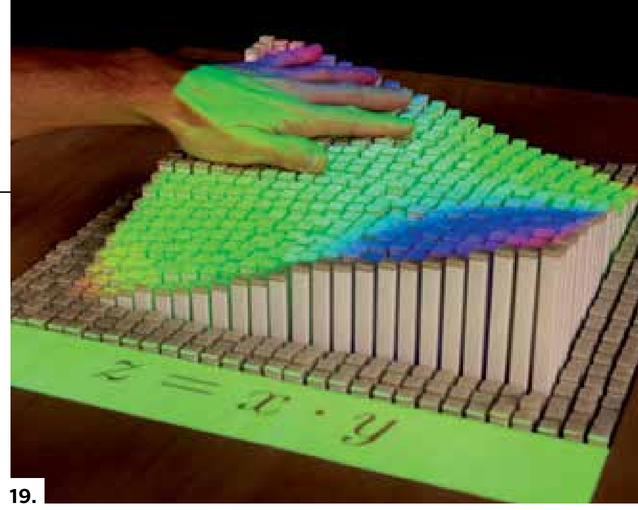
SPECTRVM

MASSACHUSETTS INSTITUTE OF TECHNOLOGY   SUMMER 2015

Water + Food

Changing the Global Equation



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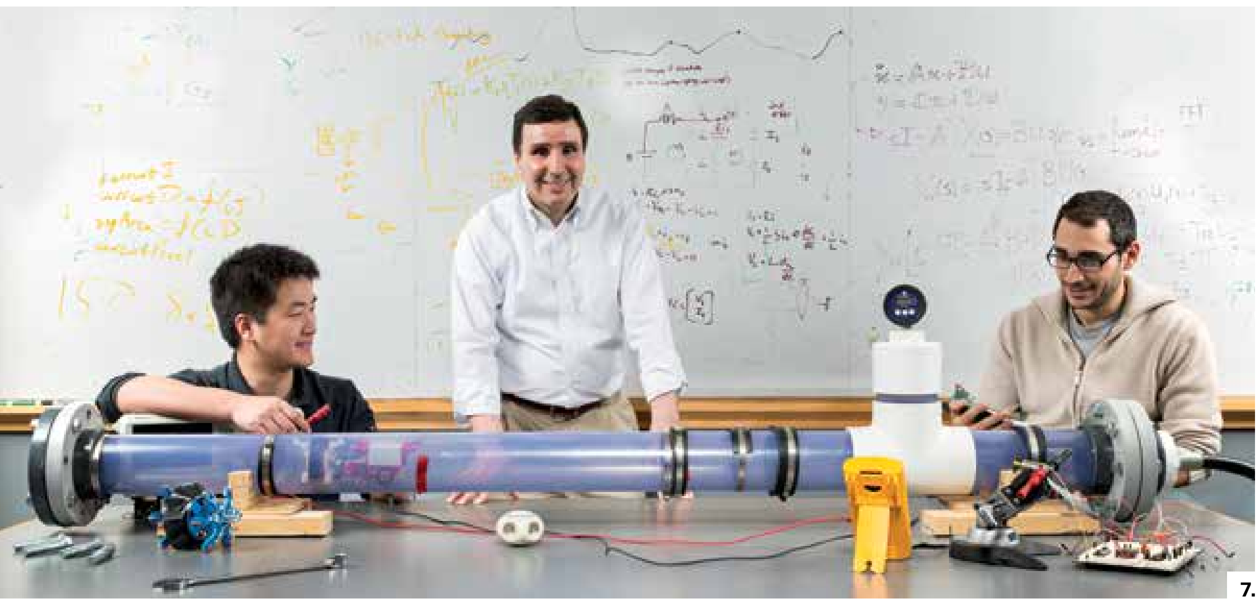

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Summer 2015

THE MIT SPECTRUM is a newsletter distributed without charge to friends and supporters of the Massachusetts Institute of Technology by MIT's Office of Resource Development.

ON THE COVER

Once the fourth largest lake in the world, the Aral Sea has been shrinking since the 1960s after the rivers that fed it were diverted by irrigation projects. The sea spans the border between Kazakhstan in the north and Uzbekistan in the south.

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Changing the Global Equation on Water and Food

DURING A RECENT TRIP TO SÃO PAULO AND RIO DE JANEIRO, I witnessed firsthand the effects of one of the most pressing issues of our time: fresh water scarcity. Brazil is suffering its worst drought in 80 years, with water shutdowns and rolling blackouts, a byproduct of the country's reliance on hydropower. From Brazil to California, which is currently in the grips of one of the most extreme droughts in state history, water is quickly becoming the next oil: abundant in some areas, scarce most everywhere else.

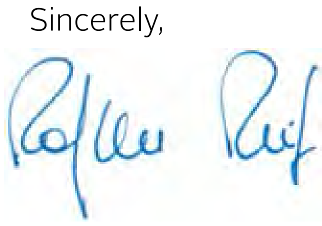
During my travels, again and again, my hosts asked me the question that inspired this issue of *Spectrum*: What is MIT doing to combat global problems tied to scarcity of water and food?

The Abdul Latif Jameel World Water and Food Security Lab (J-WAFS) represents MIT's comprehensive effort to identify practical, sustainable solutions to this growing threat. In true MIT fashion, J-WAFS draws on expertise across the Institute, in fields as diverse as biology, earth science, civil engineering, urban planning, and political science. In this issue of *Spectrum*, J-WAFS's director, John Lienhard, describes the lab's mission and approach to identifying solutions.

J-WAFS represents only a piece of MIT's water and food puzzle. From the student and alumni startups highlighted on pages 12 and 13, to the work of Antoine Allanore to find sustainable ways to replace the effectiveness of chemical fertilizer, brilliant minds across our community are bringing their knowledge to bear on this great challenge.

Our ambition is as grand as the problem itself: We aim to contribute to a fundamental change to the global equation on water and food. Together, and with the full might of MIT behind us, I believe that goal is within reach.

Sincerely,



L. RAFAEL REIF

Building a Sustainable Society

"Since 1900, global population has quadrupled. The fact that billions of human beings now take for granted their access to fresh water and food is a triumph of human ingenuity. But already, billions more struggle for those basic resources. A central challenge of our time is how to build a sustainable future for the whole human family." — President L. Rafael Reif

MIT is playing a key role in helping to ensure the sustainability of human civilization into the future. Across the Institute, and across the world, faculty and students are pursuing transformative research to address the urgent challenges of water and food.

Current trends show that by 2050 the human population will have increased by nearly 30%. The world's changing societies will need more water to produce the food and energy needed by this growing population. Worldwide, the majority of fresh water use—about 70%—goes to produce food. But from the arid states in the Arabian Gulf to the agricultural fields of California, water systems already are at the limit. With further pressures of climate change, challenges will only increase.

And yet, there is much hope that the world's thirst for water and hunger for food can be sated. MIT's international perspective and extraordinary strength in cracking complex problems is empowering faculty and students, who view the huge, interconnected challenges of food, water, and energy as an opportunity for action.

J-WAFS: A Nexus for Water and Food Research at MIT

The Abdul Latif Jameel World Water and Food Security Lab (J-WAFS) launched in September 2014 to spearhead research "that will help humanity adapt to a surging population and respond to water and food scarcity worldwide." Recently, *Spectrum* interviewed John Lienhard, director of J-WAFS and professor of mechanical engineering, to learn more about the new center's mission.

What is the role of J-WAFS?

JL: Our mission is to support the work of the MIT community in water and food and to make the whole greater than the sum of its parts. And we want to make that whole have a positive impact on the world outside MIT. Many others are working in the food and water space around the world—we clearly are not the first group to tackle these big issues—but we think that MIT's unique footprint will make for unique contributions through J-WAFS.

What strengths does MIT bring to the table?

JL: MIT as a whole has a singular strength in creating basic research and then translating it to innovations in technology that have broad benefits. And we are good at undertaking complex, coupled problems and unraveling them.

Our specific capabilities are diverse. We've got tremendous strength in environmental and climate-change science which can help us understand at a regional level what stresses are likely to affect food and water resources. We've got unparalleled strength in the biological sciences, which may allow us to look at particular problems of food safety and food production. We have strength in big data and information science that will allow us to examine and manage water and food systems at a level of detail and responsiveness not previously possible. We've got strength in sensors and nanotechnology that will allow us to detect rotting food, leaking pipes, and unsafe water—and to correlate that information to actually improve distribution. And we've got strength in water purification, desalination, and technology for safer water supplies.

One important point about these great technical solutions is that if nobody will adopt them, they're not very useful. Our faculty in the social sciences bring understanding of what makes something more or less acceptable in a particular country or culture, how you communicate—or negotiate—about these issues, and how to approach the economic barriers to implementing a solution.

And we've got great strengths in business and innovation, too. If there's one thing MIT does well, it's create technology and spin it out to market. In fact, we've just started the J-WAFS Solutions program to assist MIT students and faculty in translating their innovations in water and food, business and technology, into the marketplace.

J-WAFS specifically emphasizes solutions that vary by area of activity. Why?

JL: The problems of water and food are different in every setting: problems and solutions in urban China are different from problems and solutions in rural India, and those are different from what's happening in the Arabian Gulf or from what's happening in Brazil. And if we are going to create opportunities for MIT faculty and students to work on those problems, we need partners and collaborators in these regions who know the regional context well and know who to go to to get things done, and who, ultimately, will be the ones who translate ideas from research collaboration with MIT into solutions that are used in their own country or region.

Does this mean J-WAFS leans towards international issues?

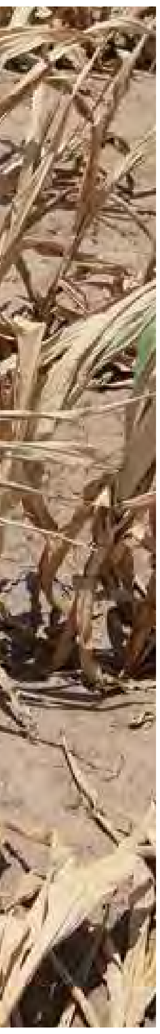
JL: We are definitely seeking international partners, but we're also interested in domestic problems. And there's clearly overlap in both the basic science and the technologies that might apply here or overseas. When we look internationally, development is a massive need in important parts of the world, and J-WAFS wants to contribute to that. But research and innovation will also help more developed societies deal with the challenges that they will face from population growth, climate change, and urbanization. Water and food are not only a problem for the developing world: they are also a problem for the first world and for everyone in between.

LEFT Professor John Lienhard is director of the Abdul Latif Jameel World Water and Food Security Lab (J-WAFS).

PHOTO: BEN BOCKO

TOP CENTER

PHOTO: SCOTT OLSON/GETTY IMAGES



Securing Water and Food for a Growing Global Population

"The time is right now to look at water and food security because both humankind and the planet itself are changing rapidly," says Mohammed Jameel '78, founder of the Abdul Latif Jameel World Water and Food Security Lab at MIT. Jameel recently shared his thoughts with *Spectrum*.

Of all the issues you could focus your philanthropic efforts on, why this new lab on water and food security?

MJ: In the past, I have supported and still support initiatives related to several global and regional issues, including education, job creation, and poverty alleviation. The time is right now to look at water and food security because both humankind and the planet itself are changing rapidly. As population and living standards rise, humans are putting unprecedented strains on water and food resources. In addition, the climate is changing and becoming less predictable.

Water and food are essential to life. Today, one billion people lack reliable access to safe water and about 800 million people suffer from chronic hunger or malnutrition. How will we find enough food to feed another two billion people by mid-century with an agricultural footprint and water resources that may be in decline? If we are serious about improving water and food security, we need to stimulate new approaches to long-standing problems. For example, if we can commercialize new disruptive technologies in water and food security that can be profitably adopted by the private sector, we have a chance to make a difference on a massive scale.

The focus of this lab is unique. It brings together faculty and students across a range of disciplines including engineering, science, urban planning, management, and social science. It will provide funding for research conducted by MIT students, postdocs, and faculty to advance these projects to the point where they are positioned to attract venture funding and establish themselves as new companies. It will also sponsor international partnerships.

There is a big opportunity to make a real difference, and I have challenged the lab to positively impact the lives of 500 million people in 10 years. It is a big number, but it will be a measure of great success if we can achieve it.

