found that better reporting helped reduce emissions. The pilot cap-and-trade strategy then emerged as a practical next step to cap total emissions.

Plants started trading permits in September 2019, and Ryan and his team are now measuring the impact on emissions, plant revenues, and compliance costs with the hope of expanding the program to other Indian cities and states. "We think it's really promising, because there's a chance to keep the source of vibrant economic growth while tamping down pollution," he says.

—Deborah Halber

(↗)

SOLVING CLIMATE | HUMANISTIC PERSPECTIVES FROM MIT

bit.ly/SolvingClimateSeries

One project undertaken via J-PAL's King Climate Action Initiative centers on reducing air pollution in Surat, a city in Gujarat, India.

PHOTO: CRS PHOTO / SHUTTERSTOCK.COM

Deep Diving into Seawater

Mallory Ringham uses optical sensor to assess oceans' chemical changes

When the Woods Hole Oceanographic Institution (WHOI) shut down due to the pandemic last spring, there was a frenzy of last-minute activity as everyone raced to gather the equipment and notebooks and hard drives they'd need to keep their science churning while working remotely.

Mallory Ringham, now a fifth-year PhD candidate in the MIT/ WHOI Joint Program in Chemical Oceanography, was among the throngs. She hoisted 20-liter glass carboys of seawater into her car and lugged them down to her basement. She also transported chemicals, an entire soldering station, and bins of supplies and spare parts. "I set up an impromptu chemical lab down there," Ringham says. "You gotta do what you gotta do."

It's vital work, she says, because she's focused on how Earth's changing climate is impacting the ocean's chemistry—for example, the extent to which seawater is becoming more acidic as it absorbs increasing amounts of CO_2. Detailed information about such processes can help limit the harm we're doing to ocean ecosystems.

"I do my work to be a part of the climate change solution," Ringham says. "The better our understanding is of the here and now of climate change, the better prepared we'll be for the future."

Optical sensor

Perhaps the most precious piece of cargo Ringham rescued from her lab last spring was CHANOS II, a special sensor the size of a wastepaper basket. Designed by Ringham; her supervisor, Zhaoui "Aleck" Wang, an associate scientist at WHOI; and a cast of engineers, CHANOS stands for Channelized Optical Sensor, and it can measure a variety of molecules in seawater—carbon dioxide, dissolved inorganic carbon, protons, etc.

"Our approach," says Ringham, "is to build an instrument to measure as much as we can in one go in the hopes of reducing our workload so we can focus on understanding the data." CHANOS II operates remotely, which means "you put it in the water and walk away."

Built from titanium, CHANOS II can withstand depths of 18,000 feet without imploding, but in the spring of 2020, it just needed to make it down the flight of stairs into Ringham's basement. She was troubleshooting the instrument, fine-tuning its electronics to optimize performance. Her only major issues were Paddy and Hazelnut, the pet cat and dog that occasionally strayed into her makeshift laboratory. "Paddy steps on everything," she explains, "so you just have to make sure he doesn't step on anything important."

Fortunately, Ringham was already quite familiar with the capabilities of CHANOS II.

Before Covid-19 stopped the world in its tracks, Ringham ferried the little sensor to a couple of field sites where it had the chance to flex its optical muscles. In October 2019, she participated in a research cruise off the west coast of Florida to study deep-sea corals. These reefs can be found hundreds or thousands of feet underwater, and they're vital habitats for

PHOTO: PRISMA BY DUKAS / UNIVERSAL IMAGES GROUP / GETTY IMAGES

Mallory Ringham visited this Red Sea coral reef to study calcium carbonate precipitation, a process that may play a role in carbon cycling.

PHOTO: MALLORY RINGHAM

numerous species. But as more and more carbon dioxide accumulates in the atmosphere, almost a third of that gas dissolves into the ocean, making seawater increasingly acidic.

The question Ringham is trying to address is, how vulnerable are coral skeletons to this ocean acidification? Or, as she put it, how big of an "ecological train wreck" is our changing world creating for the reefs?

While shallow-water corals can be studied from the surface or by scuba diving, their deep-sea cousins are harder to access and sample. That's where CHANOS II comes in. Ringham strapped the sensor onto a remotely operated vehicle and maneuvered it along the corals at depth to measure the water's carbon chemistry as the currents pulsed across the reef. The team also dispatched a few benthic landers, platforms caked in sensors that sit on the seafloor and monitor coral growth (among other things) for months at a time before being recovered so the data can be downloaded.

