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I find that people everywhere tend to think highly of MIT, but they can’t quite put their finger on what makes us different. In one sense, like any research university, MIT is an academic institution whose mission is to “advance knowledge and educate students.” What sets MIT apart, I believe, is our dedication to bringing “knowledge to bear on the world’s great challenges,” and doing so for the “betterment of humankind.”

And that focus on problem-solving in service to the world has two powerful side effects that help explain the MIT difference, too.

First, it liberates our thinking. We stop worrying about boundaries between disciplines and focus instead on what it takes to solve the problem: making new tools, seeking new perspectives, and inventing new solutions. MIT has a long tradition of interdisciplinary creativity, bringing together experts from a broad range of fields to tackle complex challenges from many directions. We also draw great strength from the alliances we build beyond our campus, with researchers, entrepreneurs, business executives, philanthropists, and innovators who share our passion and commitment to changing the world.

The second side effect is that when a group of people circle together around solving a hard problem, the human tendency to focus on differences in background almost disappears. Cultural biases tend to fade, replaced by aspirations that unite and inspire the whole team. When students, faculty, and postdocs work together to solve the world’s clean water problem or to figure out how to educate a billion people, they develop bonds of mutual respect and interdependence that are more profound than any formal diplomacy.

These two dynamics invigorate our community every day—and I am optimistic that, this fall, they will also energize the work of “Solve,” which Technology Review editor-in-chief and publisher Jason Pontin describes in this issue of Spectrum. In October, MIT will convene leaders from around the world to catalyze meaningful progress on tough global problems that no sector or institution can solve alone. Working within four themes—Learn, Cure, Fuel, and Make—we will use Solve to define and advance practical, actionable solutions, in the best tradition of MIT.

Working together, there is no end to the opportunities to advance and apply our knowledge for the betterment of humankind.

Sincerely,

L. RAFAEL REIF
Countless Solutions, One MIT

There's not much you can fathom that MIT won’t plunge in to figure out, fix, get right, or get to the bottom of. We’ve done it ever since our start: developing radar, helping to land a man on the moon, playing a key role in cracking the human genome. MIT experts are not daunted by today’s huge, interconnected problems; we’re empowered by them. We view them as an exhilarating opportunity for action.

On the pages of this issue, you’ll find just that: MIT’s problem solvers in action. In their stories, you’ll see what motivates and gives them confidence to forge ahead: MIT’s foundation of world-class engineering and science, of course, along with a proven history of interdisciplinary research; our track record of building productive partnerships here and abroad; a culture of Institute-wide collaboration that equips us to tackle complex challenges on multiple fronts; and the unbridled creativity to approach problems from unexpected directions.

Undaunted by the Big Challenges

Maria Zuber is vice president for research and the E. A. Griswold Professor of Geophysics. She oversees a dozen of MIT’s largest research centers and is responsible for research administration and policy. Spectrum asked her to explain how MIT digs into the world’s most complex problems.

We face massive hurdles—climate change, the pressing need for clean energy and clean water, cancer, Alzheimer’s disease. How is MIT positioned to solve these challenges?

MZ: We have a number of things going for us. First, we have great people who are attracted to problems because they are hard. Students who come to MIT are very bright, and tend to have a strong social conscience, fully expecting to change the world. And we have a reputation for excellence. If we aren’t going to do a world-class job, we don’t get involved. And we have the ability to work across disciplinary boundaries.

For example, the development of radar, which was instrumental in winning World War II, brought together MIT researchers from physics and engineering. Today, at the Koch Institute for Integrative Cancer Research, biology is meshing with chemical engineering, biological engineering, materials science, chemistry. We’re thinking not only about the basic science of cancer, why cells go wrong and the process of metastasis, but also about engineering solutions, like delivering drugs to tumors. (See page 7.) Another example is our Environmental Solutions Initiative. All of the seed proposals recently announced have investigators from more than one MIT school collaborating. And part of our history and part of our success is building partnerships.

Could you elaborate on these partnerships?

MZ: We’re most interested in inventing the future, the next big discovery. Once you acquire knowledge, you wish to use it to find a solution to a problem. Then you want to get that solution to market, so you’ve got to scale it up. By collaborating with industry we more effectively transmit our ideas into the outside world. Also important is having international reach. We collaborate in different places of the world with industry, as well as academia and government, on problems that are crying out for solutions. It’s important to get out and interact with people across the world, understand their real needs, their cultural settings. That won’t happen by staying in Cambridge.

Does asking big questions to solve big problems begin with fundamental research?

MZ: In this country, in research universities, and in industry, we have long been fortunate to have an ever-growing base of fundamental knowledge to draw on to design solutions. Eroding federal support and a shift to emphasize applied research are therefore matters of great concern. When we answer important basic questions, it is sometimes possible to apply the answers to new problems. In exploratory science, sometimes you find what you’re looking for easily, sometimes not. Often there are happy surprises, but they can’t be predicted. Society is now benefiting from the knowledge gained from basic research questions asked decades ago. Advances in basic physics led to GPS and the iPhone. But the researchers who made those discoveries certainly didn’t have those things in mind at the time.

What will it take to solve the world’s massive, interconnected problems?

MZ: In 35 years, we’ll need to feed 9.6 billion people; the problem seems intractable. The way to proceed is to break it down into pieces you can solve. Think about what can you do to feed one more person. What can you do to feed people in a local area? What can you do to feed people in a larger region? Part of this challenge is a biology problem, part a water management problem, part a logistics problem, part a human behavior problem. It doesn’t seem nearly so daunting when you look at it in this way.

Do you think we can solve these huge problems in time?

MZ: I’m optimistic. Having to find solutions to urgent problems is a great motivating factor. Things that seem impossible today won’t always seem that way. In 1950, sending humans to the moon was viewed as impossible. But in 1969, it happened. Although needing to feed 9.6 billion people by 2050 sounds today like a daunting challenge, if we can just make a handful of key discoveries, we’ll change the game.
Defining the Questions

**LEARN**

Provide access to a quality education by 2050 to anyone, anywhere, with the will to learn.

1. How can we prepare students to become lifelong learners by teaching at scale the skills to learn?
2. How can we support teachers and transform teaching to better prepare students for the challenges and opportunities ahead?
3. How do we transform universities to become partners in lifelong learning and retraining?
4. How can we bring the benefits of collaborative, in-person educational environments to digital learning programs?

“Our goal is not to come up immediately with solutions to these problems ourselves, but to define the questions well enough to be able to bring communities together to help solve them. In the case of education, this means identifying contributors around issues ranging from economics to politics to human rights to infrastructure and, of course, to learning.”
— ERIC KLOPFER CO-CURATOR, LEARN

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**CURE**

Leverage innovations in health care delivery and medical research to make care affordable and universally available.

1. How can we increase health care productivity by leveraging information technology?
2. How can we reduce morbidity and mortality in the case of cancer?
3. How can we accelerate advances in mental health and the treatment of brain disorders?
4. How can we mitigate the spread of infectious disease in developing and developed countries?

“Technology alone won’t solve problems. Technology, when coupled with leadership and the engagement of citizens, that can solve problems. And that’s changed the world. That’s how we can treat disease.”
— PHILLIP SHARP CURATOR, CURE

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**FUEL**

Double energy and food production, halve carbon output by 2050, and set a path to net-zero carbon emissions by 2100.

1. How can we build a scalable, safe new nuclear reactor design by 2025?
2. How will we provide clean water and food sustainably to 9.6 billion people?
3. How do we efficiently distribute and store electricity so that advanced renewable energy sources can meet most of our power needs anywhere in the world?
4. How do we mitigate the impact of climate change now and in the future?

“How do we go from a fossil-energy fueled economy—84% of the world’s energy comes from fossil fuels—how do we make the transition from those fossil energy sources to carbon-free sources in as short a period of time as possible? That’s the challenge that calls us together.”
— ROBERT ARMSTRONG CO-CURATOR, FUEL

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**MAKE**

Provide the infrastructure and economic opportunity to support a world population of nearly 10 billion by 2050.

1. How will we make the Internet accessible to all people, everywhere?
2. How will we make new buildings and create modern cities, using less energy and producing less waste than is possible with current construction practices?
3. How can we make the tools required to enable anyone to innovate, and thereby usher in a new era of entrepreneurship and innovation?
4. How can we spark a new era of business innovation that enables all who work to benefit equitably from the value they create?