What inspired you about MIT's vision of water and food security?

MJ: In September 2012, when Rafael Reif gave his inaugural speech as President of MIT, he identified the problem of water and food security as one of the most critical issues facing humankind and one that MIT was uniquely placed to address. That speech marked the beginning of a conversation with Rafael and Professor John Lienhard to explore what could be done to accelerate the work that MIT was doing in this area. It was out of this conversation that the idea of the Abdul Latif Jameel World Water and Food Security Lab emerged, with John Lienhard as the director.

What do you see as the important impacts of population growth, climate change, urbanization, and development on water and food security?

MJ: All of these trends put pressure on water and food security. Water is becoming more scarce and the agricultural footprint is declining because of urbanization and climate change. So we really need to take an "anti-disciplinary" approach that is familiar to MIT, and bring in diverse talent not only to study the problem, but also to ensure that the research effort translates into real action through innovation, commercialization, policy advice, and international partnerships.

What do you see as the role of technology, entrepreneurship, and business innovation in tackling problems of water and food?

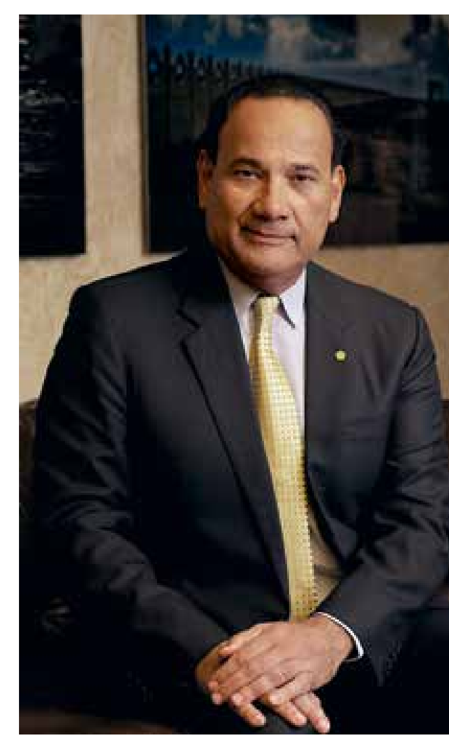
MJ: Developing and commercializing disruptive technology will be key to addressing water and food insecurity. MIT understands this, and one of the defining characteristics of MIT labs is the interplay of research and innovation. We have recently signed an agreement to create a Solutions Fund operated by the lab in collaboration with the Deshpande Center for Technological Innovation. This fund will provide initial capital to help technologies that improve food supplies or meet needs for clean water move out of the lab and into commercial production. The funds are intended to advance these projects to the point where they are positioned to attract venture funding and establish themselves as new companies. It is a significant fund, expected to provide enough money for about 15 projects over the next five years. It will also pilot a new co-investment model for intellectual property licensing at MIT, which, if successful, will likely be implemented by other programs at MIT, such as those dealing with energy or health care. The new lab also supports the MIT Water Club, which has a big focus on fostering water innovation and supporting the commercialization of breakthrough, scalable water technologies and processes.

What importance do you see for regional partnerships in MIT's contribution to these issues?

MJ: Regional partnerships are critical to ensuring that MIT's research has meaningful impacts on the ground. Last year, the new lab convened and sponsored an international, non-partisan Eastern Nile Working Group. Right now, the Grand Ethiopian Renaissance Dam is being built on the Nile River just upstream from Ethiopia's border with Sudan without any management agreement with Ethiopia's downstream neighbors. It is in its early days, but that's a real-world problem affecting one of the world's largest water systems, depended on by more than 200 million people.

Are you optimistic/hopeful that it will be possible to make meaningful progress on these issues in time to make a difference in the coming decades?

MJ: I do not want to raise expectations unrealistically, but we are thinking big. I believe in MIT, and I believe in the power of science to develop disruptive technologies. The most effective way to help improve water and food security is to create new, sustainable technologies that are disruptive to current technologies and can be adopted by global industry. This lab will be the first to combine water and food at a global level, so it has an opportunity to change millions of lives for the better.



TOP Women carry water to their tents in Jamam, South Sudan, one of the most underdeveloped countries in the world.

PHOTO: PAULA BRONSTEIN/GETTY IMAGES

ABOVE Mohammed Jameel is founder of the Abdul Latif Jameel World Water and Food Security Lab at MIT.

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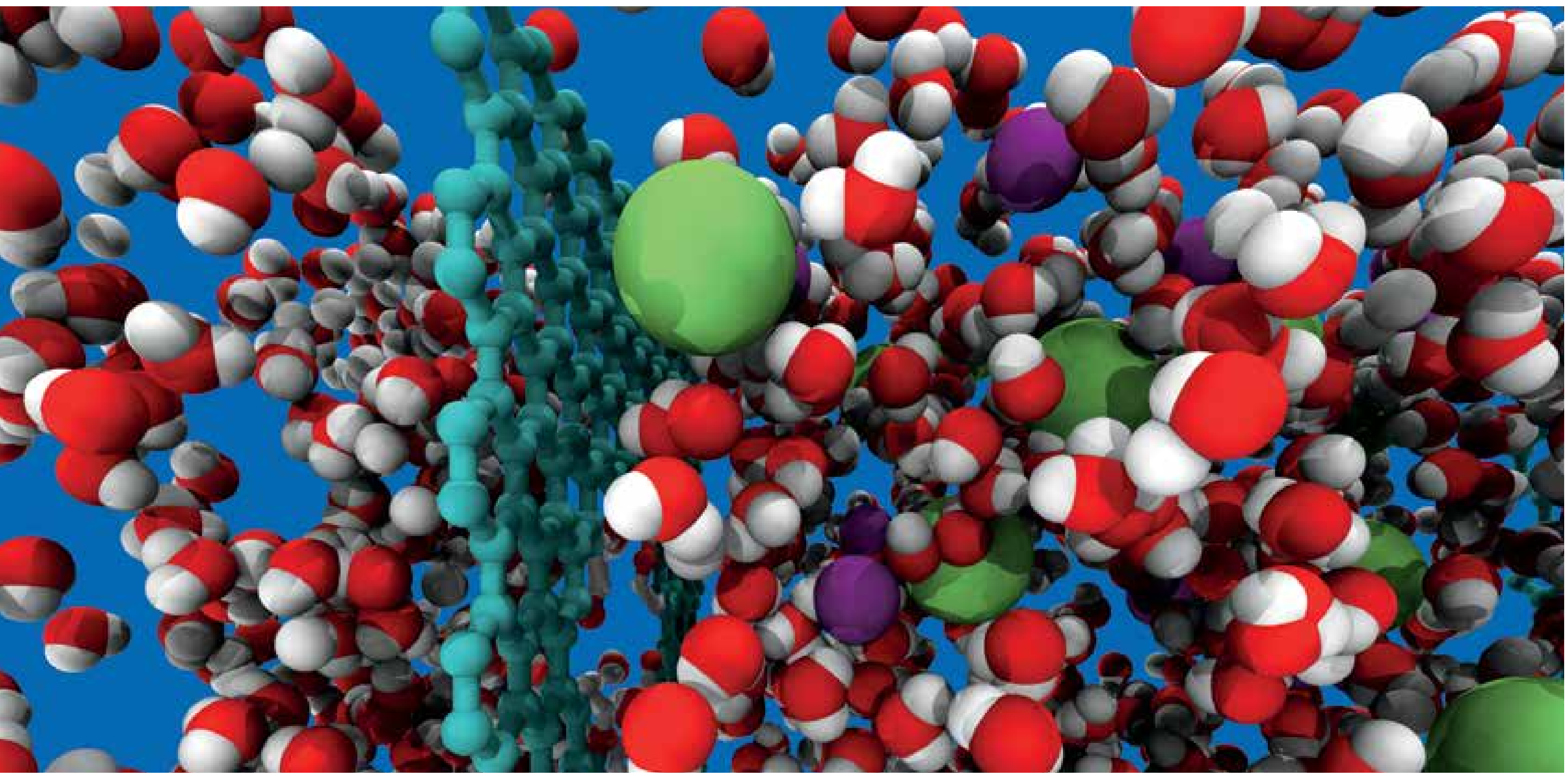

LEFT Graphene sheets with precisely controlled pores could purify water more efficiently.

ILLUSTRATION: DAVID COHEN-TANUGI AND JEFFREY C. GROSSMAN, DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING

CURRENTLY, AN ESTIMATED ONE BILLION PEOPLE lack reliable access to fresh water. Population growth and climate change threaten to increase the problem worldwide, making the oceans—which account for 97% of the water on Earth—a tempting place to seek solutions.

Desalination can make salt water potable, but significant barriers exist to its adoption at larger scales: the technology is both energy intensive and expensive. "We need to think about new ways to make clean water," says Jeffrey Grossman, a professor of materials science and engineering.

Grossman and Evelyn Wang, an associate professor of mechanical engineering, are each tackling the problem from different technical perspectives, but with a shared desire to help solve a major challenge for humanity.

"I grew up in California where drought is a major issue, so I've always been aware of water scarcity and its impact on health and quality of life," says Wang.

Both researchers believe the best hope for turning on the tap lies in transforming the central technology used in conventional desalination, reverse osmosis. This process involves pumping salt water through membranes that filter out salt and other impurities. While current technology is effective, providing 21 billion gallons of water a day to some of the world's most arid areas, the energy required to operate the plants is expensive.

"When you look for opportunities to advance reverse osmosis, the membranes are a key challenge," says Wang. The 1960s-era polymer used in membranes restricts how much water flows through, and this means the pumps have to work harder, drawing more energy. As important, says Wang, the membranes get clogged—or "foul"—over time from impurities in the water and need to be replaced. She wondered if there might be a way to prevent fouling, which would reduce or altogether avoid the need to replace membranes and at the same time achieve a more energy-efficient removal of salt and other impurities.

Wang has been pursuing these questions through two distinct research thrusts, collaborating with colleagues at the King Fahd University of Petroleum and Minerals in Saudi Arabia. In the first, she is using chemistry to synthesize zeolites, crystals that can be found in nature whose properties seem tailor-made for salt exclusion. Made of an aluminum silica hybrid, synthetic zeolites have uniformly spaced pores, 5.5 angstroms in diameter, just small enough to exclude salt ions, but not water molecules. And they can be more easily cleaned. "This is an attractive material, something you could really take advantage of in desalination," says Wang.

Her other research angle dispenses with membranes altogether. Instead, Wang and her Saudi partners have been developing capacitive deionization (CDI), a method of capturing salt ions using electric fields as water spills through a channel between two electrically conductive surfaces. Carpeting these surfaces with carbon nanotubes seems a particularly promising way to pull off salt ions as water flows past, her studies show.

The CDI process, notes Wang, is aimed at desalinating brackish, rather than ocean water, and would be of particular use "in the many remote areas of the world without resources for a reverse osmosis plant."

Approaching the membrane problem from another angle, Grossman asked, "What if you could throw out what you have today and start over: what would the ultimate filter look like?"

For the answer, he has turned to graphene, carbon that takes the form of a hexagonal lattice one atom thick. In computer simulations, Grossman's group showed that a nanoporous graphene (NPG) membrane—graphene with regularly spaced nano-sized holes—was "off the charts" in terms of permeability, hundreds of times more permeable to water than the industry-standard polymer membrane, while maintaining full salt rejection.

Follow-up research, in collaboration with Professor John Lienhard in the Department of Mechanical Engineering, looked at the real operation of a desalination plant to quantify the potential benefits of such high permeability. "It's anywhere from a 15–50% reduction in energy consumption," Grossman says. "That would be a game changer."

Grossman is racing to create a prototype NPG membrane, and contemplating a manufacturing process that would make the material competitive with the conventional polymer. "As a starting point I need to be able to do two things: make a ton of it and poke nano-holes in it, both really cheaply," says Grossman.

His research group is currently experimenting with different ways of synthesizing NPG, including carefully calibrated ripping or puncturing of the graphene lattice to remove carbon atoms and create well-spaced holes. "I am hopeful that soon we will have a prototype based on technology that can scale," Grossman says.

Wang is also moving toward the prototyping stage for her research. She has a centimeter-size sample of a zeolite-impregnated membrane, although moving up to meter scale and avoiding material defects "are issues we have yet to face," she says.