Ringham hopes the information she's gathering will inform policy decisions, such as those that determine which regions of the ocean to protect from activities like trawling and fishing that would further disrupt the corals.

The role of particulates

A few months earlier, in summer 2019, Ringham traveled to coastal Eilat in the south of Israel to collaborate with the Interuniversity Institute for Marine Sciences. She again used CHANOS II, this time deployed off a dock in the Gulf of Aqaba, to investigate a different question.

It's believed that most of the carbon entering the world's oceans from dissolved CO_2 gets built into shells and skeletons—a natural drawdown of the greenhouse gas. But there's another way that carbon can be pulled out of solution. When particulates (from river deposition or dust storms, say) are suspended in water, they act as nuclei, attracting and mineralizing carbon, locking it up in solid form.

Up until now, it's been almost impossible to quantify the significance of this process in regional and global climate models because commercial sensors struggle with bubbles or murky water—two things in ample supply in coastal waters like those off Eilat. CHANOS II worked well under these conditions, and Ringham is evaluating its findings now.

Her results on both projects will yield baseline information from places that historically have been hard to monitor. But more broadly, the work Ringham and others are doing to develop sensors like CHANOS II are helping to determine "what we need to do to tackle the atmospheric and ocean CO_2 problems to make better decisions down the line," she says.

Covid-19 certainly complicated matters. Ringham was only able to work for about a month in her basement before her samples ran out (she regained access to the lab in July). The benthic lander data from Florida was significantly delayed because collaborators weren't allowed in their labs and ship schedules were on hold for months. And Ringham was supposed to return to Eilat this spring, "but then Israel shut its borders and the world went to hell," she says. "It's been a slow process."

So over the last year, Ringham has busied herself with other pursuits: watercolor, pottery, even jewelry making ("when I came back from Eilat, my suitcase was half filled with pounds of sea glass," which she's beveled, drilled, and formed into necklaces for friends and family).

She's also served on committees implementing a range of gender equity and diversity initiatives across WHOI, work that feels especially meaningful as a woman in a field dominated by men.

As Ringham inches toward her dissertation defense, she's eyeing the horizon beyond graduation cautiously. "We'll see what happens in terms of hiring freezes and where the world is," she says. She might continue her research in a public-serving scientific institution like the National Oceanic and Atmospheric Administration, NASA, or the US Geological Survey. However things pan out, Ringham intends to continue fusing her knack for developing technologies with her commitment to improving the world around her—from a perch above basement level. –Ari Daniel PhD '08

Ringham hangs onto CHANOS II in the waters off Eilat, Israel, in 2019.

PHOTO: BOAZ LAZAR

Engineering Disease Fighters

With synthetic biology and AI, Jim Collins takes on this pandemic—and the next

In late January 2020, just as he was stepping on stage to tape a TED video in New York, Jim Collins learned that the new respiratory virus discovered in Wuhan, China, was infectious in asymptomatic people. "I turned to the folks in the audience and said, 'I think this is going to be really bad,'" recalls Collins, the Termeer Professor of Medical Engineering and Science in MIT's Institute for Medical Engineering and Science and the Department of Biological Engineering.

Within weeks, he was charging ahead on multiple research fronts to help address the rapidly expanding threat of Covid-19, the disease caused by the SARS-CoV-2 virus. These efforts, focused on new technologies to deliver accurate Covid-19 diagnoses quickly and conveniently, have yielded an FDA-approved rapid test and a diagnostic mask, both made possible by the latest advances in CRISPR and machine learning, and a multidisciplinary team that leapt into action.

"As the pandemic unfolded in February and early March 2020, more and more people wanted to do what they could to help out," says Collins. "As a lab director, I began working to figure out how we could best contribute to fighting the pandemic."