“Everything is connected. I build robots: that changes people’s jobs, and that changes their education. As we build things, that uses energy. And robots are going to have to help with health care as well, because of demographic changes.”
— RODNEY BROOKS CURATOR, MAKE
**Supporting New Connections in Immunology**

**WHEN PHILLIP “TERRY” ‘71 AND SUSAN RAGON created an institute in 2009 to accelerate the discovery of an HIV vaccine, theirs was a transformative gift in more ways than one. By linking MIT, Harvard, and Massachusetts General Hospital as partners, the Ragon Institute is helping to reinvent the silo model that constrains biomedical research.**

The role of philanthropy, in Terry Ragon's view, is to support unconventional notions and “bet on talented people.”

According to Terry Ragon, while all three institutions have outstanding researchers, it’s their differences that distinguish the partnership. Harvard’s strength in immunology, and MGH’s clinical capacity, together with the “problem-solving attitude” of MIT’s scientists and engineers, have propelled vaccine research in promising directions (see page 18).

Having earned his SB in physics at MIT before founding data management corporation InterSystems, Ragon shares that relish for tough problems. “Obviously, if we could create an HIV vaccine or a cure—and I think we’re going to do both—that will save millions of lives,” he says. “But what also excites me is that this is by far the most difficult of all viruses. We’re going to have to create new science, pioneer new solutions that could apply to all viral diseases.”

In fact, Ragon’s philanthropic journey did not begin with a focus on HIV. “I spent my senior year of high school in South America, and I saw intense poverty there,” he explains. “It was obvious to me that I had a lot of advantages that were an accident of birth. This gave me a lifelong passion for helping people in developing countries develop the ability to help themselves.” His 2008 trip to South Africa with MGH scientist Bruce Walker, MD, crystallized the issue: “There was very little you could do to help these people unless you could do something specifically about HIV, because it was overwhelming everything: health care, social institutions, culture,” he realized. “Up to that point,” Ragon continues, “I assumed there was so much money already going into this field that any money I spent would be a waste of time. That’s when I got an education on how science is funded: you get money for research in the exact field you’ve been working in for a long time. And if you don’t have at least a 70% probability of achieving what you expect, you have very little chance of getting NIH funding—which I would say means you’re not doing experiments.”

His thinking about the role of philanthropy has shifted, says Ragon, “not just because somebody needs to fill this void, but because the void’s going to get bigger.” The importance of partnerships in tackling huge scientific challenges extends beyond researchers, into the gap between conventional funders and donors willing to support unconventional notions. “The Ragon Institute’s model is to bet on talented people, and to enable them to get their ideas to a point that more traditional mechanisms can start to fund them.”

In this, too, Ragon says his MIT experiences have shaped his thinking. “My MIT education gave me an appreciation for how science and engineering work. If I didn’t have that background, it wouldn’t have been so obvious to me that there was a better approach for philanthropy to help change the world.”

— NICOLE ESTYANK TAYLOR

**MIT and Abu Dhabi Connect on Energy and Environment**

If two heads are better than one for solving tough problems, it stands to reason two nations are better still when those problems span the globe. MIT’s signature no-boundaries approach extends far beyond disciplinary borders into numerous international collaborations. One of MIT’s largest such partnerships, the MIT and Masdar Institute of Science and Technology—in the world’s first graduate-level research university dedicated to alternative energy. Today, the Cooperative Program oversees a number of research projects, including nine large-scale multi-investigator projects—comprised of MIT and Masdar Institute faculty and graduate students—who focus their projects on climate, energy, health, food, and clean water.

The desalination project underway, led by MIT’s John Lienhard, the Abdul Latif Jameel Professor of Water and Food, along with Masdar Institute professor Hassan Arafat, benefits from input from the MIT Deshpande Center for Technological Innovation. Grants funded by the MIT & MICP and administered by the Deshpande Center support MIT and Masdar Institute faculty and students in efforts to move their ideas into the marketplace. The team is looking at potential markets for portable desalination systems for use on small-scale projects. “Our partners are now learning how to do translational research and are building their own version of the innovative and highly successful Deshpande program,” Boning says.

Alexie Kolpak, MIT’s Rockwell International Career Development Professor of Mechanical Engineering, is now working with one team that’s using solar energy to split water into hydrogen and oxygen, and later using the hydrogen as fuel. “One reason I was drawn to MIT was the chance to join an international collaboration,” she says. “Interacting with different cultures provides different perspectives, and together we see how science and technology move forward.”

— LAURIE EVERTT

**ABOVE** Working on a joint research project are PhD student Wei Li, postdoc Ana Costa, Dr. Rita Sousa of Masdar Institute, and Dr. Herbert Einstein of MIT.

**PHOTO PETER JONES**
A Bridge to Cancer Solutions

NEW WAYS TO FIGHT pancreatic cancer, a technique for the detection of invisible skin cancers, and a tool for uncovering the secrets of aggressive brain tumors are among the advances from the Bridge Project, a collaboration between MIT and Dana-Farber/Harvard Cancer Center (DFHCC) that has yet to celebrate its fifth birthday.

Couple that with four patent applications, a startup, and 11 peer-reviewed scientific papers—all from only 15 teams of researchers, many of them together for less than two years—and you can understand why “all of us involved feel really good about the progress we’ve made,” says Tyler Jacks, director of the Koch Institute for Integrative Cancer Research at MIT.

David Livingston, deputy director of DFHCC, the largest federally designated comprehensive cancer center in the US, agrees, stressing the importance—and novelty—of bringing together engineers, scientists, and clinical investigators to tackle difficult medical problems. “The goal of the Bridge Project is to make major advances for cancer therapeutics and diagnostics. And the way we make advances is by collaboration between people with complementary interests, skills, and talents.”

In 2010 Livingston and Jacks, longtime friends, realized the potential for a formal collaboration between their two institutions, both powerhouses in cancer research. The National Cancer Institute has 65 designated cancer centers around the country; the Koch Institute and DFHCC are the only two in Massachusetts.

“We wanted to move beyond a model that was pervasive in our field, where institutions like MIT and Harvard felt it was important to go it alone. Now we recognize that it’s critical to join forces,” says Jacks, who is the David H. Koch Professor of Biology.

Thanks to gifts from several philanthropists and organizations, key among them Arthur Gelb ’61 and the Commonwealth Foundation for Cancer Research, the two established the Bridge Project to distribute peer-reviewed grants of $750,000 each over two years to teams composed of researchers from both MIT and DFHCC. Those grants, says Livingston, “are larger than many single project grants from the National Institutes of Health.”

And they’re getting results. One team, for example, uses Raman spectroscopy to visualize pre-cancerous melanoma lesions on certain fair-skinned people. Without the technique, this early stage of cancer is invisible to the naked eye. With it, “the chance of missing these goes way down,” says Livingston, who is Emil Frei Professor of Genetics and Medicine at Harvard Medical School. Melanoma is much more curable when caught early.

The Bridge Project is now entering phase two. “We’ve built the bridge and there’s plenty of traffic flowing. Now it’s time to expand,” says Jacks, noting that “every year we leave on the table highly ranked and meritorious grants that we wish we could fund.” The 15 Bridge Project teams selected to date came from a pool of 84 applications. The three-pronged goal of the expansion is to double the number of annual Bridge grants from four to eight over the next five years, provide Extension Grants for an additional year of support for projects moving toward clinical implementation, and create smaller Footbridge Grants to help establish proof of concept for early-stage ideas.

Jacks notes that “technology development in a vacuum is almost worthless.” The Bridge Project “applies those advances to critical problems in cancer, which brings meaning to the science and technology in a very fundamental way.” — EIZABETH THOMSON

Training Robots to be Better Co-Workers

ROBOTS IN INDUSTRIAL SETTINGS have become really good at performing highly repetitive actions at lightning speed. But when required to work alongside humans, they can be like teenage boys at a dance: all left feet, tripping on their partners, and freezing up after making a mistake.

Julie Shah wants to create a new generation of assembly line robots that will be more attentive and better coordinated with their human coworkers. An associate professor of aeronautics and astronautics, and director of MIT’s Computer Science and Artificial Intelligence Laboratory’s (CSAIL) Interactive Robotics Group, Shah is designing factory-based machines that will better anticipate human movement, and sidestep rather than shut down to avoid injuring flesh-and-blood partners.