Both researchers are bullish on the potential for laboratory innovations to make inroads in quenching the world's thirst. "In an age where we can put atoms almost anywhere we want to make almost anything," says Grossman, "we have the capability to design practically limitless new materials…that don't just slightly improve a process, but completely change performance, offering us a chance to solve crucial problems in the world such as access to clean water." — LEDA ZIMMERMAN

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Carlos Riva '75 on San Diego's history-making desalination plant
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WASTE LESS
Detecting Leaks with Robots, Wireless Sensors

ONE WAY TO INCREASE the supply of water for cities and regions is simply to waste less of the water we already have.

"I don't think there is a city in the world that does not have leakage in its water system," says Kamal Youcef-Toumi, a professor of mechanical engineering. Many water systems lose vast amounts of this precious resource through leaks in the pipes that carry it to our homes and businesses. In New York and Boston, for example, some 10% of our water is lost in this way. In London the number is closer to 30%, Rome leaks away 30–40%, and some cities in the developing world lose almost half.

From aging infrastructure to damage wrought by burst pipes, it's easy to see that "there are big challenges associated with water losses in the system," says Andrew Whittle, the Edmund K. Turner Professor in Civil Engineering.

Youcef-Toumi and Whittle are each working to increase the world's water supply by decreasing water loss through leaks.

Whittle's work began as a research project through the Singapore-MIT Alliance for Research and Technology. He and colleagues approached Singapore's Public Utility Board about installing a test bed of wireless sensors inside water pipes. The idea was that the sensors could pinpoint leaks in real time by detecting changes in the water pressure along a pipe, then transmit the data wirelessly to control centers. Sophisticated analytical tools not only allow the sensors to extract important signals from the background noise at every location, but also help pinpoint the locations of leaks.

Whittle's team was the first to deploy instrumentation inside water pipes for the detection of leaks. The conventional approach to the problem involves utility employees who listen for leaks with acoustic devices as they traverse a neighborhood.

The researchers soon realized the potential of the technology. "We went rather quickly from concepts and prototyping to a point where we were starting to observe real events [leaks and bursts] fairly regularly," says Whittle.

In 2011 his team formed Visenti, a company to commercialize the technology. Today, they've deployed sensors all the way across Singapore. Visenti has also completed pilots in Melbourne and Hong Kong, and is conducting two others in Paris and Bordeaux.

Swimming robots are key to the system being developed by Youcef-Toumi and colleagues at the Center for Clean Water and Clean Energy at MIT and King Fahd University of Petroleum and Minerals (KFUPM). The intelligent machines, which travel inside the pipes, include onboard sensors that, like Whittle's stationary ones, detect leaks in real time due to changes in pressure. They, too, relay the data through a wireless network to control centers above ground.

The robots can not only detect leaks on the fly as they whisk past in swiftly moving water; they can also stop to fix them. "A robot can lock into place around the area of the leak, then, for example, spray a liquid compound at it that hardens very quickly," says Youcef-Toumi, who is co-director of the MIT-KFUPM center. The robots are also designed to adjust their size automatically when moving into pipes of different diameters.

The team has tested the robots in the lab. This summer they plan to conduct their first field tests in a mile-long network of pipes in Saudi Arabia.

Both Whittle and Youcef-Toumi are excited about the potential for their technologies. "We are developing technologies for the good of mankind," says Youcef-Toumi. — ELIZABETH THOMSON

ABOVE Andrew Whittle and Kamal Youcef-Toumi are working to increase the world's water supply by decreasing water loss through leaks.

PHOTO: KEN RICHARDSON

WASTE LESS
The Water-Food-Energy Nexus

PROVIDING SUSTAINABLE SUPPLIES of water, food, and energy are deeply interrelated challenges. "It's a major focus for researchers today as we realize the dependency of each of these systems upon the performance and sustainability of the others," says James Wescoat, the Aga Khan Professor of Islamic Architecture and an expert in water management.

Wescoat and Afreen Siddiqi, a research scientist in MIT's Engineering Systems Division, collaborate at the epicenter of the water-food-energy nexus, tackling those interdependencies through projects in the Indus Basin in Pakistan, which has the world's largest contiguous network of irrigation canals. Working with Professor Abubakr Muhammad of Lahore University of Management Sciences, they are exploring the impact of smart irrigation systems on energy and food security.

Among other things, they are hopeful that a network of sensors connected to multiple IT portals in different agencies, universities, and the field will allow a more efficient use of water and the energy used to pump and transport it, all while increasing the yield of staples like wheat. Such a network "should give us more information about the water system, which then allows you to manage it better," says Siddiqi, who notes that Pakistan's water productivity for wheat, or the amount of wheat produced per volume of water, is one of the lowest in the world.

"My dream," says Siddiqi, "is to harness these resources in an environmentally sensitive, sustainable way for future generations. Ultimately, what we hope is that these smart irrigation systems can improve productivity and therefore allow us to grow more with the same amount of resource." — ELIZABETH THOMSON

LEFT Afreen Siddiqi and James Wescoat hope a network of sensors will allow more efficient use of water and the energy used to transport it, while increasing yield of wheat.

PHOTO: KEN RICHARDSON

Making the "Green Revolution" Truly Green

By the mid-20th century, hunger and malnutrition were rampant in many parts of the world, exacerbated by population growth and drought. But a wave of new agricultural technologies and practices, now known as the "Green Revolution," averted the catastrophic global famine that was widely predicted in the 1960s. Through the breeding of hardier varieties of cereal grains, new irrigation tactics, and expanded use of chemical fertilizers, heavily populated and developing countries saw substantially higher crop yields by century's end. In India and Pakistan, for example, wheat production nearly doubled between 1965 and 1970; dramatic gains were also realized in countries including Mexico, China, and the Philippines.

The Green Revolution has fed billions of people—but not without a price. One area of major concern: fertilizer-rich agricultural runoff is triggering toxic algal blooms in ecosystems around the world, jeopardizing human health and depleting fish populations. And the demands of irrigation have strained many regions' water supplies.

MIT's researchers are now working to sustain and extend the bounty of the Green Revolution while mitigating its costs. They are pursuing technological solutions, such as alternatives to harmful chemical fertilizers, and advancing the development of new policies and practices that could transform food production for the 21st century.

Rocks for Crops

IN 2011, AFTER GIVING A TALK about low carbon emission steel making, MIT metallurgist Antoine Allanore was approached by a Brazilian iron ore miner with a proposition: turning rocks into fertilizer.

"Okay, I'm listening," said Allanore, Thomas B. King Assistant Professor of Metallurgy, who specializes in sustainably extracting metals from ore.

The miner wanted to make potassium-based fertilizer, often called potash since farmers used "pot ash" as their source of potassium before industrialization. "Man has known for a long time that ashes from wood fires make crops grow better," Allanore says.

Now Allanore is scaling his patent-pending potash extraction process in preparation for the launch of a pilot production plant in Brazil. He is also collaborating with an agronomy agency there to test his product on hectares of crops. "After so much hard work in the lab, it's fantastic to see crops growing," he says.

Allanore's technology has the potential to remove a significant barrier to agricultural expansion in Brazil caused by difficulties in securing and making use of traditional potash products. More broadly, however, his work could also have an influence on agriculture in other areas of the world struggling to improve crop yields, such as some areas of China, Africa, India, and South Asia.

Modern potash production has focused on the mining of potassium-based salts from dried-up seas. The salts met the needs of farmers in the United States and northern Europe, where the soil is rich with silica-based clay that retains potassium as the salts rapidly dissolve during rainstorms. But in tropical soils, rain washes the potassium away.

Another problem is that the key mines supplying today's potash market are located in Canada, Russia, and Belarus. Few suppliers control the market, and small farmers in developing nations don't have much bargaining power. These farmers also pay to ship the salts overseas, and then from seaports to remote interior farmlands, a costly, difficult prospect given poor road and railway conditions in the developing world. "These regions need their own sources of potassium, and their own fertilizers that match their soils," says Allanore.

The rock presented to Allanore in 2011 was potassium feldspar, a strong, insoluble, granite-like rock found around the globe. Allanore needed to find a way to get at the potassium inside, about a fifth of the rock's composition. But he also needed to be sensitive to the realities of farmers in remote areas of Brazil or Africa, who may have limited access to energy or water. "I like electricity and could use it," he says, "But electricity isn't readily available in remote areas."

Instead, Allanore applied heat, at a mid-range temperature of 200°C, and calcium oxide from limestone. The resulting chemical reaction breaks down the feldspar into smaller rocks, exposing potassium that slowly dissolves in water. These rocks also contain other components, such as silica, that are good for enriching tropical soil. "For use in the north, we'd get rid of the silica and leave behind potassium that would dissolve faster," says Allanore. "But in Brazil, the silica will help form a better soil over time."

In trials in greenhouses in Brazil, Allanore's potash rocks fertilized crops as well as salt-based potash. Trials are underway to compare performance in fields of potassium-dependent crops that are important to Brazil, such as soybean and sugar cane, with results coming in a year or so. "It will be a practical demonstration of whether our material is actually a solution to the potash problem in Brazil," says Allanore.

Allanore's potash rocks could also be produced in Africa and other tropical regions using local feldspar and limestone, though similar field tests would need to be done since each region grows different crops.

— ELIZABETH DOUGHERTY

LEFT Antoine Allanore, who specializes in sustainably extracting metals from ore, talks with visiting scientist Katsuhiro Nose.

PHOTO: BEN BOCKO

ABOVE LEFT

PHOTO: TIM GRAHAM/GETTY IMAGES

Rice Experiment Yields Results

EVERY SUMMER IN SIERRA LEONE, people face two months of hunger when stocks of rice run dry and prices escalate. Professor Tavneet Suri conducted a randomized experiment on the economics of a new high-yield rice to learn more about addressing this glaring issue. She found the hunger season could potentially be shortened, and yields increased for the adopters of this technology, mitigating the adverse effects of this lengthy period of starvation.

Suri, a development economist and the Maurice F. Strong Career Development Professor in Applied Economics at MIT Sloan, serves as scientific director for Africa in the Abdul Latif Jameel Poverty Action Lab (J-PAL) and co-chair of the J-PAL Agriculture program. She and J-PAL executive director Rachel Glennerster conducted an experiment—designed like a clinical trial in medicine—which tested the adoption and impact of a new kind of rice known as NERICA (New Rice for Africa). NERICA combines the high-yield properties of Asian rice with the resilience of African rice, which is known for resistance to drought and disease. The experiment tested mechanisms that could encourage farmers to try NERICA, such as subsidies to purchase seed, training in new cultivation methods, and information about how its adoption might affect agricultural and health outcomes.

"Initially we thought NERICA's shorter growing season could produce two rice harvests, or that a higher yield would give farmers more rice to sell and increase their overall economic situation," Suri says. "But that was not quite the case. We found instead a profoundly simple outcome. The duration from planting to harvest decreased from 130 days for traditional rice, to 100 days for NERICA. By coming in four weeks earlier and producing a higher yield, the hunger season was reduced. Families had more food, they could eat more consistently through the year, and their children's nutrition improved.

"The effects were striking. As an economist, I look for causality. This is one of the first studies of its kind, using a randomized control trial to quantitatively show how an agricultural technology affects child nutrition."

Suri's research takes her across Africa, from Sierra Leone to Rwanda and Kenya. A fourth-generation Kenyan, Suri returned to her home country to conduct a credit experiment there, exploring creative ways to help dairy farmers obtain credit to purchase water storage tanks.

Storing rainwater in tanks is the best way to have a reliable supply of fresh, clean water for dairy cows during the dry season. But the storage tanks are expensive and farmers cannot afford them without a loan. Pondering new ways to provide credit, Suri had a eureka moment: she would test an asset-collateralized loan, using the tank itself as collateral. If a farmer falls behind on payments, the tank is repossessed. While this credit model is common in the US, for car loans and mortgages, it is almost unheard of in Kenya.

"Many more farmers purchased tanks; only one tank out of almost 1,000 was repossessed," reports Suri. "With a more consistent water supply, cows did not get dehydrated and were healthier. But the effects did not end there. We saw an increase in school enrollment for girls, as they no longer had to spend long days fetching water for the household.

"Most of my ideas come from my travels through Africa," she says. "It's hard to imagine having that eureka moment sitting in my office staring at my laptop."