Poised for action

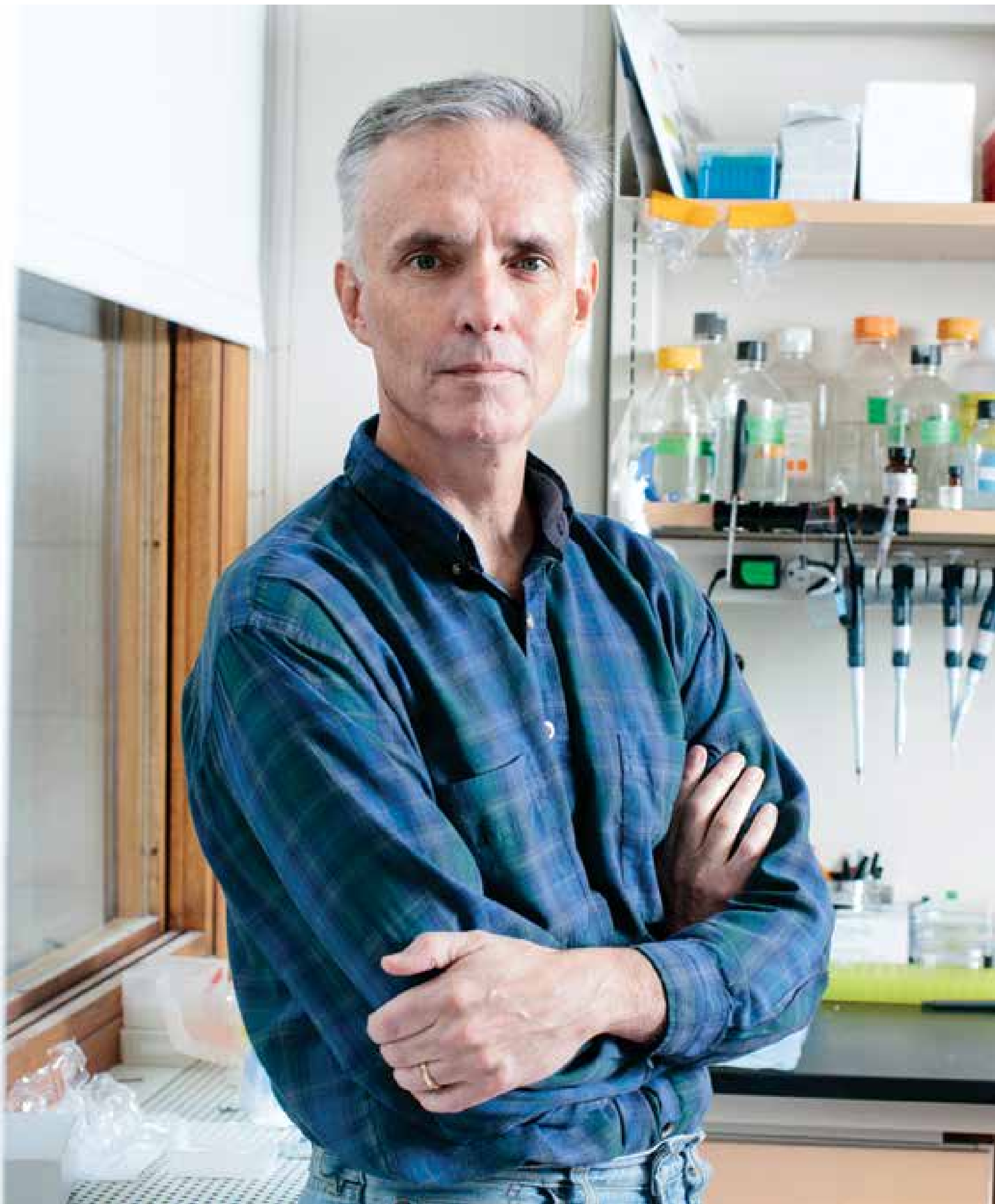
In many ways, Collins was perfectly positioned to take on the crisis. A driving force behind the field of synthetic biology, the engineering of biological parts and systems at the molecular level, he was already focused on pathogens and their impacts on human health. Affiliated with the Broad Institute of MIT and Harvard and Harvard University's Wyss Institute, Collins could count on a deep bench of students, postdocs, and collaborators in bioengineering, physics, computer science, chemistry, and microbiology. Further, he was a cofounder and director of the startup Sherlock Biosciences, which is pioneering the application of CRISPR technology and synthetic biology to transform molecular diagnostics.