“We’re developing robot planning, decision making, and control technology that allows robots to adapt their actions, using a model of what a person is doing, or might do,” she says. “This vision of a safer and more efficient factory floor is already becoming a reality, through a series of collaborations with major corporations. At a Boeing factory that assembles commercial airplane fuselages, Shah has developed an algorithm that enables robots to continue working if nearby humans leave and return to the line. With the firm ABB, she has developed predictive models so robot systems can “track human arms for elbow-to-elbow work.”

Shah’s designs for robots and their industrial environments are intended to speed up production from start to finish. “Assembly lines are limited by the slowest station,” she says. Her hope is to staff each station, even those requiring the most dexterous work, with inherently human-safe machine assistants.

A recent breakthrough with partner BMW brings this future closer. In an industrial machine first, Shah successfully tested a freely mobile robot worker that moves on and off an automatic final assembly line with tools and materials, navigating safely, and gracefully, around human partners. — LEDA ZIMMERMAN

TOP A lung tumor acquiring a supply of oxygen and nutrients.  PHOTO: THOMAS TAMPELLA

Far Left Tyler Jacks  PHOTO: ALEXA NEDEL

LEFT David Livingston  PHOTO © SAM COHEN / GOAL-PAPER

Above Professor Julie Shah is shown with an ABB industrial robot; she uses these robots in research on elbow-to-elbow manufacturing, in which humans and robots work side by side in the same area.  PHOTO: M. SCOTT BRAUER

More Shah fields robot questions on radio’s “Ask the Expert” spectrum.mit.edu/webextras

More Shah fields robot questions on radio’s “Ask the Expert” spectrum.mit.edu/webextras
In the fight against Alzheimer’s disease, new research from Li-Huei Tsai’s lab suggests the immune system may play a role in the disease. Tsai is a leading researcher in the field of Alzheimer’s disease and is leading the Aging Brain Initiative, which aims to undertake a portfolio of targets to develop effective treatments for the disease.

Tsai’s discovery that the immune system may play a role in Alzheimer’s disease is an example of how fundamental research can drive new ideas for clinical therapies. The team investigated brain epigenetics, changes in cellular interactions with DNA that redirect gene behavior. This work led to the discovery of misbehaving immune cells in the brains of mice engineered to mimic Alzheimer’s. “Now we realize the immune system plays an important role, and possibly a causative role in Alzheimer’s disease,” she says.

Tsai’s discovery is welcome news since, so far, clinical trials of Alzheimer’s drugs that target neurons have been unsuccessful. “We really need a portfolio of targets,” says Tsai, Picower Professor of Neuroscience and Director of the Picower Institute of Learning and Memory.

About 35 million people worldwide have dementia. More than 5 million Americans have Alzheimer’s disease. And the numbers are expected to rise in the coming decades as the population ages. Also, because there are no effective therapies for these diseases, the costs of care are high. In fact, in the US, the cost of Alzheimer’s disease care exceeds all other health care costs.

“If we don’t address the need for treatment now, the economic burden is going to be unbearable soon,” says Tsai, who is taking on this challenge.

Tsai is leading the Aging Brain Initiative. This collaborative effort at MIT focuses on brain aging because it is a risk factor that spans all forms of dementia, but how it influences these diseases is unknown. “We still don’t quite understand how dementia begins and progresses,” says Tsai. “This contributes to the fact that we don’t have a whole lot of options when it comes to drugs.”

The Aging Brain Initiative brings together an accomplished group of MIT researchers, including neuroscientists, biologists, computer scientists, and engineers, to leverage MIT’s strengths to build foundational brain-aging knowledge and rapidly bring solutions to the clinic. The Initiative’s four-pronged approach will identify aging biomarkers, develop circuit-specific therapeutics, explore personalized molecular medicine, and identify strategies to promote healthy brain aging. Other founding members include: Edward Boyden, associate professor of Biological Engineering and Brain and Cognitive Sciences; Emery Brown, Edward Hood Taplin Professor of Medical Engineering and of Computational Neuroscience; Leonard Guarente, Novartis Professor of Biology; Robert Horvitz, David H. Koch Professor of Biology; Susan Lindquist, Professor of Biology; and Susumu Tonegawa, Picower Professor of Biology and Neuroscience.

Tsai is also co-associate director of the new Paul F. Glenn Center for Science of Aging Research at MIT, which will leverage the strengths of MIT biologists, neuroscientists, and cancer researchers to understand aging.

Tsai’s discovery that the immune system may play a role in Alzheimer’s disease is an example of how fundamental research can drive new ideas for clinical therapies. The team investigated brain epigenetics, changes in cellular interactions with DNA that redirect gene behavior. This work led to the discovery of misbehaving immune cells in the brains of mice engineered to mimic Alzheimer’s. “Now we realize the immune system plays an important role, and possibly a causative role in Alzheimer’s disease,” she says.

Tsai is already acting on these findings, which were published in Nature last winter. One effort is sharply focused on screening for drugs that might correct immune cell behavior. Another effort, in collaboration with the Broad Institute, will look at the individual gene expression profiles of a wide range of immune cells. This analysis, called single-cell RNA sequencing, will provide Tsai with an extraordinarily detailed view of how many different types of immune cells there are in the brain. “There’s a sense that there are beneficial immune cells and bad immune cells in the brain,” she says. “So we say, how many different kinds are there? We need to get to know them better before we know the best way forward.”

The Aging Brain Initiative aims to undertake a portfolio of these types of collaborative projects, to foster rapid progress of discoveries into clinical medicine, and to move forward as a large consortium-like team. — Elizabeth Dougherty
**“SOLAR ENERGY IS POISED to play a major role in our energy future, and MIT is poised to deliver new technologies to make that possible,” says Robert Armstrong, director of the MIT Energy Initiative (MITEI), who notes that with appropriate investments in R&D and sound public policies, the energy source could account for half of the world’s electricity by the middle of the century, up from a mere 1% today.**

Armstrong is one of 30 authors of “The Future of Solar Energy,” the latest of seven interdisciplinary reports from MITEI exploring major energy technologies that might play significant roles as the world looks to address climate change over the coming decades. “We face a dual challenge with respect to energy and climate,” Armstrong says. “Energy demand is expected to double globally by 2050. But it’s clear that because of global warming we also need to decarbonize the energy system,” or replace today’s energy systems with alternatives that don’t emit carbon dioxide and other greenhouse gases.

Richard Schmalensee, the study chair, agrees. “If we are going to seriously decarbonize the economy, it is hard to see how we can do that globally without a lot more solar generation. The question is, how will we make solar power useable at large scale by mid century?” Schmalensee, who is the Howard W. Johnson Professor of Economics of Chemical Engineering, adds: “There’s no doubt that a lot more can be done to assure that solar technology is properly developed for use when the sun doesn’t shine. The success of photovoltaics in particular at very high penetration is heavily dependent on the availability of cost-effective storage,” O’Sullivan says. From a regulatory perspective, “solar represents a lot of new dynamics that will require regulators to be more nimble.”

The study further recommends changing the subsidy paradigm for solar in the United States. Currently, subsidies are based on the investment associated with a solar installation. Although that’s helpful, “we believe the government can do much more” to encourage solar, O’Sullivan says. For example, “we ought to transition to a subsidy based on solar energy production. That will give asset owners much more of an incentive to maximize the amount of solar generation.”

Armstrong is optimistic about solar and MIT’s continuing contributions to the field. “There are many new technologies we are working on that could make a big difference to our solar future,” he says. “I think one of MIT’s jobs is to shake up the world of technology on a regular basis.” — ELLIOTH THOMSON

**“Solar as a technology has rapidly transitioned through its nascency to a point today where it is increasingly competitive as a source of electricity.”**

— Robert Armstrong, director of the MIT Energy Initiative (MITEI)

Research Initiative will develop policy with input from many disciplines at MIT, including computer science and political science; and the Interdisciplinary Consortium for Improving Critical Infrastructure Cybersecurity, based at MIT Sloan School of Management, examines managerial, operational, and strategic issues.

**“Cybercrime may seem inevitable today, but with the right people, resources, and approach, we can change that.”**

— Laurie Everettt

**“Cybercrime may seem inevitable today, but with the right people, resources, and approach, we can change that.”**

MIT’s contributions to computer security go back to the 1960s. Project MAC, the antecedent of CSAIL, devised a system for shared computing that required users to create passwords to protect their content, thereby creating the world’s first computer password. But Rus explains that many of today’s cybersecurity issues result from older, poorly designed systems, which were initially constrained by limited computing power. “In fact,” she says, “many of these systems viewed security as an afterthought, if they thought of security at all. This haphazard approach, known in the industry as ‘patch and pray,’ leaves organizations scrambling to react after a data breach, and by then it’s too late.”