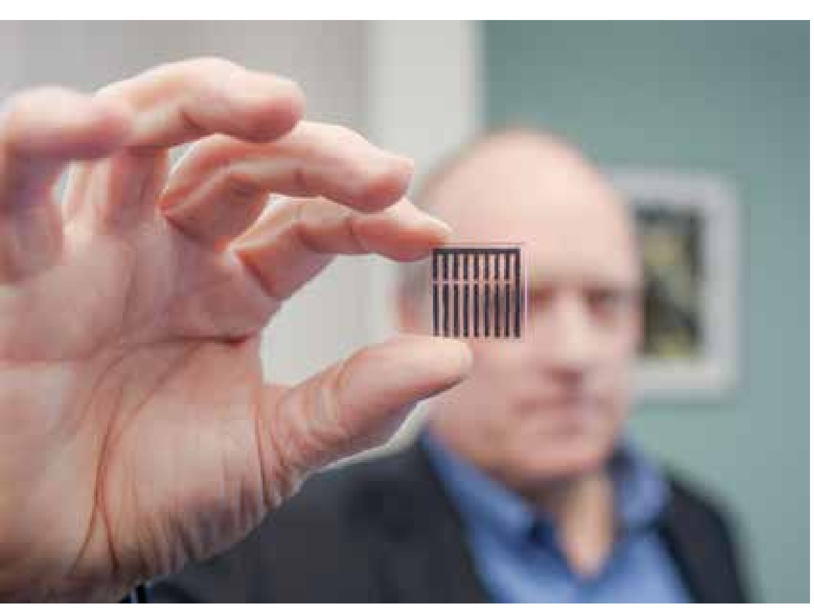
— LAURIE EVERETT

RIGHT Tavneet Suri conducted an experiment and found that the hunger season could potentially be shortened and yields increased.

PHOTO: COURTESY TAVNEET SURI

LEFT In the Philippines, a high-yield rice dries on a road after harvesting.

PHOTO: PETER SROUJI



Weapons Sensor Technology Detects Rotten Meat, Ripe Fruit

WITH FUNDING FROM THE US ARMY, Timothy Manning Swager created tiny sensors that detect chemical weapons and explosives. But he also sees the potential for the technology to be used in a civilian application: smart food packaging.

Swager, John D. MacArthur Professor of Chemistry at MIT, has altered the chemistry in the sensors so that they can detect rotting meat and fruit ripeness. "What I would really like to make is a sensor that can be used in a grocery store to tell if a tomato tastes good," he says.

As part of smart packaging, the business card-sized sensors can be embedded in meat crates being shipped to a grocer. Upon arrival, a worker can scan the shipment with the press of a button to get an instant readout of which crates have questionable contents. "It's a lot like a passive transponder in your car, which can be powered and read when you drive through the tollbooth," says Swager.

The sensors' smarts come from Swager's combined use of carbon nanotube-based circuitry and radio frequency identification (RFID) tagging technology. When the sensor receives a pulse of power from a remote scanner, electricity flows through the carbon-nanotube circuits. If the target chemical is present, it will either enhance or slow the electron flow and cause a measurable change in electrical resistance. That signal plus the sensor's RFID tag allow the grocer to quickly locate and cull bad pieces of meat.

Swager sees a range of other potential applications, such as installing fruit ripeness sensors in greenhouses to allow farmers to precisely time harvests and embedding sensors that detect explosives and other harmful agents in public transportation passcards to improve public safety. — ELIZABETH DOUGHERTY

LEFT The sensors' smarts come from Tim Swager's combined use of carbon nanotube-based circuitry and radio frequency identification (RFID) tagging technology.

PHOTOS: BEN BOCKO

Mapping Soil Moisture from Space

DARA ENTEKHABI leads the international science team behind a NASA investigation that literally spans the entire planet and could have a similarly outsized effect on everything from our understanding of the conditions for life on Earth to agriculture in Africa. Key to the work? The first-ever global high-resolution observations of soil moisture from space.

"Soil moisture is the variable that links the water, energy, and carbon cycles, or the three cycles that make life possible on Earth. So my ultimate science goal is to use our data to globally understand how these three cycles should be coupled, like gears in a clock," says Entekhabi, the Bacardi and Stockholm Water Foundations Professor. Such an understanding will allow more robust predictions of global change.

And that's not all. "One of my other dreams is to bring applications like flood forecasting and drought monitoring into the 21st century," says Entekhabi.

The Soil Moisture Active Passive (SMAP) mission is a NASA satellite launched in January 2015. Every two to three days, it creates a global map of the moisture in the top two inches of Earth's soil. Before now, soil moisture was estimated based on the history of precipitation and other indirect indicators.

Key to the work are two complementary sensors aboard the satellite. One captures the low-frequency microwaves naturally emitted at the surface of the planet. The other actively beams low-frequency microwaves to the surface and captures what is reflected back. Soil minerals and water molecules have extremely different microwave emission and reflection properties, so the two sensors together allow the detection of the moisture content.

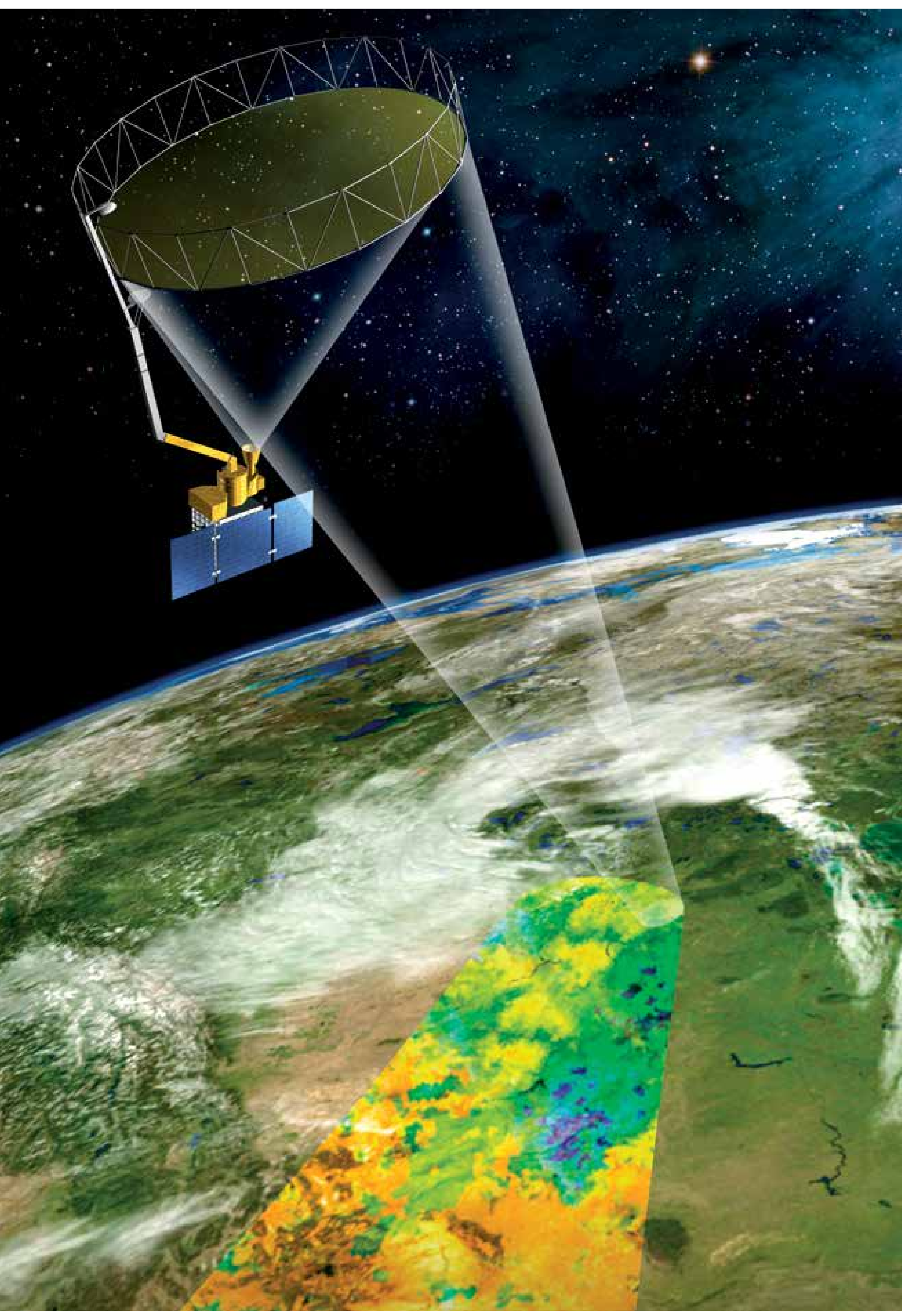
Entekhabi notes that in a first for NASA, routine data from the mission will be available almost immediately to a group of some 40 early adopters, agencies, and organizations from around the world with near-term applications. These include the US Department of Agriculture's Foreign Agricultural Service, which will use the data to monitor global crop production, and the Masdar Institute of Science and Technology in the United Arab Emirates, which will map the extent of the Saharan dust emissions that can be hazardous to human health.

Over the last few years Entekhabi and colleagues have been working closely with these groups, providing them with simulated data similar to what they can expect from SMAP. The idea "was to let them get used to the data, and incorporate it into their decision support systems, so that when the data faucet is turned on [with SMAP's commissioning] they're ready to use it," says Entekhabi, who has joint appointments in the Department of Civil and Environmental Engineering and the Department of Earth, Atmospheric and Planetary Sciences. "We're going to see every granule of data used very quickly in very different domains."

About one third of the early adopters have applications related to food, says Entekhabi. That's because a knowledge of soil moisture can help monitor crop productivity. It can also be used to predict monsoon rainfall, data that will be especially important for places like West Africa. "Even an indication of above- or below-average forthcoming conditions is extremely important to these farmers, who rely on rainfall rather than irrigation for crops," says Entekhabi. "At the beginning of the season they must decide whether to plant crops that have high caloric content but are very fragile with respect to drought, or hardier crops that have lower caloric content but are more resistant to drought."

Entekhabi notes that of the 15 members of the SMAP science team, almost half have advanced degrees from MIT in a variety of disciplines. "That shows the footprint of MIT in advancing our capability to sense our environment from vantage points that are new and much more comprehensive than what we can have on the ground," he says.

— ELIZABETH THOMSON



LEFT Artist's rendering of the SMAP satellite capturing a swath of high-resolution data on soil moisture.

ILLUSTRATION: COURTESY NASA

Air Pollution, Climate, Affect Global Food Security

THE GLOBAL POPULATION is expected to grow by several billion by 2050—and to feed these additional people, researchers estimate we'll need to produce 50% more food.

Many scientists also project that the pressure on food will be all the greater due to global warming. But in a study published last July in *Nature Climate Change*, Colette L. Heald identified another threat to food security: the interaction of rising temperatures and air pollution.

"We've known that the warming climate damages crops and reduces yields, and that ozone is toxic to plants, but ours is the first study that brings the impact of climate change and air pollution together," says Heald, Mitsui Career Development Associate Professor, Department of Civil and Environmental Engineering and the Department of Earth, Atmospheric and Planetary Sciences.

Ozone, the primary component of smog, is photochemically produced from two key pollutants (nitrogen oxides and volatile organic compounds) emitted from sources such as vehicles and industry. In high enough concentrations, the compound proves destructive to plants, entering through pores in leaves called stomata and reducing the plant's ability to feed itself and resist environmental stress.

There have already been "huge economic consequences" to high ozone levels around the world, Heald notes. She points to research suggesting that due to ozone exposure, crop yields since pre-industrial times are 10% lower than they should be, at a cost of $11–18 billion per year.

Heald's paper focused on crop yields in coming decades. She quantified the individual and combined effects of mean temperature and ozone pollution levels through 2050, focusing on four of the world's most significant food crops—wheat, rice, maize, and soybeans. Her study offered some surprises.

"We learned that the effect of ozone pollution can go in either direction," says Heald. Higher levels of ozone exacerbate the impact of warming to damage crops, lowering yields even more. But in areas with lower ozone levels, crop yields may increase—even in the presence of warmer temperatures.

Rising temperatures are a given globally, with geographic variations, because once in the atmosphere, the greenhouse gas CO_2 sticks around for decades. But ozone only persists for a month or two, and levels vary from region to region. "This is because ozone is very connected to domestic air quality management," says Heald.