Collins and his partners swiftly realized they could repurpose some of their bioengineering work and pivot to focus on Covid-19. The first effort out of the gate involved Sherlock Biosciences. The biotechnology company, launched in 2018, is built in part around a unique diagnostic platform originally devised by Collins and his Broad and MIT colleague Feng Zhang, the James and Patricia Poitras Professor in Neuroscience at MIT. Their method, which harnesses CRISPR technology to detect minute amounts of DNA or RNA and thereby identify pathogens, had been used successfully to detect the Zika and Ebola viruses.

"In February, in a matter of a few weeks, our team at Sherlock Biosciences was able to develop a SARS-CoV-2 test that has 100 percent specificity and 100 percent sensitivity at a fraction of the cost of PCR [polymerase chain reaction, the most commonly used, high-accuracy test] and can produce a result in a fraction of the time," says Collins. In May 2020, this test became the first FDA-authorized use of CRISPR technology to hit the market.

Seeking avenues for even greater impact, Collins and Sherlock researchers also began developing a point-of-care version of this CRISPR diagnostic test. "We want to eliminate the need for centralized testing, which is currently the dominant testing infrastructure," Collins explains. "We envision setting up facilities at workplaces and at schools that could process results in 25 minutes, unlike most PCR tests conducted at centralized facilities, which take several hours."

Collins also launched a third research effort, a venture into wearable diagnostics at his Wyss Institute lab. "We have developed a face-mask insert based on our



freeze-dried, cell-free synthetic biology technology that collects water vapor and droplets given off during the normal acts of breathing, talking, coughing, and sneezing," he says. "If the virus is present, CRISPR elements detect it and the results read out on a flow strip similar to a pregnancy test, in roughly an hour."

Collins notes this diagnostic insert is intended exclusively as a personal surveillance scheme. "It wouldn't have the readout on the outside like a scarlet letter, but as a way of offering additional functionality to masks, which people should be wearing anyway," he says. Better diagnostics and continued containment will be essential for months to come, even as vaccinations continue, Collins believes, because we won't soon reach the required levels of collective immunity for return to normal life.

Space to create

Difficult, high-impact problems have long appealed to Collins. When his two grandfathers became disabled—one blind and the other partly paralyzed by stroke—Collins wanted to acquire the tools for restoring human functions. In high school and college, he immersed himself in physics, math, and biology. After studying medical engineering on a Rhodes Scholarship, he spent a decade at Boston University developing neurological and physiological aids to improve balance control and sensory function. Then Collins's mentors suggested he look into "what an engineer could do in molecular biology," he says.

"The room for creativity in the field was expansive," he comments. "There were so many things we could do both in basic and applied sciences." While training himself in this new discipline, he discovered that the most intriguing questions "lay at the interface of engineering and biology, and that this was where we could be most innovative and impactful."

Collins has invented dazzling technologies, including genetic circuits that enable new functions in cells and a process for freeze-drying a cell's genetic machinery onto paper, where it can later be rehydrated. These techniques serve as the scaffolding for a range of biomedical diagnostic tools, including those that target viral and bacterial infections. But Collins has also harnessed his bioengineering breakthroughs to crack another problem of critical importance.

"Antibiotic resistance is one of the existential threats to humankind," he says. "And it has figured prominently in the pandemic—50 percent of Covid patients who die have a bacterial coinfection." With Regina Barzilay, the School of Engineering Distinguished Professor for Artificial Intelligence and Health, Collins is applying machine-learning algorithms to plumb vast molecular databases for antibacterial properties. The first result of this partnership was announced in February 2020: a compound called halicin that proves broadly effective against such dangerous bacteria as *Clostridium difficile* and *Mycobacterium tuberculosis*.

Collins and Barzilay co-lead the Abdul Latif Jameel Clinic for Machine Learning in Health at MIT, which is focused on applying artificial intelligence (AI) to challenges in health care. With a major award from The Audacious Project, a TED venture to find solutions to the world's most urgent challenges, they are expanding their use of AI to avert a lethal microbial plague. "Even in the midst of this pandemic, we have been advancing our work to discover and design new classes of antibiotics against the world's deadliest bacterial pathogens," says Collins.