Now, Rus and the CSAIL team, led by Dr. Howard Shrobe, are working toward a model of “security by design,” designing and implementing security measures that systematically prevent attacks and make systems more resilient, even capable of repairing themselves when breaches occur. “Many in the cybersecurity field think that these problems are inherent because computer systems are so complex,” says Shrobe. “Our view is most vulnerabilities are due to a small number of architectural weaknesses. We have to re-architect our systems to make them safer.”

Rus adds: “Cybercrime may seem inevitable today, but with the right people, resources, and approach, we can change that.” — LAURIE EVERTT
Crowdsourcing Global Climate Strategies

Can Collective Intelligence Save the Planet?

“I don’t think there’s anything else that could,” says Thomas Malone, who leads MIT’s Climate CoLab, and who thinks that the kinds of collective intelligence the world has used so far to deal with climate change—like scientific conferences and international treaty negotiations—aren’t enough.

“We now have a new way of solving huge problems that wasn’t possible even 20 years ago,” Malone says. “Think about Google and Wikipedia, which demonstrate that we can attack tough problems at a global scale and with a degree of collaboration never before possible. Our goal in the Climate CoLab is to apply this crowdsourcing approach to the problem of global climate change.”

The Climate CoLab is a fast-growing global community of more than 36,000 people who are passionate about addressing this issue. The community includes some of the world’s leading experts on the science and policy of climate change, as well as business people, scientists, policymakers, students, and many others. Anyone can submit their own ideas or offer feedback on others’ ideas on the CoLab site.

“There’s a broad consensus within the scientific community that human activities are contributing to changes in the climate that will result in things like rising sea levels, frequent droughts, and more severe storms,” says Malone.

“But there is not yet any consensus on what to do about this.”

The answers will come, he believes, only by pooling knowledge from many disciplines and many people. “It’s a big, hard, complicated problem and needs all kinds of expertise—from the physics of the upper atmosphere, to the economics of technological change, to the politics of government regulations, and the psychology of human behavior. Good solutions also require detailed local knowledge of, say, how farmers in India pump water and how homeowners in Canada insulate their houses.”

An eight-year-old project of MIT’s Center for Collective Intelligence, the Climate CoLab includes online tools to help people collaborate on developing proposals for what to do; computer simulations to predict end results; and online contests in which expert judges and community voters identify the most promising ideas. Malone believes that this approach could also apply to other big problems, from terrorism to unemployment to the availability of clean water.

In advance of the international climate talks in Paris this winter, the Climate CoLab has seven contests now open that invite ideas for regional and global climate action plans. Winners will present their plans at MIT’s Solve conference this fall and share a $10,000 prize. (See page 5.) Last year’s winners, from 17 countries, offered such ideas as a US carbon tax that uses the revenue to benefit poor households, reduce corporate income taxes, and shrink the federal deficit.

Malone emphasizes that the CoLab wouldn’t exist without the work of project managers Rob Laubacher and Laur Fisher, as well as a group of over 100 volunteers who serve as expert judges, advisors, and fellows.

“Arguably, there’s no institution on the planet better than MIT to help the world figure out what to do about climate change,” says Malone. “We’re still a long way from having solved the problem, but I think MIT can make a real difference.” — LIZ KARAGIANIS

Looking for Change, Online and Off-Center

Amazon spent $970 million last year to buy Twitch, a website that streams videos of people playing computer games such as League of Legends. The site attracts an enormous audience for advertising—with more than 100 million community members—but who could have predicted that back in the early 2000s, when broadcast gaming first started to take off in South Korea?

Ian Condry and T.L. Taylor probably could have. The MIT ethnographers explore the connections between online and offline worlds through the Creative Communities Initiative, a research group within Comparative Media Studies/Writing, and both professors have long recognized that the passion that drives today’s fringe activities often catches fire more broadly, producing tomorrow’s blockbusters.

“Movements go from the margins into the center,” says Condry, who has written a book on how hip-hop, defying the predictions of the music industry, surged to popularity in Japan.

“You can identify scenes of intense, passionate devotion on the part of fans and audiences that are harbingers of future development in media and culture.”

The Creative Communities Initiative investigates the phenomenon of growth of online communities, social networking, and collaborative creativity by studying how the people involved behave—in contrast to other studies of Internet culture, which rely on crunching numbers.

When it comes to solving global challenges, “it’s a seductive idea that we don’t need to get to know people individually,” Condry says. But communities are made up of individuals—and “marginal communities can be a little out of the zone of attention, but they offer inspiration for new approaches.”

The success of sites like Twitch, for example, is already blurring the boundaries of authorship and challenging traditional definitions of copyright, notes Taylor, the author of Raising the Stakes: E-Sports and the Professionalization of Computer Gaming (MIT Press, 2012). Industry giants are being forced to adjust to this new reality, revealing the power of grassroots communities to effect change.

“I believe we’re moving to a post-copyright era,” Condry says.

The bottom line, Taylor says, is that “communities are very good at knowing what they want and need to sustain themselves and they’ll take or make any technology to do it. Any problem-solving approach has to engage with that fact.”

— KATHERYN M. O’NEILL
Erected in Rome in AD 113, Trajan's Column is an architectural wonder famous for its bas-relief decoration, which spirals 23 times around to a height of 625 feet. Architecture major Frankie Perone ’16 has been investigating the relevance of this historical precedent for contemporary architecture through MIT’s Undergraduate Research Opportunities Program, which matches students with faculty in research partnerships.

In Perone’s case, the research focuses not on one specific problem, but on cultivating an entirely new perspective. Working with Associate Professor in architecture William O’Brien Jr., Perone has been creating two-dimensional labyrinths similar in pattern to the bas-relief on the column to investigate what new properties emerge when you wrap such forms around three-dimensional objects such as cylinders.

“How can we abstract this to a point where we understand very fundamental architectural ideologies about figures?” says Perone, who began drafting shapes on a plane and slowly moved to building a three-dimensional labyrinth out of acrylic. “These different visualizations give you a more in-depth understanding of what the original thing can be or what it is.”

O’Brien says, “This design research offers the discipline of architecture a body of work that is invested in form, history, narrative; and considers architecture first and foremost as an act of cultural production.”

While the project is admittedly abstract, Perone says the work has given her a more holistic understanding of architecture. Also, she says, she has found the process of working with pure lines, shapes, and forms a refreshing change from classwork, which focuses on solving practical problems in architecture. “I don’t expect there to be a building made from this research,” she says. “But I’m really learning to think for myself honestly, to think critically about what I’m doing and why.”

Exploring the same lines and shapes in different ways has given Perone an intuitive understanding of form she believes will ultimately help her produce more thoughtful designs. “Knowing how to establish clear, logical rules can be applied at any scale, to anything we interact with that has some sort of design element,” she says. “I think it’s a great way of looking at architecture.” — KATHRYN M. O’NEILL

Arriving at MIT, One Solution at a Time

“FOR 11 YEARS, I’ve wanted to go to MIT,” says Ahaan Rungta, now a 16-year-old freshman, who did math puzzles at age 3, calculus at 7, quantum mechanics at 13. Homeschooled, he has worked on problems since he was 5 through MIT’s OpenCourseWare (OCW) and later, edX, online courses open to the world for free. He has taken 55 courses and passed them all. “OCW is more than a school. It’s a paradise.”

He loves it all—the lectures, problem sets, exams. He studied math, chemistry, physics. At 10, he wrote MIT: “I’ve progressed immensely from getting a 10% in solving problems to 60%. I look at problems differently now and solve them with a more detailed conceptual approach. I solve OCW problems everywhere, even when I go out to eat at my dad’s restaurant.”

Born in Calcutta, at 2 he moved to Fort Lauderdale, where growing up he longed for “like-minded people,” so when he was 13, the family packed up and moved to Cambridge. On his 13th birthday, he first visited MIT. “That was the day my life changed.”

Every day since, he has visited MIT, often stopping at Café Spice, the Indian restaurant inside MIT’s Student Center that his dad manages, where he loves to sit solving problems. Every hour or so his dad stops by to say hello. “In school, you’re given homework and one week later you find out how you did,” he says. “The benefit of learning to solve online is you get instant feedback; you learn right away and then the next problem is all of a sudden easier.”