For example, in the US and Europe, which impose strict regulations on tailpipe emissions, steady or declining ozone levels should limit harm to crop yields even while the planet warms. But Heald's research on China detailed two scenarios: one showing an air quality trajectory with improvement, and another with continued degradation, with matching impacts on crop production.

In one of Heald's worst-case global scenarios—modeling a rise in ozone levels across a number of regions—she predicted undernourishment rates in developing countries would increase by nearly 50% by 2050 due to the effects of air pollution and a warming climate.

Yet Heald believes much can be done to head off even the most dire impacts suggested by her study. Since some crops weather temperature and pollution impacts better than others, Heald says "farmers should understand exactly what is affecting their crops and make informed choices about what to grow." This requires accurate pollution and climate information, something Heald hopes might come from innovative, small-scale sensors that could provide local ozone measurements around the world, as well as new geostationary satellite observations.

But ultimately, she says, "limiting the environmental risk to food production worldwide requires government intervention to reduce emissions, and society needs to think about tackling CO_2 sooner rather than later." — LEDA ZIMMERMAN

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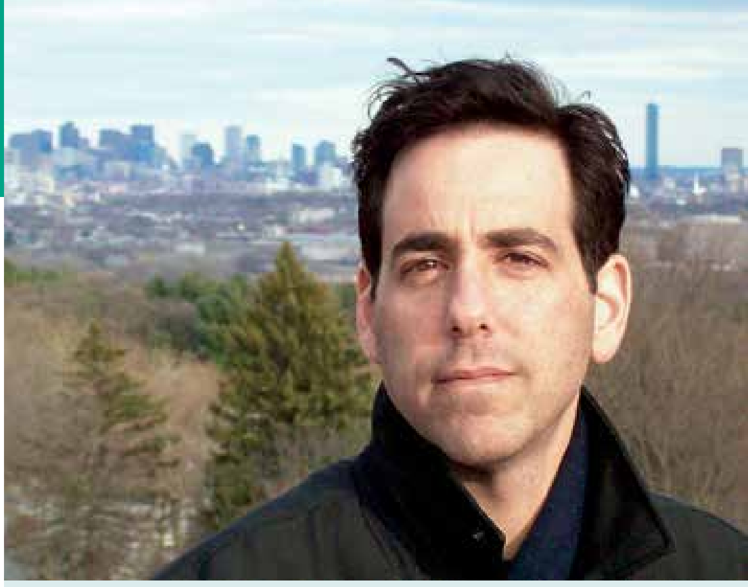
READ MORE
Brazilian climate scientist
Carlos Nobre PhD '83
spectrum.mit.edu/webextras

ABOVE Colette Heald's study is the first to bring the impact of climate change and air pollution together.

PHOTO: KENT DAYTON



Toward the Holistic City

NEAR THE SHORES of Lake Volta in Ghana, MIT researchers are working with villagers and other stakeholders on a project that could shape the future of African cities. They are developing no less than a new urban model for "a changing continent that is expected to add close to a billion people over the next 100 years with an economy increasingly based on large-scale industrial agriculture.

"We call it the holistic agribusiness city," says Alan Berger, co-director of MIT's Center for Advanced Urbanism (CAU), which creates new models for 21st-century cities. "The idea is to design thousands of small cities from scratch that reuse as much as possible in a sustainable way using the best technologies, the best in environmental planning, the best architecture, and the best infrastructural integration."

One component of the conceptual design in Ghana, for example, is "a system that closes the loop on water consumption," says Berger, professor of Landscape Architecture and Urban Design in the Department of Urban Studies and Planning. It uses lake water to irrigate many acres of a principal crop like corn managed by Africa Atlantic Franchise Farms, a CAU partner. That water is then recycled through smaller constructed wetlands in the interstitial areas between the irrigated land. There villagers—who may also work for Africa Atlantic—can grow their own secondary crops for personal use or export. "It's a holistic cycle where the water and the nutrients in it are constantly being filtered out and reused," Berger says.

"Together we're helping to design the future urban form of a continent."

And the potential for real impact is not limited to just one city or one country, Berger says. "Together we're helping to design the future urban form of a continent."
— ELIZABETH THOMSON

ABOVE Alan Berger is developing "the holistic agribusiness city."

PHOTO: COURTESY ALAN BERGER

On the Ground

Anywhere people face challenges related to water and food—which is to say, just about everywhere—you are likely to find MIT students and recent alumni building projects and companies around creative solutions.

CA, USA
Cambrian Innovation
EcoVolt transforms industrial wastewater into clean water and energy, slashing utility costs.

IA & IL, USA
Jaybridge Robotics
Agricultural vehicle automation addresses seasonal labor shortages for corn and soy production.

MA, USA
AquaFresco
Closed-loop laundry system saves 95% of water and detergent use for hotels.

TX, USA
Gradiant
Technology-driven treatment of highly contaminated water with current oil and gas focus.

NICARAGUA
recicLARVA
Fly larvae converts problem-atic organic waste into animal feed and compost.

GHANA
MoringaConnect
Improving nutrition and sustainable livelihoods through nature's "miracle tree," moringa.

ECUADOR
Qasta
Quinoa-based pasta will connect farmers to the international market.

BRAZIL
Mokane
Affordable sensor with smartphone interface measures water consumption of individual residences.

FOOD

Distribution
Getting maximum value from crops for those who need them, and those who grow them

Production
Implementing technology and practices that improve agricultural yield

WATER

Assessment
Gathering and analyzing information about existing water supplies and systems

Treatment
Converting unusable water into usable supplies and addressing sanitation issues

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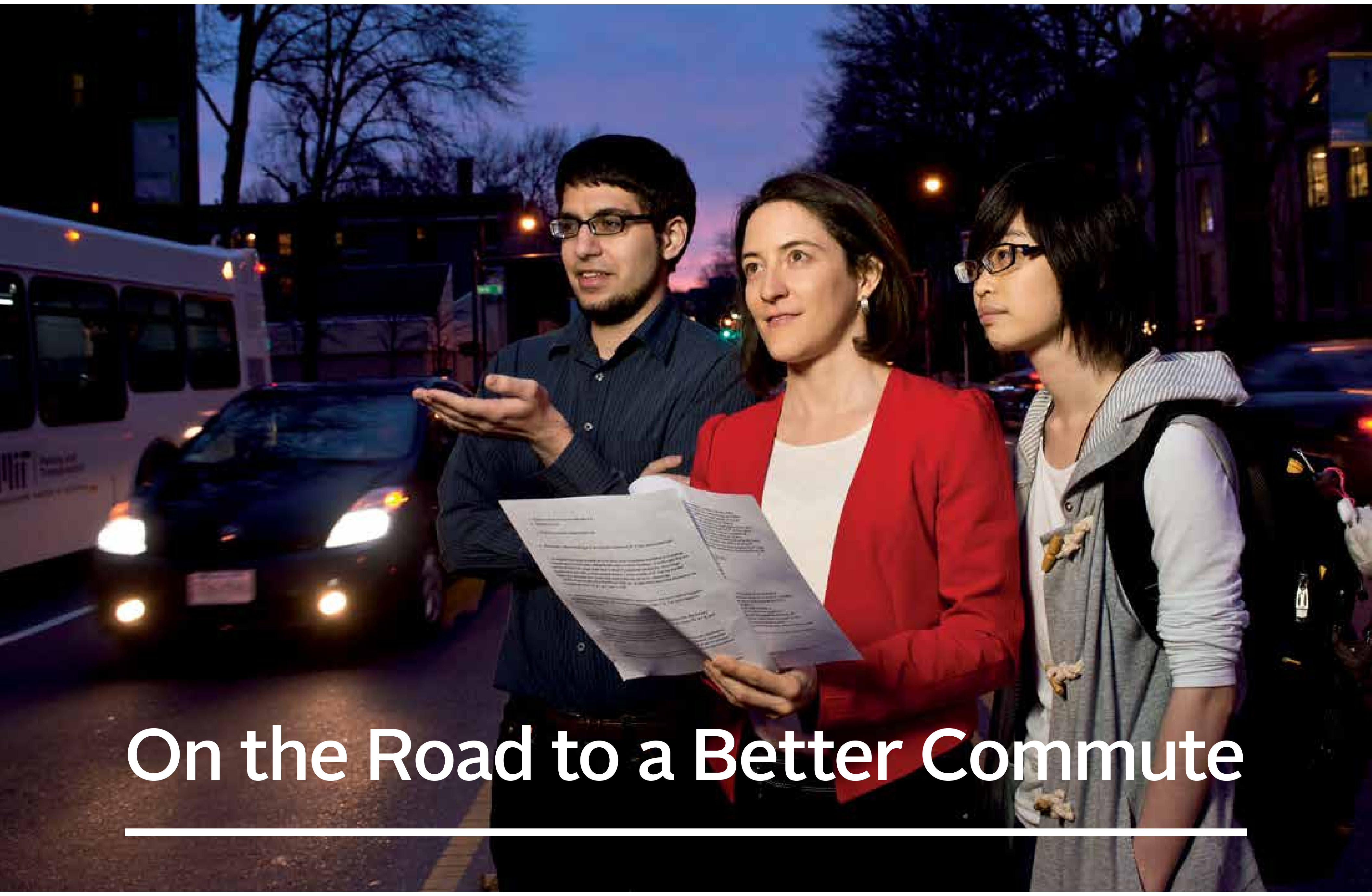


On the Road to a Better Commute

ABOVE Carolina Osorio's work just might ease rush hour. She is shown here with grad student Nate Bailey and researcher Jing Lu.

PHOTO: LEN RUBENSTEIN

THOSE OF US WHO'VE IDLED at an endless red light or navigated a gridlocked intersection might be glad that Carolina Osorio, assistant professor of civil and environmental engineering, is researching ways to ease rush hour. She works with transportation agencies and private transportation stakeholders to optimize their planning and operations decisions, such as better-timed traffic lights and strategic placement of vehicle-sharing stations. The goal? Less congestion, more reliable travel times, more efficient fuel consumption, and fewer emissions—beneficial for the environment and a blessing for harried commuters.

Agencies and companies share their traffic data with Osorio; from it, she designs simulation-based optimization algorithms that address their particular challenges, like bottlenecks at centrally located intersections or extreme congestion during rush hour. These algorithms combine principles of probability theory, simulation, simulation-based optimization, statistics, traffic control, and traffic flow theory.

"Transportation agencies and transportation consultants often use traffic models, known as traffic simulators, of an urban area of interest to inform their planning and operations decisions, and together we define the optimization problem to be addressed," she explains. "These simulators describe the network supply—such as infrastructure—and the network demand for a given time of day. For instance, they'll determine, on a weekday morning, the expected number of trips that will originate at location A and terminate at location B."

Her work is uniquely fine-tuned and predictive. She analyzes cities' historical data on traffic flow in key areas but also considers detailed driver behavior, such as route decisions, based on potential changes like signal-light timing. After all, a better-timed traffic light might lure more drivers to the intersection. This way, she can get a wider view of traffic's domino effect. The goal: improving congestion not just at one intersection but potentially citywide. Her research might change the timing of a red light at a crucial intersection, which is helpful for commuters at that particular spot, but it also assesses how drivers might behave based on that enhancement—helpful for managing flow across an urban area.

Using this broader, balanced technique, she's working with the New York City Department of Transportation to develop a traffic-management strategy to mitigate bottlenecks that affect flow on the Queensboro Bridge. In a recent simulation case study based in Lausanne, Switzerland, Osorio optimized traffic signals in the city center to reduce commuters' average travel time during rush hour by 34%. These ideas for large-scale optimization garnered her an Early Career Award from the National Science Foundation.

Osorio's next frontier is vehicle sharing, helmed by companies like Zipcar. She's currently collaborating with them to determine where to place car-sharing stations, enhancing a city's preexisting infrastructure. She's also exploring technology that explains how autonomous cars—consider them vehicles of the future—will interact with our infrastructure, and how that may impact congestion patterns, fuel efficiency, and emissions. It's an exciting time in the field: "Car manufacturers are no longer solely focused on selling cars; rather they want to provide urban mobility services," she says.

So does Osorio. She says MIT is a prime place to conduct research that actually benefits everyday citizens. "MIT is always dedicated to making a practical, tangible impact—in my case, toward making cities more livable. This drives me every day," she says.

