Energy Futures

MIT ENERGY INITIATIVE AUTUMN 2008

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Energy Futures

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MIT Energy Initiative
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Update on the MIT Energy Initiative

Photo: Justin Knight

MITEI Deputy Director Robert C. Armstrong, left, and MITEI Director Ernest J. Moniz.

Dear Friends,

Since publishing our last newsletter, the MIT Energy Initiative has made significant progress on developing a network of support for MIT faculty, students, and researchers. MITEI has also sponsored a range of outreach activities designed to enhance and inform the public dialogue on key energy policy and technology issues.

This issue of *Energy Futures* highlights some of the progress we are making in research, education, and outreach, with a special focus on the research area we call "Transformations"—development of the science, technology, and policy options that can enable alternative energy sources to displace significant fossil fuel use.

We would like to take a moment to focus on two key development efforts within MITEI: the Industry and Public Partners Program and the Sustainable Energy Revolutions Program.

The portfolio of MITEI's research partners

Among the most exciting signs of MITEI's growth is the community of partners that have now joined the Initiative to support energy research and education and to contribute to the innovation discussion fostered by MITEI.

When we released our first newsletter, MITEI had eight members; it now has 27. These members range from global enterprises to venture capital firms to government-sponsored enterprises to small innovative startups.

We also have added two new membership categories, the MITEI Founding Public Members and the MITEI Sustaining Public Members. These categories reflect the special needs and requirements of publicly funded and supported enterprises such as those of our inaugural Sustaining Public Member, the Portuguese Ministry of Science, Technology, and Higher Education.

Each MITEI Founding and Sustaining Member makes a commitment to the sustained sponsorship of a research program that can range from a highly focused multi-faculty "flagship" program, such as solar frontiers or advanced coal, to a set of discrete projects that meets the organization's diverse strategic needs. These members also support a seed fund program that draws in innovative early-stage ideas from faculty across the campus (see article on page 18). The breadth of the current research portfolio that has emerged from discussions between members and faculty is impressive. MITEI members are sponsoring research projects in the following areas:

Innovations: improving how we produce, distribute, and consume conventional energy sources.

- development of high-value products—electricity, liquid fuels, and chemicals—from low-value carbon feedstocks while minimizing carbon dioxide emissions
- increased efficiency in buildings
- intelligent infrastructure
- carbon management
- new technologies to develop and produce remote ultra-deepwater oil and gas resources in water depths of 5,000 feet or greater
- coal combustion
- new materials and concepts for efficient energy conversion systems
- power electronics
- heat management
- oxyfired coal plants

Transformations: developing clean alternative energy sources to replace conventional fuels.

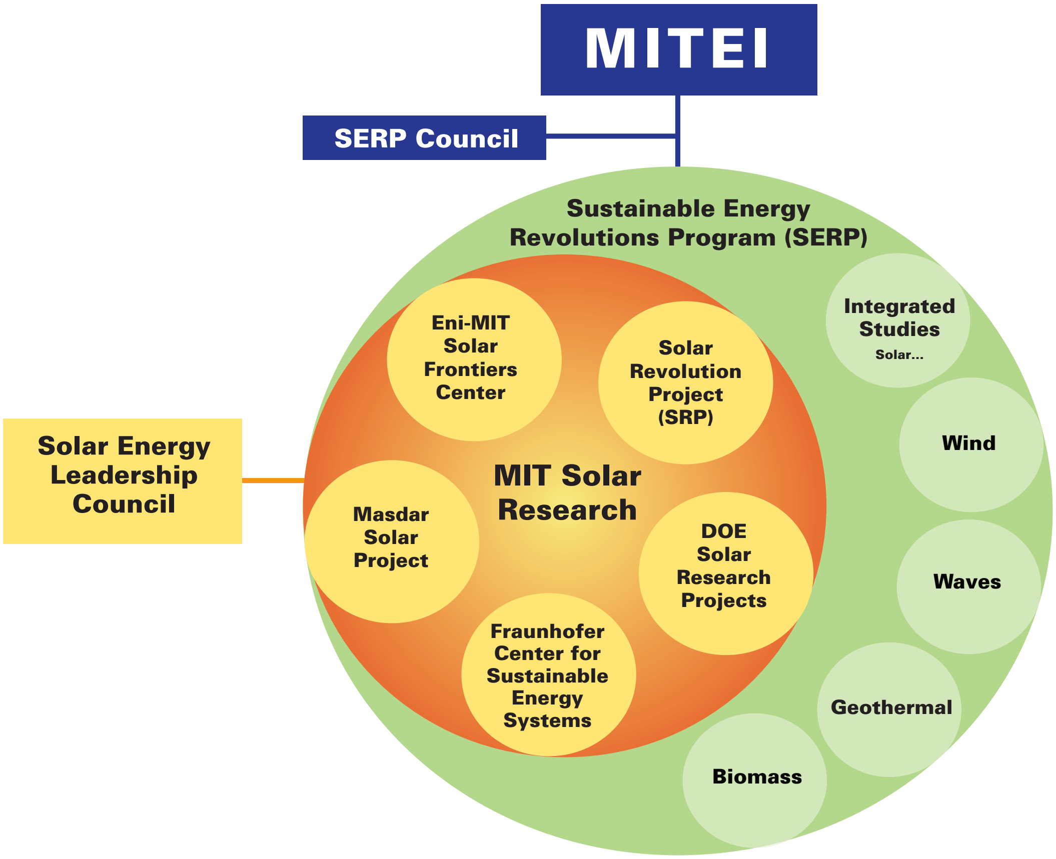
- geothermal energy
- biofuels
- wind, including offshore wind
- advanced solar technologies, including nanostructured thin film photovoltaics, self-assembling photovoltaic materials, solar to fuels
- materials for batteries, fuel cells, photovoltaics, thermoelectrics, catalysts, extreme conditions
- wave energy
- tidal energy