“IN SCHOOL, YOU’RE GIVEN HOMEWORK AND ONE WEEK LATER YOU FIND OUT HOW YOU DID,” he says. “THE BENEFIT OF LEARNING TO SOLVE ONLINE IS YOU GET INSTANT FEEDBACK; YOU LEARN RIGHT AWAY AND THEN THE NEXT PROBLEM IS ALL OF A SUDDEN EASIER.” — LIZ KARAGIANIS
YOU NEVER KNOW WHERE THE WIND WILL TAKE YOU, as Teasha Feldman-Fitzthum ’14 has discovered. She started out as an MIT undergraduate trying to predict wind patterns and ended up as CTO and cofounder of a company that provides financial risk analytics to the wind industry.

What Feldman-Fitzthum learned at MIT is that predicting the wind wasn’t the industry’s biggest problem. “The bigger problem was getting [projects] financed, convincing banks that renewables are a good idea and that they make money,” she says, noting that the industry is rich with investment opportunities; about $60 billion is spent every year on US wind projects.

Feldman-Fitzthum cofounded Cardinal Wind with Michael Reynolds MBA ’14 last June to make it easier for potential investors to see the benefits of investing in wind, which is already generating enough power to keep more than 130 million metric tons of CO2 emissions out of the atmosphere. Her motivation was simple: “I love technology and innovation. I love that we have this world that runs on electricity, but wouldn’t it be great if we weren’t killing the planet?”

Wind power generation is expected to more than double by 2018, yet investors have been slow to embrace such projects, which are capital-intensive and face complex financial and technical challenges. Cardinal Wind’s financial risk analysis software enables investors to evaluate projects to see how various factors will affect revenue, operations, costs, and returns.

“We are telling them how this will turn out,” Feldman-Fitzthum says, noting that the software is expected to be ready for pilot testing in September. “We’re tricking Wall Street into changing the world.”

PRIME WORKS to funnel more money into promising technologies by helping motivated philanthropists take advantage of a rarely used financial vehicle called a PRI, or program-related investment, to fund for-profit ventures while still gaining the tax benefits of charity. At the same time, PRIME works with entrepreneurs to help them market the charitable potential of the businesses they’re building.

“Until this year, the grant mechanism we enable at PRIME had never been applied to early stage energy innovation,” Kearney says, noting that her nonprofit brokered its first, proof-of-concept deal in May. The deal provided seed capital for a grid-capacity energy storage startup from a syndicate of four philanthropic investors that includes superstar couple Will and Jada Smith’s family foundation. “Our goal at PRIME is to make this type of grant-making more commonplace for philanthropic families and foundations that might be interested in the advancement of science across sectors to solve big social problems—to make grants fuel capitalism in a way that could benefit humanity for generations to come.”

PRIME Coalition

CHALLENGE
Expand funding opportunities for socially beneficial energy startups

SOLUTION
A vehicle for philanthropists to give charitably to for-profit ventures

Energy is an incredibly complicated, massively intricate problem to solve. And MIT graduates love that. By 2050, 9.6 billion people will inhabit the planet, and by some estimates, we’ll need 80% more energy than today. The young alumni on these pages are among the scores of MIT people dreaming up fresh ways to harness nuclear, wind, and solar power; optimize our use of fossil fuels; and create smarter systems to support the development of energy solutions.
PK Clean

**CHALLENGE**
Increase the percentage of plastic waste that can be recycled

**SOLUTION**
A chemical process that converts a wide mix of plastics into oil

**SOLUTION**

**Ubiquitous Energy**

**CHALLENGE**
Overcome aesthetic objections to opaque solar cells

**SOLUTION**
Transparent photovoltaics that expand potential use to virtually any surface

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PK Clean, a startup founded by CEO Priyanka Bakaya MBA ’11, is tackling this problem using a novel chemical process developed at MIT that can convert a wide mix of plastics—even dirty plastic—into oil.

“IT’s not a beautiful plastic stream. We’ve had to really innovate,” Bakaya says. In addition to dealing with contamination, recyclers have to address the fact that “plastic” isn’t actually one kind of material. The term encompasses a wide range of complex polymers with different molecular structures and physical properties, including melting points.

PK Clean gets around this problem by breaking down plastic’s large carbon chains to reduce the mixed materials to their lowest common denominator. The process converts 70% to 80% of plastic into oil, which the company sells; and 10% to 15% into hydrocarbon gas, which PK Clean uses as fuel for its operations.

In 2013, the company opened its first commercial recycling plant in Salt Lake City; it can convert 20,000 pounds of waste plastic into 60 barrels of oil every day. Still, Bakaya wants to do more. “Long term, we want to position ourselves to come up with innovative solutions for all kinds of waste streams,” she says.

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Transatomic Power

**CHALLENGE**
Reduce the health and environmental risks of conventional nuclear plants

**SOLUTION**
A new kind of meltdown-proof reactor fueled by existing nuclear waste

Leslie Dewan ’06, PhD ’13, envisions a world where energy is cheap, plentiful, and carbon-free—thanks to nuclear power. She and Mark Massie SM ’08, PhD ’12, cofounders of Transatomic Power, “you have to have nuclear in the mix along with solar and wind.”

Building new nuclear power plants is controversial because the waste generated by today’s light water reactors is highly radioactive and because reactors can melt down, releasing radiation into the environment.

Transatomic addresses these concerns head-on. Its advanced molten salt reactor can be fueled by existing nuclear waste—which Dewan says the company views as “a resource to be tapped rather than as a liability that needs to be disposed of”—and it cannot melt down.

The crucial innovation relates to how the reactor uses fuel. Most reactors today use uranium fuel rods, which need to be actively cooled to prevent meltdown. Transatomic employs uranium dissolved in liquid salt, which does not require active cooling. And, if the power fails, the nuclear material drains passively away from the core, making the reactor “walk-away safe.”

Using molten salt also enables Transatomic to draw 92% more energy from the uranium—thus its ability to reuse existing spent fuel rods and to significantly reduce the burden of radioactive waste on the planet. The company plans to break ground on a prototype facility in 2020.

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Ubiquitous Energy

**SOLUTION**
Transparent photovoltaics that expand potential use to virtually any surface

**SOLUTION**

The sun’s energy can power a planet many times over. Miles Barr is working to put solar panels on enough of that surface to harness that power—visibly.

“What we’re doing at Ubiquitous Energy is commercializing a transparent version of a solar cell,” says Barr SM ’08, PhD ’12, creator of the startup, which builds clear, thin-film photovoltaics. “Conventional solar technology is opaque, shifty, and generally black or blue. We’re eliminating the aesthetic complaints, maximizing the potential surfaces you can put the cells on.”

Historically, makers of solar cells have only been interested in efficiency—getting the most energy possible out of the light hitting the cells’ surface. Ubiquitous Energy’s innovation was to sacrifice some efficiency in order to expand potential usage to virtually any surface. The company’s technology, which emerged from the labs of MIT faculty member Vladimir Bulović and Michigan State University faculty member Richard Lunt, selectively harvests infrared and ultraviolet light, allowing visible light to pass through to the eye.

“It’s kind of a trick, but the cell looks visibly transparent,” Barr says, noting that Ubiquitous Energy has started pilot production on cells that can fit right on the screens of small electronic devices and charge batteries using ambient lighting.

Letting visible light through means Ubiquitous Energy’s cells could produce only up to two-thirds as much power as the best opaque solar cells. But Barr says the trade-off is worth it. “The transparency opens up a lot more surfaces for application.”

Barr hopes one day the windows of skyscrapers will be covered with photovoltaics, all producing electricity from the sun. — Kathryn M. O’Neill
thought of energy as cheap, so it became easy to make bad designs, building glass boxes all over the world and then burning fossil fuels to make them comfortable, says Ochsendorf. “But those glass boxes aren’t efficient from an embodied energy or an operational energy standpoint.”

Ochsendorf has made it his mission to make that change. Along with several graduate students and practicing architects and engineers, Ochsendorf helped build two buildings — one in South Africa, and one in England — that each used just 40 kilograms per square meter of embodied carbon dioxide, 10% of the energy consumed in constructing a typical building. They did it in part by choosing more optimal structural forms — for example, curving vaults instead of flatslabs. But a large part of the energy savings came from utilizing low-carbon materials (in this case, locally made bricks) to bear the load.