Expanding this arsenal against pathogens is essential preparation for the next, inevitable pandemic. The worldwide response to Covid-19 revealed weaknesses, Collins believes. "We are behind in developing diagnostics, especially at-home, point-of-care diagnostics; we need better technology in place for appropriate and meaningful contact tracing; and we should encourage more young people to use their talents to tackle problems in infectious diseases," he states. "We need to do a much better job for the next pandemic." —Leda Zimmerman

The face mask at left was developed in the lab of Professor Jim Collins (far left). It can detect Covid-19 and produce a lateral flow assay (LFA) readout like those seen in pregnancy tests. Researchers tested the mask using a breathing simulator, top photo.

FACE MASK AND DEVICE IMAGES: COURTESY OF WYSS INSTITUTE, HARVARD UNIVERSITY; PORTRAIT PHOTO: M. SCOTT BRAUER

DAVID ’69 AND JEANNE-MARIE BROOKFIELD

Second-Generation MIT Family Gives Back

Donald Brookfield ’32 first saw MIT in 1926, when he and his father drove by the campus. David Brookfield ’69, Donald’s son, explains: “He asked his dad what it was. He said, ‘That’s a university where you can get really excellent technical skills.’ So my dad decided right then that MIT was where he wanted to go.”

Donald was admitted just one year later, although the Institute required him to wait a year until he turned 17 to enroll. He graduated in 1932 with a degree in electrochemical engineering and throughout his life brought creativity and determination to his work as well as appreciation for a job well done, his son David says.

Like his father, David Brookfield attended MIT. He studied mechanical engineering before following his father and grandfather into the family business, Brookfield Engineering Laboratory. Founded during the Great Depression, the business grew into a globally recognized company. Its signature product, the Brookfield viscometer, was designated by the American Society for Testing & Materials as the national measurement standard for quality control of viscosity. David notes with pride that the Brookfield viscometer has become the global standard in viscosity measurement.

Before the family company developed the instrument, David explains, there was only one reasonably affordable viscometer on the market. Donald took a look at it and told his own father, “I can make that better, if you’ll give me a chance.” And he did. “He was a very sharp engineer,” David says. “He invented the original Brookfield viscometer.”

To celebrate his father’s legacy and their family’s long connection with MIT, David and his wife, Jeanne-Marie, established the Donald Brookfield Graduate Fellowship in Mechanical Engineering in the fall of 2019. “My father was definitely the inspiration for this gift,” says David.

Now retired, David and Jeanne-Marie live in Sharon, Massachusetts, in the home where they raised their four children.

The family sold Brookfield Engineering Laboratories in 2016 (it remains in operation as part of AMETEK, Inc.), but David says he is grateful to have spent his career working with his father, siblings, and other relatives to build and grow the company. “I was very happy to be involved in a small family business, because those businesses are really the heart blood of American industry.” His hope for the Brookfield Fellowship is that it will nurture in MIT graduate students some of the same ingenuity and drive that helped his family’s business to flourish.

Supporting students

Jeanne-Marie connects their fellowship gift to the family’s core values of living simply and sharing what they have with others. “You need a sense of purpose,” she says, noting that giving back, whether to MIT, other philanthropies, or to family and friends, provides purpose as well as joy. “MIT does wonderful things,” Jeanne-Marie says. “I was very heartened to read in [the Fall 2020 issue of] *Spectrum* about the wonderful contributions being made by MIT students and faculty in Covid-19 research during this pandemic.”

David says he hopes the fellowship will help MIT students meet the challenges they will face both at the Institute and after graduation. “Everybody that goes to MIT has to work incredibly hard. It is not a school that gives benefits away; you have to earn your stripes.” That rigor may be why MIT graduates are known for achieving the extraordinary, he says, whether they are starting a new business or founding a new field of study.

“I hope, with the fellowship, to help MIT attract the most talented students and help those individuals to achieve all that they are capable of,” David says.

One such individual is Elizabeth Pedlow ’20, a master’s candidate in mechanical engineering who is the first recipient of the Brookfield Fellowship. The Brookfields were pleased to meet Elizabeth in early 2020 and hear about her work at MIT and her hopes for the future. Their meeting also meant a great deal to Elizabeth, who was grateful for the chance to thank the Brookfields in person for supporting her MIT education. “This fellowship has changed my life,” she says. —Kris Willcox

READ MORE

“Everyone at MIT has something that makes them light up when they talk about it,” says Elizabeth Pedlow ’20, inaugural recipient of the Brookfield Fellowship.