Well, actually, she doesn't drive. The Harvard Square resident usually walks or bikes to work. Maybe someday.
— KARA BASKIN

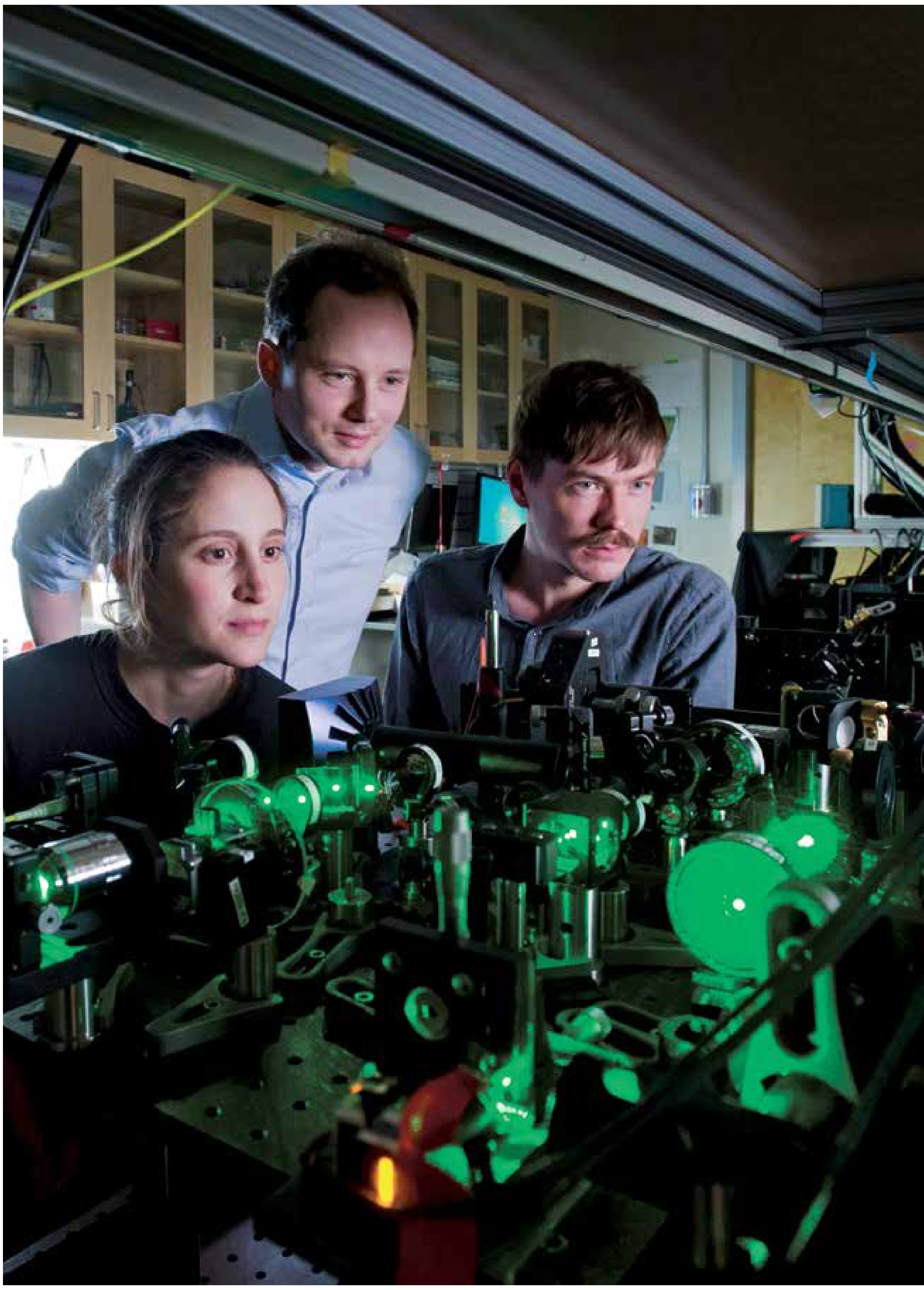
Key to Quantum: Diamonds

THE QUANTUM MECHANICAL DEVICES that Dirk Englund's lab develops are a bit like the vacuum tubes used in the first digital electronic computers: they are rather bulky, and each is the product of careful hands-on assembly by Englund's group members. But these vacuum tubes are special: they hold inside them not classical information, but quantum bits, which portend the birth of a new era in technology. These "quantum vacuum tubes" are the building blocks of quantum information processors, a long-promised type of ultra-powerful computer that Englund and colleagues say is finally coming within reach.

The next chapter in the history of technology is not simply about faster computers, says Englund, a quantum engineer and the Jamieson Career Development Professor in the Department of Electrical Engineering and Computer Science. Quantum information processing encompasses computing, communications, and sensing, and enables activities that aren't possible with today's—or even tomorrow's—digital electronic computers, no matter how powerful they are. Imagine unhackable secret communications, computers that can search vast databases in an instant, and GPS that can position you with millimeter accuracy.

Quantum information processing can improve all manner of sensors. For example, it can enable magnetometers sensitive enough to detect a door opening on the far side of a building. Another sensing technology that Englund is working on, together with neuroscientists Edward Boyden at MIT and Rafael Yuste at Columbia University, could enable real-time movies of synaptic activity in the brain. Englund and colleagues are also working on applying quantum information processing to simulate quantum mechanical systems, a technology that could revolutionize drug discovery and materials research. "That might allow us to discover new materials, not in a trial and error way, like we've been doing, but in a systematic way," says Englund, who is a member of the Research Laboratory of Electronics and Microsystems Technology Laboratories, and director of the Quantum Photonics Lab.

"I would say there is no fundamental roadblock to building a quantum computer. I'm very optimistic that we are actually entering a new era of information processing."



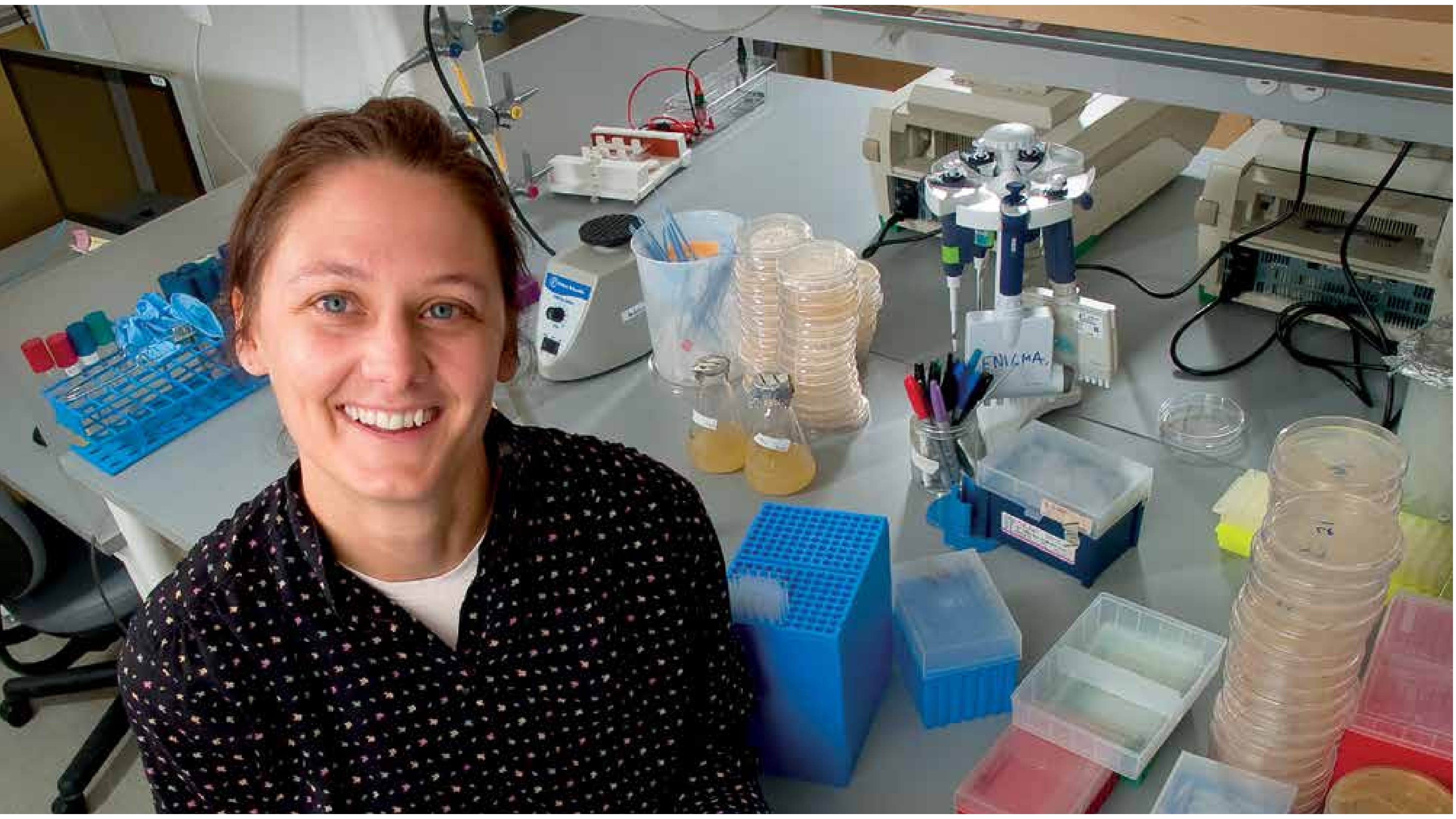
Quantum information can be stored in the smallest constituents of light and matter—the states of photons and atoms. The catch, says Englund, is that these particles are notoriously difficult to control, and even harder to link together—but these are prerequisites for realizing the promise of extraordinarily fast quantum information processing. Englund's lab works with small pieces of diamond that contain a fluorescent defect made of an embedded nitrogen atom next to a gap in the diamond crystal. These "nitrogen vacancy" centers behave a bit like trapped atoms, whose electrons and nucleus can be used to represent quantum information. "We could potentially very tightly integrate large numbers of quantum memories on chips," he says. "They would look somewhat similar to today's semiconductor chips."

"It's still very early in the game, and we're just learning how to build the first 'vacuum tubes' and to string a few of them together—but we have a much clearer vision than we did five years ago about how to go about it," he says. "I would say there is no fundamental roadblock to building a quantum computer. I'm very optimistic that we are actually entering a new era of information processing."

With his award-winning blend of physics and engineering acumen, Englund is well-positioned to help usher in this new era. — ERIC SMALLEY

ABOVE Dirk Englund says the next chapter in the history of technology is not simply about faster computers. He is shown (center) with grad students Sara Mouradian and Marco Schukraft.

PHOTO: LEN RUBENSTEIN



Ancient Life, Cast in Stone

AS A GEOBIOLOGIST, Tanja Bosak studies the co-evolution of geology and biology, or how microbes helped form both the rocks under our feet and the atmosphere that sustains life on Earth. "Geobiology is both an old and very modern science," explains Bosak, associate professor in MIT's Department of Earth, Atmospheric and Planetary Sciences. "The discipline began in the 1700s when people dug up fossils and realized that previous life forms were different from our own." Today, Bosak looks for microbial fossils, and combines fieldwork with the tools of molecular biology, genomic sequencing, imaging, and geochemistry to learn about the world the microbes lived in. Her work is filling in gaps in understanding how Earth's environment changed from one antithetical to complex life forms to one supporting an explosion of such organisms 540 million years ago.

> "Geobiology is both an old and very modern science. The discipline began in the 1700s when people dug up fossils and realized that previous life forms were different from our own."

For the first three billion years of life on Earth, the landscape was devoid of trees, grasses, flowers, mosses, ferns, algae, and animals of any size. The atmosphere contained sulfur, methane, and carbon dioxide, but no oxygen. Water saturated with silica, calcium carbonate, and other minerals burped up noxious-smelling gases from the volcanic activity just under the surface. Yet shallow waters teemed with bacteria that grew in dense, multispecies colonies. These colonies produced slimy substances called biofilms that formed thick mats. "Some organisms didn't want to be coated in minerals, so they secreted sticky slime to prevent that mineral nucleation," Bosak says. "Then other organisms that degraded the slime came as the layer of active organisms moved up. Today we see these layers of biological interactions frozen in stone."