For someoneso forward thinking, Ochsendorf finds much of his inspiration in studying the past, investigating construction techniques such as Renaissance masonry, Gothic cathedrals, and Incan bridges to learn their secrets. “There are better solutions out there, in particular local solutions all over the world that were developed over the centuries by people for their climates,” he says, absently stacking model clay bricks on his desk while he talks.

In order to truly change how buildings are made, Ochsendorf believes, we must integrate architects and engineers more closely in the design process; together, they can make early-stage, crucial energy-saving decisions. Ochsendorf has long been interested in green building — he proposed a thesis on sustainable practices in civil engineering while at Cambridge University 20 years ago — but it wasn’t until coming to MIT in 2002 that he made it the focus of his work, inspired in part by the multidisciplinary nature of the Institute. “No one discipline is going to allow us to create low-energy cities in the future,” he says. “MIT is one of the few universities in the world that has a really strong architecture program and a really strong program in civil engineering — and not only that but the two departments are physically linked [with the former in Building 1, and the latter next door in Building 5].”

Now, he and colleagues in both departments are linking the fields even more closely: revamping the curriculum for increased collaboration among architecture and engineering students, and developing a software platform to exchange rapid feedback between disciplines on strategies to reduce energy cost. “These projects are really only possible with an integrated team where you are thinking about structure, and materials, and geometry, and operating energy all at once.”

— Michael Blanding

“It’s like taking a Hummer and putting a solar panel on top to power the windshield wiper and saying, look, that’s a green car.”

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By using phone data, González was able to record individual patterns of movement and also the ways in which interconnected people move in relation to one another. Through this data, González and her team deduced that one-fifth of urban movement is for social purposes. This discovery will influence urban planning, infrastructure, and the environment. For instance, González is currently working with the metropolitan planning office in the Saudi Arabian capital of Riyadh to help policymakers coordinate a bus system that reflects urban travel patterns. “As the city grows, they envision traffic will only get worse—something that’s very costly in terms of carbon emissions and fuel consumption,” González says. Building a bus system with stops and frequencies that anticipate how groups of people actually travel will hopefully encourage more passengers to use it.

This summer, González is working in Rio de Janeiro, Brazil, upcoming site of the 2016 Olympic Games. The city is trying to coordinate traffic routes, as street capacity will be reduced during the events. Understanding how to encourage travelers to use fewer cars will be key. “I’m analyzing how similar people might have similar mobility patterns. Knowing how people move helps us propose solutions,” such as carpooling, González says.

To that end, a logical outgrowth of her research focuses on networking apps for “the greater social good,” she says. By quantifying how much urban movement is social, it could be possible to pair like-minded travelers through social media apps that increase traveling efficiency. González points to ride-sharing service Uber as a company that leverages this kind of dynamic social mapping.

“The information that we generate can be captured in real time, from people using their devices, and we can actually see mobility in a city. This is the age of instant information, and it can directly affect policy. Imagine you have a set number of people traveling along a certain route, and you want to add an extra lane—this data can tell the mayor that you need it, and you can really quantify the need,” she says. “It’s hugely exciting.” — KARA BASKIN

STEWINIG CITY TRAFFIC with nothing but the radio or a smartphone for companionship, it might seem like your trip is a solitary one. But look around at the hundreds of other cars, just like yours, idling nearby. Do you ever wonder who these people are, where they’re going—and if you know them?

“We can actually see mobility in a city. This is the age of instant information, and it can directly affect policy.”

Marta González, civil and environmental engineering associate professor, did just that, and her findings will directly affect urban policy and planning. González co-authored a groundbreaking study recently published in *Scientific Reports* demonstrating that urban networks are not determined solely by geography, as is often suspected, but socially too.

The study extracted phone data from more than 25 million phone users in 155 cities in France, Portugal, and Spain over the course of six months, analyzing seven billion mobile phone interactions. The mode of data collection is revolutionary: In the past, analysts would have relied on travel diaries and anecdotal reporting. By using phone data, González was able to record individual patterns of movement and also the ways in which interconnected people move in relation to one another. Through this data, González and her team deduced that one-fifth of urban movement is for social purposes.

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From Mobile Data, Drawing Social Circles
From Individuals to Industries: Finding Solutions in Nanofluidics

Vastly different environments. Take blood analysis, which can be particularly challenging in developing countries where health care workers have limited or no access to expensive diagnostic lab equipment. His lab is creating a handheld device that can quickly and cheaply separate and analyze individual cells in a blood sample.

“I always think about what might have lasting impact. What will make a difference a hundred or a thousand years down the line?”

On another front, Karnik is developing ultrathin, strong, graphene-based membranes that have potential applications for water purification, energy systems, and the chemical industry. But he is also pursuing a low-tech approach to filtration: the use of thin slices of sapwood to remove impurities from drinking water. Using porous membranes that make up the system of tubes and transport cells that circulate water and dissolved minerals within the tree, Karnik’s lab fashioned a filter. Passing contaminated water through the membrane removed more than 99% of bacteria, potentially leading to a simple, safe, inexpensive water purification method for the more than 1 billion people globally who lack access to clean drinking water.

After completing an undergraduate degree from the Indian Institute of Technology at Bombay in 2002, Karnik became interested in “the huge diversity” of topics affected by the nanoscale properties of fluid flow. He earned a PhD at the University of California at Berkeley before joining the MIT faculty in 2007.

“What really drives me is a curiosity to learn about different phenomena—and then make connections between science and technology to turn them into something useful that adds value to society,” he says.

“I always think about what might have lasting impact,” he continues. “What will make a difference a hundred or a thousand years down the line? What will civilization even look like? Having that perspective helps me make important decisions about the direction of my research.” — DEBORAH HALLER

WHAT IF YOU COULD QUICKLY TELL from a drop of blood whether a patient had a bacterial infection? Or gauge how well his or her immune system was functioning? Rohit N. Karnik hopes his groundbreaking work on fluid flow will lead to a way to quickly discern important information about blood cells in real time. His insights could also result in cheaper and more effective ways to purify water and improve drug delivery within the body.

An associate professor of mechanical engineering, Karnik investigates the most fundamental nature of fluid transport: how cells navigate channels, how water flows through membranes, and how vapor molecules act when they encounter a liquid’s surface. His work on fluid flow at the micro- and nanoscales will be among the countless branches of research to benefit from MIT.nano, a new 200,000-square-foot building due to open on campus in 2018. It will house state-of-the-art equipment, teaching labs, imaging and prototyping facilities supporting research with nanoscale materials and processes, with potential impact in such areas as energy, health, life sciences, quantum sciences, electronics, and manufacturing.

Within the field of nanofluidics, Karnik designs solutions to widely varying problems and

ABOVE Rohit Karnik is developing ultrathin, strong, graphene-based membranes that have potential applications for water purification, energy systems, and the chemical industry.

PHOTO: KEN RICHARDSON

From Individuals to Industries: Finding Solutions in Nanofluidics
American households collectively generate about 400 million tons of waste on an annual basis, most of it landfilled, and the rest recycled or composted. Elsa Olivetti PhD ’07 feels compelled to address this vast and growing mountain of rubbish. Her research spans the design and manufacturing phases of materials through their final disposition.

“I’ve found waste and inefficiency abhorrent as long as I can remember,” says Olivetti, who became MIT’s Thomas Lord Assistant Professor of Materials Science and Engineering in January 2014. “All this stuff around that we’re not handling intelligently drives me crazy.” In elementary school, Olivetti urged her best friends to use recyclable paper bags rather than plastic wrap as schoolbook covers. Today, she leverages a multidisciplinary skill set in systems engineering, chemistry, and policy to attack the waste problem.

“I’m interested in more resource-effective materials design and recovery,” says Olivetti, “and I want to reduce the ultimate impact on the environment of new materials we create.”

Olivetti credits a course she took at the University of Virginia with architect William McDonough for providing her with both inspiration and a robust research methodology.

“I was looking for a vehicle by which to solve problems, especially the management of waste,” says Olivetti. “After I learned about McDonough’s ‘cradle-to-cradle’ paradigm, which promotes thinking about a product’s end of life when designing it, I decided to go after material science in a focused way.”