READ HER STORY AT
spectrum.mit.edu/pedlow

PHOTO: COURTESY OF DAVID AND JEANNE-MARIE BROOKFIELD

THUAN ’90, SM ’91 AND NICOLE PHAM

A Financial Aid Success Story

Thuan Pham ’90, SM ’91 began life in the United States as a refugee from Vietnam and rose to chief technology officer of Uber, a post he left last year. He credits MIT with helping make his successful career possible.

“MIT taught us how to think, and that was very, very important,” he says. “An MIT education is rigorous. It gives you a sense of grit that is very applicable in the workforce.”

The technologies Pham learned as a computer science major at MIT are very different from those he works with today, but he says the education he got at the Institute remains relevant. “The skill MIT gave us was the way to solve problems.”

Beginning his post-MIT career at Hewlett-Packard, Pham soon learned where and how he worked best. “I seek out smaller companies; I tend to get bored at large companies,” says Pham. “I continued to develop and grow new skills and went from one company to another to succeed.” Pham worked at VMware, NetGravity, and Silicon Graphics, among other companies, before joining Uber in 2013. “Getting through MIT gave me the agility you need.”

Now Pham and his wife, Nicole, are philanthropists, recently establishing the Thuan and Nicole Pham Professorship Fund in the MIT Stephen A. Schwarzman College of Computing. “I was always very clear that I was going to endow a professorship in the computer science area,” he says. “That’s my profession, and I love technology.”

Why choose MIT as the recipient of their first substantial gift? “MIT has given me an amazing education and also opened so many doors for me on my career journey,” he says. “This is the least that I can do to give back and to pay it forward.”

Refugee experience

Even before MIT, Pham felt lucky to be in the United States, since his family had a harrowing escape from Vietnam in 1980. “You didn’t just get on a plane,” he explains. “You sneaked out in a rickety boat.” Many thousands died on such journeys, but Pham’s mother was determined to get her children to the United States.

Unfortunately, Pham’s father had to stay behind. “He didn’t come for a decade,” says Pham. “He came the year I graduated from MIT, so I grew up without a father.”

En route, Pham, his mother, and brother spent months in a refugee camp in Indonesia. “There was no infrastructure,” he says, and no schooling was available. “The only way I could study was listening to the man right next to us who spoke English very well.”

Once safely in Maryland, the Phams doubled up with another refugee family in a two-bedroom apartment. “My mom had to work two jobs,” he says. “We hardly ever saw her.”

Pham excelled in math, science, and computer science. He was accepted at MIT, but at first assumed it would financially be out of reach. Then, his financial aid package arrived. Pham and his mother were stunned to find that with the help of a scholarship, work study, and a Pell Grant, his mother could make it work. “I never forgot that,” he says.

Pham enjoyed his years at MIT enormously. “I made a lot of lifelong friends.” But it was his academic experience that left the strongest impression: “I absolutely loved all the computer science,” he says. “I was able to take classes, some outside my major, with world-famous professors like [Institute Professor] Barbara Liskov, who won the Turing Award, and Robert Solow [emeritus professor of economics], who won a Nobel Prize.”

Pham’s goal now is to sustain that level of world-class education for students. “What I want is to help the world by helping MIT students.” —Christine Thielman

PHOTO: DAVID ROBERT ELLIOTT

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CHALK TALK

Intrepid students take tradition online

JESSIE
using paper

JESSICA
using paper

LUCY
using iPad

ALICIA
using iPad

Until the pandemic disrupted the tradition, the huge chalkboard in the Ray and Maria Stata Center featured inspirational artwork created by students: the Chalk of the Day. During January's Independent Activities Period, with support from the Council for the Arts at MIT, Jessie Wang '21 and Jessica Xu '21 organized a series of workshops to recapture the joy of chalk art virtually. Alicia Guo '22, Lucy Wang '21, and Priscilla Wong '20 helped with the workshops, which introduced drawing techniques to 90 people. Pictured are breakout rooms from the first workshop.

IMAGE: COURTESY OF CHALK OF THE DAY

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