To study these interactions, Bosak travels to places like Yellowstone National Park, where similar microbial mats in vivid greens, deep reds, and mustard yellows form in scalding, bubbling sulfurous pools and slowly evolve into rock. Her lab has also replicated the biochemistry of the Precambrian ocean of around 575 million years ago, when multicellular animals first emerged. To do so, the lab grows bacteria in custom-built wave tanks with water adjusted to the pH, temperature, and mineral content believed to have existed at that time.

The bacteria form mats with microscopic features similar to those seen in fossilized formations, and also in some of Yellowstone's microbial mats. Using this system, Bosak explained how the physics of photosynthesis and competition for nutrients led to conical patterns in microbial mats that occurred as cyanobacteria began emitting oxygen into the atmosphere, creating conditions amenable to more complex life forms.

In a 2014 paper in *Nature Geoscience*, Bosak's lab explained a long-standing puzzle about the millimeter-wide ripples characteristic of microbial mats. "We didn't know how these stone ripples formed or why they disappeared," Bosak says, "but we knew they appeared when thick microbial mats probably coated the ocean floor. We see a lot of them in Precambrian times before the appearance of more complex life forms."

When Bosak's lab grew bacterial mats in a tank, they observed ripples forming when fragments of the mat broke off and rolled along sand. She speculates it was tiny burrowing or grazing animals (not waves) that increased the fragmenting of the tough mats of ancient times. "You need some, but not too many, early animals to break off these fragments. They can't form once you have larger animals that burrow deeper or that chomp on the mats. Finding these features tells you that certain activities were present and others were absent."

The animals themselves were too soft-bodied to be fossilized. But like many features of Earth's past three billion years, their lifestyle can be gleaned from microbial traces in the rocks.

— CATHRYN DELUDE

ABOVE Tanja Bosak's work explores how the Earth's environment changed from one antithetical to complex life forms to one supporting an explosion of such organisms 540 million years ago.

PHOTO: MARC LONGWOOD

Medical Anthropology

Aiming to Heal the World

WHAT IS THE RELATIONSHIP between religious belief and healing? How does poverty affect who gets sick? And, in what ways do gender inequities influence health outcomes?

These are the kinds of questions that interest Erica Caple James, a medical and psychiatric anthropologist and director of MIT's new Global Health and Medical Humanities Initiative, which launched last fall.

James has spent two decades investigating how behavior, culture, and structural inequalities impact health. While working with rape survivors in the aftermath of Haiti's 1991 to 1994 coup period, James found that aid designed to improve the lives of victims often had the unintended effect of fracturing community ties. Haitians living in extreme poverty fought to gain access to the unusual flow of funds, and humanitarian organizations themselves fought over lucrative aid contracts.

"The research I've done has shown the complexity of trying to intervene to improve people's lives," she says.

James's current research focuses on the health experiences of Haitians who chose to leave their conflict-ridden nation for the relative security of the United States. Her research has revealed that "the vulnerabilities one might have in your country of origin often travel with you, whether it's illness, conditions of economic vulnerability, or mental health challenges," James says.

These findings underscore the need to think more broadly about global health impacts, says James, who founded the Global Health and Medical Humanities Initiative to address just such issues. The goal of the initiative, she says, is "to try to expand and deepen the conversations that occur around medicine and illness, healing and health disparities, and various kinds of inequalities."

James included "medical humanities" in the name, she says, because "I also want to draw from literature, history, and the arts in future programming—alongside drawing on anthropology, sociology, political science, and economics perspectives to think about medicine, illness, and healing critically."

The initiative will provide a formal program for MIT students who aspire to take an active role in improving global health. "I want to help students to think in a nuanced way about the determinants of health," James says, noting that she is hoping the effort will draw expertise from all five MIT schools.

For its inaugural event in October, the Global Health and Medical Humanities Initiative examined the roots of the recent Ebola epidemic as well as the social and scientific responses to the crisis. "We've seen with the Ebola crisis that the mobility of people means that we have to think of disease and healing in a much more complex way," James says.

Now James is developing an interdisciplinary subject—tentatively titled Infections and Inequalities—that might one day be incorporated into an undergraduate minor in health. Down the line, she hopes the initiative will provide students with firsthand experience in tackling health challenges.

"What's driving the Global Health and Medical Humanities Initiative is a recognition that in order to truly understand and improve health and health care, it is vitally important to bring into conversation biomedical and technological perspectives with those of the humanities, arts, and social sciences," James says. "MIT may be uniquely positioned to offer new research and teaching models that can solve persisting health problems worldwide." — KATHRYN M. O'NEILL

ABOVE Erica Caple James investigates how behavior, culture, and structural inequalities impact health.

PHOTO: LEN RUBENSTEIN

MRIs for a More Peaceful World

Neuroscientists and Political Scientists Join Together

AN MRI SCANNER IS an unusual tool for resolving war and conflict, but an MIT collaboration now underway is deploying MRIs as an instrument for peace.

The goal of the collaboration—among the Social Cognitive Neuroscience Lab; the Department of Political Science; and Beyond Conflict, an international nongovernmental organization dedicated to global challenges to peace and reconciliation—is to use knowledge of neuroscience to develop innovative, more effective conflict-resolution strategies. Already the groups are putting into practice what they are learning in instances of extreme prejudice against Roma populations in Hungary, and between Israelis and Palestinians.

"The driving idea behind this collaboration is that big problems take different forms of expertise, and that each approach has something powerful to offer," says Rebecca Saxe, professor of brain and cognitive sciences.

"We want to create a new framework of understanding of what drives humans to and away from conflict, not based on theories but based on shared human experience," says Tim Phillips, co-founder of Beyond Conflict, which initiated the collaboration between the Saxe Lab and political science department. "It is revolutionary to break down these silos between disciplines but also to blend science and practice in the real world."

BELOW An MIT collaboration is underway using MRIs to develop innovative conflict-resolution strategies. From left: Rebecca Saxe, professor of brain and cognitive sciences, Marika Landau-Wells, a PhD student in political science, and Emile Bruneau, a cognitive neuroscientist.

PHOTO: LEN RUBENSTEIN

WHY MRIS

Saxe, along with Emile Bruneau, a cognitive neuroscientist, are members of the McGovern Institute for Brain Research, and they're using MIT's MRI scanners to better understand the brain mechanisms underlying a whole constellation of biases, intergroup conflict, empathy, conflict resolution, judgment, prejudice, dehumanization, fear, or disgust.

"MRIs or neuroimaging give direct access to the entire brain. The hope is that this could bring more information that otherwise is too hard to measure," says Bruneau, who has participated in conflict-resolution programs across the globe, including with Israelis and Palestinians, Americans and Mexican immigrants, and US Republicans and Democrats.

"MRI scanners are one of the best ways to study the brain," says Saxe. "Many things that happen during conflict are unpalatable. Or illegal. Sometimes, there are things about someone's experience of conflict that they don't know how to put into words. Neuroimaging has the advantage. Its power is that it can tell us when many things are happening simultaneously. And not only can we extract aspects of bias and empathy that people acknowledge, but also determine things they're less willing to talk about."

Marika Landau-Wells, a PhD student in political science and in MIT's Comparative Politics and Security Studies Program that focuses on war and conflict, is helping to bridge conflict resolution, neuroscience, and political science. Traditionally in political science, she says, there is an assumption that "more or less, we are all rational actors, and that if offered the right incentives, people will do the rational thing. But new lessons from neuroscience are teaching us that what people value, what generates strong emotional responses, are not always those rational things we assume. We're often not even aware of some of the processes that are driving our behaviors."

"It is likely that we all have biases, particularly biases we're unaware of," says Bruneau, adding that scientists offer the analogy of a man riding an elephant. The man represents the part of the brain we're consciously aware of, the elephant the part we're unaware of. "What's difficult to measure is the elephant."

Consider, he says, a dialogue program between Israelis and Palestinians designed to increase open-mindedness. "If you ask, 'Are you open-minded?' they're motivated to say yes, because they want a good self-image. But that's only the part of their brain they have access to. In reality, they might not know at all how open- or closed-minded they are. The MRI," Bruneau says, "can determine that.

"For neuroimaging to measure open-mindedness is for me one of the great hopes for this technology. A lot of outcome goals that we have for conflict-resolution programs are difficult to measure directly. Indirect measure holds the greatest promise."

Bruneau believes that individuals are capable of making dramatic changes. "Japan and the US were at war, and now just one generation later, we've gotten past much animosity," he says. "The key is figuring out how they did it, and turning that into something we can consciously move along. We feel MRIs will help us get beyond differences better and faster."

— LIZ KARAGIANIS

Technology to Touch Across the Globe

TOP inFORM is a surface of 900 individual pegs that move dynamically based on the hand motions of someone across the room—or across the ocean.

PHOTO: JIFEI OU

ABOVE Hiroshi Ishii says our vision is the future.

PHOTO: JEAN-BAPTISTE LABRUNE

ONE OF THE LATEST INVENTIONS at the MIT Media Lab is inFORM, a Dynamic Shape Display. Picture an area of 900 individual pegs that move dynamically based on the hand motions of someone across the room—or across the ocean.

"The idea is physical telepresence. People can point, touch, and manipulate objects remotely over long distance," says Hiroshi Ishii, co-inventor of the project with Daniel Leithinger and Sean Follmer.

inFORM is a giant step toward Ishii's dream to bridge the gap between computers and people. For the past 20 years, Ishii—associate director of MIT's Media Lab and the Jerome B. Wiesner Professor of Media Arts and Sciences—has had a glaring vision to give digital information physical form. By making bits something that we can manipulate with our hands and perceive through our senses, he aims one day to bridge physical space with cyberspace. Imagine, he says, the day we will no longer need a computer to get digital information, but the whole physical world could become an interface to the virtual world.

inFORM makes it possible to create sculptures by manipulating the surface of the pegs, and yet, your hands never actually touch the display. Instead, hand movements are made before a computer screen in another city. The display makes it possible for a user to virtually turn the pages of a book, grab an object, say, a flashlight, and move it.

Ishii's colleagues at the Media Lab already are testing inFORM with urban planners, since they could build and adjust models in real time over great distances, reflecting changes immediately in the underlying digital model. And it would be useful, Ishii says, for people to collaborate without having to travel. In addition, because inFORM gives physical form to computation, it could aid in the health care industry—CT scans could be swiftly browsed in layers to help better visualize 3-D data—and it also could be used in other industries that use vast amounts of data.

Ishii's latest vision, as founder of the Tangible Media Group, is called Radical Atoms, a dream to make atoms dance. His goal is to create a hypothetical generation of materials that can dynamically change form and appearance.

Ishii believes that soon phones, computers, and furniture will be able to communicate with us. He's now working on TRANSFORM, a project where furniture and other materials can change shape. Consider, he says, patients in wheelchairs or those with back pain. A hospital bed could change shape to provide relief or comfort.

The future is not to predict but to invent. "So we have to dream up what kind of future we want to see."

Ishii believes that the future is not to predict but to invent.

"So we have to dream up what kind of future we want to see," he says. "We'll all be gone by 2100, but our grand-grand-children will still be living, and in this way, life will never end. I tell students: 'We must have vision; we must become pioneers, to shape our own mountain from the ground up, and then become the first explorer to conquer the new summit.'"

— LIZ KARAGIANIS

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SEE MORE
video: inFORM in action
spectrum.mit.edu/webextras

Mending a Broken Heart

TO MEND A BROKEN HEART—that is, to regenerate a damaged cardiac muscle—it helps to know how hearts are built. "How does one stem cell, which has no specific identity, develop into multiple cell types that organize into this beautiful three-dimensional structure?" asks Laurie Boyer, associate professor of biology, who tackles that problem by investigating regulatory elements that switch genes on and off at the right time and place during development. Faulty regulation can lead to congenital heart defects, which are the greatest cause of infant morbidity and mortality.

> "We'd like to manipulate the gene regulatory circuitry so we can reprogram human cardiac cells to repair themselves after injury."

Heart cells must be "super-strong" to withstand continuous pumping throughout life, she says. Yet they stop dividing shortly after birth, losing the ability to repair or replace themselves if damaged by a heart attack. In contrast, skin or intestinal cells can continuously regenerate.