This meant, says Olivetti, “understanding how the atomistic behavior of materials translates to properties at a macroscopic level.” She created compounds in the laboratory, and studied manufacturing processes at scale. Her MIT doctoral research combined polymer science and electrochemistry to find ways to improve cathode materials for rechargeable lithium ion batteries. Postdoctoral research at MIT’s Materials Systems Lab focused on developing tools for understanding recycling in geographic and regulatory contexts.

“After building up all these years,” says Olivetti, “I finally have all the pieces together for my own research platform.” With her broad foundation in the micro- and macro-study of materials, Olivetti is pursuing multiple projects. But she finds two research threads particularly exciting.

The first involves a large-scale analysis of US paper recycling and the development of tools to help the forest and paper industry make a more efficient business of recovering and reusing wood fiber from products such as recycled cardboard, paperboard, and copy paper. Assessing the overall supply and demand of fiber, as well as manufacturing constraints involving recycled and virgin wood fiber, Olivetti visits dozens of mills. “It’s one of the reasons I love this job,” she says.

Her goal is a simulation tool that consolidates and captures the overall flow of fiber, from tree to product, to recovered material and reuse, within the complex web of manufacturers, markets, recovery technologies, and regulatory schemes. This kind of analytical model “has implications across all materials systems, such as aluminum alloys and battery recycling,” says Olivetti. “If we can understand what’s driving the environmental cost in systems we can direct fundamental research or policy to making more resource-effective decisions.”

In Olivetti’s second research thrust, she is helping to build a computational model to accelerate evaluation of the economic feasibility of new compounds with desirable properties for use in energy and other applications. In addition to evaluating costs of parts, materials, labor, and manufacturing processes, Olivetti wants “to understand environmental impacts as well.”

The end goal of Olivetti’s research: reducing what must be recycled, reusing recycled materials more efficiently, and influencing “as early as possible what folks are thinking at the lab bench to improve society’s footprint on resource use.” — Leda Zimmerman

**Reducing Waste Across a Product’s Lifecycle**

**Above** Elsa Olivetti with bales of recovered paper for recycling.

Photo: Ken Richardson
MIT researchers and colleagues are harnessing the power of multiple disciplines—from cutting-edge biology to physics, engineering, and computer science—to tackle one of the world’s great scourges: HIV, the virus that causes AIDS. Their ultimate goal, toward which they’ve made progress, is a vaccine against the disease.

HIV is difficult to combat because it can quickly mutate to evade the body’s immune response. As soon as the immune system recognizes the virus and begins to attack it, the virus changes, thus avoiding detection.

As a result, “designing a vaccination strategy for HIV is very hard because you must produce an immune response that HIV cannot mutate around.” That’s why, 30 plus years after the virus’s discovery, there is still no vaccine, says Arup Chakraborty, the Robert T. Haslam Professor of Chemical Engineering, Chemistry, Physics, and Biological Engineering and director of MIT’s Institute for Medical Engineering and Science (IMES).

Chakraborty approaches the challenge of creating such a vaccine from a unique perspective: he applies computational and theoretical techniques developed in the physical sciences to questions in immunology. Specifically, he and colleagues use these techniques, coupled with the power of genetic sequencing and computation, to define the mutational vulnerabilities of HIV. The goal, explains Chakraborty, is to figure out “where can you target HIV with an immune response so that if it tries to evade detection, it becomes less fit, hurting its ability to survive.” In other words, the idea is to corner the virus, forcing it either to be detected—and destroyed—by the immune system, or to mutate into a form that makes it weaker and less capable of reproduction.

The approach is bringing results, says Chakraborty, who is a founding member of the Ragon Institute of Massachusetts General Hospital, MIT, and Harvard; his colleagues in this work are all associated with the Ragon Institute. The team has identified an immunogen, or active component of a vaccine, made of protein fragments, or peptides, that could induce multiple mutations in the virus that would make it less fit.

Peptide-based vaccines, however, are difficult to deliver to the immune cells. So Chakraborty and his key clinician-scientist collaborator, Bruce Walker, MD, director of the Ragon Institute, joined forces with Darrell Irvine, a professor in the Koch Institute for Integrative Cancer Research, the Department of Biological Engineering, the Department of Materials Science and Engineering, and a founding member of the Ragon Institute. Irvine is a specialist in creating carriers for vaccines. He, in turn, linked the peptides to a lipid that causes them to bind to a protein called albumin. Albumin naturally travels to the lymph nodes, or the tissues where an immune response is induced. “We designed vaccines that hitchhike on albumin to get to where they need to be,” says Irvine.

Walker, who is also a professor at Harvard Medical School and one of the world’s experts on HIV, says, “It’s been exhilarating to work together with colleagues on this really big problem.” To date, he sums up, “we’ve identified vulnerable regions of the virus to target; we’ve made an immunogen based on that; and we’ve started to test it in non-human primates. Ultimately we hope to take this into human clinical trials.” — Elizabeth Thomson
It’s been several decades since chemical engineers first used microbes as miniscule chemical factories. Kristala Jones Prather now hopes to boost production to the next level, generating substances such as tumor-fighting drugs and food additives in more efficient ways.

Prather, professor of chemical engineering, has come up with genetic devices she calls metabolite valves, which redirect metabolism-related molecules from their primary purpose—supporting cell growth—to helping the cell manufacture useful chemicals and specialty compounds.

Since scientists found they could genetically tweak cells to churn out important substances such as insulin, the race has been on to make cells produce more with less. For some compounds, the goal is to improve on the microbes’ natural mode of production. Others necessitate that the microbes perform in ways not found in nature. Prather’s lab created a specially engineered strain of the common bacteria E. coli that synthesizes substances it would not normally produce, such as the flavorant vanillin, and a compound related to the pharmaceutical ephedrine, used as a stimulant, decongestant, and appetite suppressant.

After earning a bachelor of science from MIT, Prather went on to a PhD program at the University of California at Berkeley and then a four-year stint in R&D at drug powerhouse Merck, both of which furthered her fascination with biology as a tool for chemical engineering. At Merck, Prather used bacterial enzymes to catalyze a chemical reaction. The method turned out to be more efficient than the traditional chemical factory approach, making her wonder if she could fine-tune cell metabolism pathways even further in the hope of coming up with new and improved methods of chemical synthesis.

Prather, who joined the MIT faculty in 2004, continues to pursue her goal of having the field reach new milestones. “I would love to see more bio-based products making it to market,” she said. “I would also like to see more novel organisms being employed for chemical synthesis, both at the academic and industrial scales.”

Prather is exploring ways to tweak different pathways within the cell. Instead of knocking out genes that might be necessary for cell health and growth, she modulates enzyme levels that allow host cells to switch between growth and production modes. Her metabolite valve strategy works well to generate glucaric acid, an ingredient in health supplements, detergents, and road deicers.

“With our valves, we’re able to regulate substrate usage between cell growth and product formation. This approach can improve yield of a product in E. coli twofold; a similar system engineered in yeast leads to improvement in product yields of about fiftyfold,” she says. “We’re very excited to continue applying this approach to other systems. We certainly want to push more of our work towards commercial relevance.”

“I would love to see more bio-based products making it to market. I would also like to see more novel organisms being employed for chemical synthesis, both at the academic and industrial scales.”

— Deborah Halber

Prather is particularly excited by the idea that one day, “we may view biological synthesis of chemical compounds in much the same way that we think of synthetic organic chemistry—expanding the toolbox of chemical transformations that can be used to solve problems and change lives.”

Below: Kristala Jones Prather is developing new, improved methods of chemical synthesis.

Photo: M. Scott Brauer
“If I want to know how the guitar and saxophone became the important instruments throughout classical repertory or how chord progressions have changed, those are questions musicology has been unable to approach,” says Associate Professor of Music Michael Cuthbert. Spotting trends and patterns in a large corpus of music is nearly impossible using traditional methods of study, because it requires the slow process of examining pieces one by one. What his field needed, Cuthbert determined, was a way to “listen faster.”

With that goal in mind, Cuthbert gathered a team of computer programmers at MIT to develop music21, a suite of software that provides many of the same tools for analyzing music that so many of us depend upon when working with text and data. For example, musicologists can use music21 to search for chords or graph pitches.

“In music, we haven’t been able to approach analyzing pieces with anything like the bird’s-eye view that major text repositories give us,” explains Cuthbert, who is also an experienced programmer. “Music21 was the first modern system to lay the groundwork and set libraries for working with music.”

“Once the data is in there,” he says, “we can ask 1,000 questions.”