Boyer began her career at a time when genome sequencing started to reveal that gene regulation was more complex than anticipated. She focused on learning how networks of genes are regulated during heart development, because by learning how these genes are turned on or off, she hoped to understand congenital heart disease. In a 2013 paper in *Cell*, she characterized a novel gene belonging to a poorly understood class of molecules called long non-coding RNAs (lncRNAs). The gene, which she named Braveheart, helps specify which early cells will develop as heart cells. Braveheart was the first lncRNA implicated in heart development, and its discovery revealed an entirely new, previously unsuspected regulatory layer.

In a series of papers from 2012 to 2015, she describes her investigations of these processes in mice. Cardiac cells in mice continue actively dividing during their first week of life, and then stop after a discrete interval. During that interval, if the heart is injured, cardiac cells revert to a more immature state. They begin dividing again, and those new cells mature into functional cardiac muscle cells.

"We realized we could exploit this short developmental window to identify the molecular roadblocks to regeneration. What changes in gene regulation happen in the injury response?" Some of those changes involve regulatory elements called enhancers: short DNA sequences that bind to transcription factors (which are proteins that actually turn genes on and off) and that act very specifically in different tissues at discrete developmental stages.

"Now we are asking: How can we turn back the developmental clock for mature cardiac cells? We'd like to manipulate the gene regulatory circuitry so we can reprogram human cardiac cells to repair themselves after injury." She is focused on transcription factors because as proteins, they are easier to target. Preliminary results point to factors not previously known to play a role in heart development and disease.

Boyer is excited to gain new knowledge about the heart, especially if it might one day help develop cures for heart defects and disease. She had no idea where her interest in stem cell development would lead. "Success is different for everyone," she advises young scientists, "and its measure for me is how I overcome obstacles to follow my passion." — CATHRYN DELUDE

ABOVE Laurie Boyer's work might one day help develop cures for heart defects and disease.

PHOTO: KENT DAYTON

Atomic Insights

WHAT ACTUALLY HAPPENS to arrangements of atoms as materials perform—and fail—in the real world? With the help of an add-on device he designed for a powerful microscope, Ju Li has created a window into a world where things are inconceivably small and change inconceivably fast.

Li's device zaps a beam of electrons through ultrathin specimens, allowing him to see materials transform as they undergo strain, are electrified, bombarded with radiation and gases, or immersed in chemicals.

Li, the Battelle Energy Alliance Professor of Nuclear Science and Engineering, believes that illuminating the structural, mechanical, and electrochemical properties of materials at the atomic and nanoscale levels will lead to better nuclear reactors, batteries, superconductors, and safer long-term storage of nuclear waste.

A video of a material used in high-capacity batteries, for instance, shows tiny protrusions flying off conductors submerged in a liquid electrolyte, Li says, "like cherry blossoms in a breeze." The batteries don't hold a charge very well, and now Li can see why. "No one witnessed the microscopic mechanism underlying this battery material's failure before," says Li, who is also a professor in the Department of Materials Science and Engineering. Building with atoms like Lego blocks, Li boosted the material's performance by coating its surface with a one-atom-thick layer of a material impervious to electrons.

Ju Li has created a window into a world where things are inconceivably small and change inconceivably fast.

Growing up the son of engineers in Sichuan Province in China, Li was drawn to the mysteries of the physical world. A friend who lived in the same apartment block built makeshift radios, microscopes, and model airplanes while Li concentrated on their design. "Even then, I was more involved with the theory part," he jokes. The friends read a Chinese translation of a cartoon-filled book by nuclear physicist George Gamow that "made a scientific career look incredibly glamorous to both of us," Li says. The book inspired them to attempt to derive the equations of special relativity. "Nothing seems out of bounds when you are eight or nine," he says.

After enrolling in the University of Science and Technology of China at age 15 and graduating at 19, Gamow's book spurred Li to apply to graduate programs in the US. He earned a PhD in nuclear engineering from MIT in 2000, and following faculty stints at Ohio State University and University of Pennsylvania, in 2011 joined MIT's nuclear science and engineering department with a joint appointment in materials science and engineering.

Li had collaborated closely with experimentalists but upon returning to MIT, he started to shift from theory and simulation to working with materials in the lab.

"We care a lot about the behavior of materials under extreme conditions such as extreme stress, heavy electrical currents, and aggressive corrosion. Materials in nuclear fission and fusion applications also need to withstand exceptionally high temperatures and exposure to radiation," he says. With knowledge gleaned from multiscale experiments and modeling, Li and postdoctoral fellow Kangpyo So have fabricated a new class of nanocomposite that is particularly radiation resistant.

Li is now working on the challenges of scaling up the miniscule components of his experimental world to real-world dimensions and time frames. By incorporating insights from the atomic world, he's confident the new radiation-resistant material, for one, will have a lasting impact.

— DEBORAH HALBER

ABOVE Ju Li believes that illuminating the structural, mechanical, and electrochemical properties of materials at the atomic and nanoscale levels will lead to better nuclear reactors, batteries, superconductors, and safer long-term storage of nuclear waste.

PHOTO: KENT DAYTON

Davos, Switzerland ▶

President L. Rafael Reif and Mrs. Christine Reif, along with 12 faculty members, participated in the 2015 World Economic Forum in Davos, Switzerland. MIT hosted a dinner, *The Glass Half Full: Forging Solutions to the Emerging Crisis of Water and Food*. Fifty guests listened as President Reif, along with Professors Alan Berger, Karen Gleason, Colette Heald, and John Lienhard shared MIT's research in the priority areas of water and food. The dinner was moderated by Thomas Friedman, *New York Times* columnist and celebrated author.

1. President L. Rafael Reif and Thomas Friedman
2. José Antonio Fernández
3. Fady Jameel
4. Hassan Jameel
5. Professors Karen Gleason '82, SM '82 and John Lienhard
6. Professor Colette Heald

PHOTOS: PHIL WENGER


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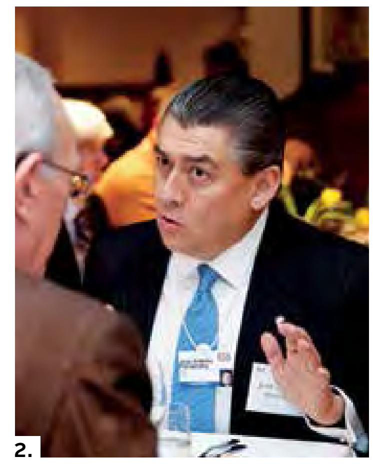
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◀ São Paulo, Brazil

Eighty MIT alumni and guests recently gathered at the Renaissance São Paulo for a Presidential reception hosted by MIT's Alumni Association. Among the participants were four newly admitted undergraduates from Brazil, as well as several alumni from Rio, who flew in that night to attend the special event. After the reception, guests enjoyed a conversation between MIT President L. Rafael Reif and Carlos Nobre PhD '83, a leading climate scientist in Brazil. Nobre moderated the discussion, and the pair later took questions from the group regarding Institute priorities.


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1. MIT volunteers in Brazil include from left: Marcelo Maziero SM '00, Ana Luisa de Araujo Santos SM '09, Eduardo Pires-Ferreira '72, President Reif, Christine Reif, Ricardo Betti SM '86, Roberto Engels '85.
2. Guests, including newly-admitted Brazilian students, gather around President Reif.
3. President Reif and Ricardo Betti SM '86, president of the MIT Sloan Club of Brazil
4. Carlos Nobre PhD '83
5. President Reif enjoys the chance to meet alumni and friends in Brazil.

PHOTOS: JULIANA DE FREITAS FIGUEIRA

Boston ▶

More than 100 guests gathered recently at the Taj Boston for the 2015 MIT Charter Society event. The black tie gala was held in recognition and celebration of MIT's most generous philanthropic partners. The evening featured an interactive cocktail hour showcasing new companies founded by MIT young alumni and students.

1. Charter Society 2015 gala dinner
2. President L. Rafael Reif tries out the heating and cooling wearable technology developed by embr labs. From left: Sam Shames '14, President and Mrs. Reif
3. New Charter Society members Lisa and Robert Reitano PhD '76

PHOTOS: JOHN GILLOOLY

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Water Challenges

"I'M ACUTELY AWARE of the challenges society has in finding reliable water supplies of an acceptable quality, whether they're for human consumption or industrial needs," says Doug Brown '75.

Some of those challenges can be addressed by technologies that are commercially available right now—and that Brown has helped implement through two companies, Seven Seas Water and Quench USA. Last year they merged into Aqua-Venture Holdings, and Brown serves as founder and CEO. Quench USA provides filtered drinking water to more than 45,000 companies across the US. It does so using coolers with built-in filtration technology that purifies tap water on the spot—no more environmentally wasteful plastic jugs or the truck traffic involved in deliveries. Last year Brown donated 50 Quench units to MIT to help the Institute become more ecofriendly. Seven Seas Water, on the other hand, operates large seawater desalination and wastewater treatment plants internationally.

But many water challenges remain, especially for people in developing countries. Commercially available desalination systems, for example, can be too expensive. "They're simply not economically viable in a lot of situations," says Brown. That's why he and his wife, Deborah, recently made a major gift to support research on new techniques for purifying water by John Lienhard, the Abdul Latif Jameel Professor of Water and Food in the Department of Mechanical Engineering.

One of Lienhard's many projects, for example, is a promising alternative to currently available desalination systems. Among other advantages the technology, known as humidification-dehumidification (HD) desalination, can use an energy source readily available to many third-world countries—the sun—rather than fossil fuels. The system components are also easily able to withstand difficult operating conditions.

Deborah Brown, who has worked in luxury real-estate sales, remembers how inspired she and Doug were upon meeting Lienhard, who is also director of the Abdul Latif Jameel World Water and Food Security Lab (see page 4). "He gave us a synopsis of the different technologies and research [the lab has] in the pipeline, as well as his goal of connecting the different efforts at MIT so that "there can be a consolidated and cohesive approach to bringing this work forward," she says. "I think we both just really felt that this is the guy who can make that happen." — ELIZABETH THOMSON

RIGHT Doug '75 and Deborah Brown support research on new techniques for purifying water. PHOTO: KEN RICHARDSON

Catalyzing Change

JOHN CARLSON'S CAREER as an emerging markets portfolio manager has taken him to more than 70 countries, and his travels have allowed him to see firsthand the effects of climate change. "From the glaciers of extreme South America, to the deserts of Africa and Mongolia, and to the countryside of Thailand, I see the impact of climate change on the world," he says.

These experiences have inspired him to endow the John Carlson Lecture at the Lorenz Center in the Department of Earth, Atmospheric and Planetary Sciences (EAPS). The Center is a climate think tank named in honor of late MIT professor Edward N. Lorenz, an early contributor to the study of climate science, who was Carlson's mentor when he studied meteorology at MIT. The public lecture features leading scholars in geophysics and climate science and is held each fall at the New England Aquarium in Boston.

"I've always been drawn to both financial markets and weather and climate," says Carlson. Now in his 20th year at Fidelity Investments, he relies on the analytical scientific training he received at MIT when making investments in developing countries.

This year will be a memorable one for Carlson, whose boyhood heroes were the early explorers of the Earth's poles. In January, he ventured to Antarctica, joining Susan Solomon, the Ellen Swallow Richards Professor of Atmospheric Chemistry and Climate Science and founding director of the MIT Environmental Initiative, on an MIT Alumni Travel Program excursion. In June, he heads for the North Pole, aboard a nuclear powered icebreaker to learn about wildlife ecology, glaciers, and the changing landscape of the Arctic.

Carlson also recently made a gift to support an EAPS project in Africa, funding the installation of a high-frequency climate observatory in Rwanda. This observatory will advance understanding of greenhouse gas emissions that result from agricultural activities, wildfires, and deforestation.

"My MIT education has served me well and I want to give back," says Carlson. "My primary goal in endowing the lecture series is to raise awareness about climate, and to get people focused on how interdisciplinary it is. Geology, chemistry, biology, mathematics, physics, all play a role. I hope to be a catalyst for others to invest in climate science research at MIT." — LAURIE EVERETT

LEFT John Carlson ('83) supports a project in Africa, funding installation of a high-frequency climate observatory in Rwanda.

PHOTO: KEN RICHARDSON

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Carlson's Antarctic odyssey with the MIT Alumni Travel Program
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