An open-source, cross-platform toolkit written in Python, music21 employs more than 9,000 pages of code to endow the computer with a basic understanding of music theory, thereby enabling researchers to examine large bodies of works, identify trends, and pinpoint interesting outliers worthy of deeper study.

Developed with funding from the Seaver Institute, which supported the project from 2008 to 2012, music21 now boasts 3,000 downloads a month. The toolkit has been used for a wide range of projects worldwide, from identifying who wrote various segments of collaborative Beatles songs to supporting opposing arguments in a Society of Music Theory debate about the concept of key.

About a year and a half ago, Cuthbert finally put music21 to work on his own research in medieval European music, using the computer for such tasks as determining a composition’s country of origin and reconstructing damaged notation. For example, music21 was able to determine the missing clef and signature information for one 14th-century Italian piece by running through all the approximately 300 possible options in minutes—saving Cuthbert two days of work.

Music21 has also proved a boon to teaching, Cuthbert says, noting that students in his Fundamentals of Music class use it to test their understanding of music theory and to practice composition. The software allows him to spend less time grading papers, which means he can accommodate more than twice the usual number of students in the popular class. Next spring, he plans to pilot the use of music21 for teaching in other MIT classes and at other universities.

“Once the data is in there, we can ask 1,000 questions.”

While music21 currently requires its users to have some programming capability, Cuthbert says he is planning to develop new applications tailored to those who lack such skills. “Music21 has been career-changing for musicians who have some technical ability,” he says. “We’re hoping to bring it out to the rest of the world.”

— Kathryn M. O’Neill

**Data in a Major Key**

**Musicologist puts computers to work**

*bellow* Michael Cuthbert gathered a team of computer programmers at MIT to develop music21, musical analysis software.

*Photo: Allegra Bourman*
Ibrahim Cissé, MIT Assistant Professor of Physics, is devising new ways to look inside a living cell to see how DNA is read and written out as messenger RNA, the instructions used by the cell to make the molecular machines that do the cell’s work. An understanding of how cells perform this essential task of transcribing DNA has obvious practical implications. Many pharmaceuticals aim to control gene expression, and finding new ways to regulate genes is a priority for drug developers and bioengineers.

But Cissé is a physicist who happened to get excited by the idea of visualizing these subtle molecular interactions in cells and seeing what might come of them. “What are we missing?” he asks. “What can a closer look at this process teach us about how nature works?”

Cissé recently won a National Institutes of Health New Innovator Award to develop new microscopy techniques to answer these questions. His approach builds on three chemists’ 2014 Nobel Prize–winning super-resolution microscopy technology, which allows for finely detailed visualization of individual molecules, typically in a non-living cell fixed on a slide.

But Cissé isn’t looking for a clearer snapshot of the compounds that read and transcribe DNA. He wants to know how these wildly complex machines, which are made on the fly from a multitude of parts, can come together fast enough to allow the cell to quickly activate genes in response to environmental cues. “From what we know about biochemistry, this assembly should be a very inefficient process, but we know that genes can be turned on very efficiently and rapidly,” says Cissé. “How is it that cells can do that?”

The answer, he believes, lies in an area of biochemistry that isn’t yet well understood: that of weak and transient interactions between biomolecules. The strong bonds between molecules inside cells are fairly well understood. They build complex, long-lasting machines that are relatively easy to study because they hold together even when they are removed from a cell. In contrast, weak and transient molecular interactions are much harder to study because they are so fleeting and also because they tend to happen only in the tightly packed confines of a living cell.

In fact, weak interactions between molecules are so subtle that, taken individually, they may seem insignificant. But when they happen en masse, special things happen. A group of molecules following similar cues can start to work together, taking on what physicists call “emergent” properties.

Emergent properties can be seen elsewhere in nature, such as in schools of fish that self-assemble into an efficient feeding cloud through slight but collectively significant interactions between individual fish following one another’s leads. “It turns out that nature has a way in complex systems for things to come together and exhibit properties where the whole is more than just the sum of the individuals,” Cissé says. “We think this is also how gene expression regulation happens.”

Existing methods to visualize single molecules miss these weak and transient interactions, but Cissé has found new and clever ways to apply a form of super-resolution microscopy called photo-activated localization microscopy (PALM) to capture the movements of molecules in a living cell. He has found that RNA polymerase II, the molecule that initiates the reading and writing of DNA, clusters around genes that are about to be transcribed. He has also shown that these clusters appear to regulate gene expression, tuning the level of gene activation. “Now,” he says, “we’re trying to figure out how the clusters self-assemble in the first place.”

— Elizabeth Dougherty

The Science of Subtlety
Weak interactions between biomolecules hold tantalizing mysteries
Venice, Italy

Chairman Emeritus John Reed ’61, SM ’65, and Cindy Reed recently hosted a celebratory dinner at Palazzo Pisani Moretta for 250 guests to honor Professor Emerita Joan Jonas. Jonas’s exhibition, They Come to Us without a Word, is showcased at the 2015 Venice Biennale, the world’s most prestigious contemporary art event. A pioneer in video and performance art, Jonas created a multimedia installation for the US Pavilion. Paul Ha, director of the MIT List Visual Arts Center, served as commissioner of the US Pavilion. Guests included: President L. Rafael Reif and Mrs. Christine Reif; W. Eric L. Grimson PhD ’80, chancellor for academic advancement; Philip Khoury, associate provost; Hashim Sarkis, dean, School of Architecture + Planning; and John Phillips, US ambassador to the Italian Republic and the Republic of San Marino.

Cambridge, MA

The School of Engineering recently hosted its annual Dinner Under the Dome for 150 alumni and friends. Ten MIT students showcased their engineering research projects at a reception preceding the dinner. School of Engineering Dean Ian Waitz addressed the guests, citing current engineering projects that could one day change the world. Other speakers included: Professor Munther Dahleh, Professor Paula Hammond ’84, PhD ’93, and Jean Yang SM ’12.

1. President Reif and Christine Reif
2. Henriette Huldisch, curator, List Visual Arts Center; Greg ’70 and Karen ’70 Arenson
3. Paul Ha
4. Joan Jonas
5. Cindy Reed, Christine Reif, John Reed
6. Eric Grimson and John Reed
7. Morris Chang ’52, SM ’53, ME ’55 and President Reif
8. Valeria Navarro and Jean Jacques Desreux SM ’93, PhD ’02

Photos: Francesca Bottazzin

1. Anne Marinan SM ’13
2. Professor Jesus del Alamo and his wife, Sophie Vandebroek
3. Graduate student Nikhil Vadakur, Forrest Meyen SM ’13, Edward Obropta ’13, SM ’15
4. Professor and Associate Dean for Innovation Vladimir Bulovic
5. Arthur Gelb ScD ’61 and Paula Hammond
6. Ian Waitz
7. Gerald Appelstein ’80 and Divya Pillai ’15
8. Marina Hatsopoulos SM ’93

Photos: Gretchen Ertl
Mark McDowell believes that “the whole field of education, for the first time in a thousand years, is going to undergo a huge change over the next two decades.” Education, he says, “is finally going digital,” and MIT is helping to pave the way.

To that end, Mark ’88, SM ’89 and his wife, Jill, have made a major gift in support of MITx, the Institute’s approach to massive open online courses. McDowell, who was raised by teachers so “education was a top priority,” notes the courage it took for MIT to create MITx in December 2011. At the time, he says, no one knew “where it would lead or whether people would use it. MITx was kind of an experiment in progress.”

Today, more than 1 million students from 195 countries have registered for courses through MITx. The initiative has also “illuminated some new methods of teaching that are highly effective and can actually be moved into the classroom,” says McDowell. These include shorter teaching modules followed by questions that reinforce what the students just learned.

McDowell also notes the importance of MIT’s Office of Digital Learning (ODL), the home to MITx and related initiatives. “It’s phenomenal,” says the longtime entrepreneur and current partner in Real Ventures, a venture capital fund based in Montreal that invests in education technology. Earlier this year “the ODL announced a major collaboration with the Woodrow Wilson National Fellowship Foundation to radically change how teachers and principals are taught.” That will become ever more important as the field of education continues to evolve, he says.

Mark and Jill, an attorney who received a BS from the University of Florida and a law degree from the Catholic University of America, have two children, ages 10 and 12. They helped to inspire the McDowells’ gift. “We want the best for our kids, and the best for other kids, too,” Mark says.

— Elizabeth Thomson
What happens when we put our heads together?