Global Systems: multidisciplinary research and analysis of global systems that integrate energy policy design and technology development.

- science and policy of global change
- buildings and urban systems
- vehicles and transportation systems
- decentralized energy
- urban metabolism and green mobility

Tools: developing fundamental enabling or transformational tools and concepts to meet global energy needs.

- nanotechnology
- advanced materials discovery for energy applications with a focus on integrated computation and synthesis
- multielectron chemistry
- intelligent robotics
- catalysis
- separations
- small molecule chemistry



MITEI launches the Sustainable Energy Revolutions Program

On a related front, MITEI has launched the Sustainable Energy Revolutions Program (SERP), a new program to coordinate and enhance support for breakthrough and long-term research in renewable energy sources, such as solar, wind, waves, geothermal, and biomass, as well as associated enabling technologies, such as storage.

This program also will support related analysis and will help grow the renewable energy research community at MIT through support for seminars, conferences, symposia, colloquia, and related events. In addition, SERP will leverage its activities with other programs and projects at or associated with the Institute to solidify and enhance broad support for renewable energy activities and research.

The diagram on this page is a depiction of SERP. It shows the current cluster of solar research programs, which will be loosely coordinated by MIT faculty and researchers through the Solar Energy Leadership Council. It also illustrates where we intend to take the program in the next phase of MITEI's growth—to a larger renewable energy research and integrated studies cluster.

The SERP Council, now being formed, will include donors interested in the program's core objective—breakthrough research for renewable energy. Its initial co-chairs are the MITEI director and Arunas Chesonis of the Chesonis Family Foundation. The council will serve as an advisory body and will help MITEI define, refine, and guide the mission of SERP; provide strategic direction and advice to the program; help develop key relationships and interfaces with philanthropic and industry donors interested in supporting renewable energy research and advancing SERP goals; help identify and support opportunities to transfer renewable energy technologies into the energy marketplace; and serve as a liaison between SERP and key opinion leaders.

These two elements of MITEI help to highlight the range of partners and programs we are working with to address global energy challenges. But they are only a small part of the story. A number of high-impact activities, programs, projects, and education and outreach efforts at MITEI also are generating a great deal of excitement, both on campus and in the broader public and policy arenas.

Highlights of many of these activities can be found in this issue of *Energy Futures.* We look forward to hearing from you—and working with you—in the days ahead.

Sincerely,

Professor Ernest J. Moniz
MITEI Director

Professor Robert C. Armstrong
MITEI Deputy Director

Solar power: Making fuels for when the sun doesn't shine

MIT researchers have a vision for a novel device that promises to overcome the main barrier to widespread use of solar power: storing it for use when the sun is not shining.

The device utilizes a standard photovoltaic (PV) panel to capture the energy in sunlight. It then uses that energy plus specially designed catalysts to split water into hydrogen and oxygen under inexpensive and easy-to-manufacture conditions. The hydrogen and oxygen can be stored and used later to run an electricity-generating fuel cell in which they recombine into water.

"This advance can make water—with solar light as an input—into a renewable, environmentally benign energy source for the future," says Daniel G. Nocera, the Henry Dreyfus Professor of Energy, professor of chemistry, and co-director of the Eni-MIT Solar Frontiers Center.

Recently, Nocera and his colleagues invented a key catalyst that will make it possible to implement his design. "There's a lot of engineering work to be done yet, but I think that in under 10 years from now we may all have these PV systems on our roofs, providing power to our homes and fuel for our cars," Nocera says.

Nocera believes that sunlight is the only renewable, carbon-neutral energy source of sufficient scale to replace fossil fuels and meet rising global energy demand. Indeed, the daily dose of sunshine on the planet is enough to power the world's energy needs for 30 years. The challenge is to capture that energy and store it in fuels such as hydrogen that can be used later.

One approach would be to use the electricity from PV panels to split water into hydrogen and oxygen. That process—electrolysis—is well understood, but today's electrolyzers are huge, expensive, inefficient devices. They require a concentrated base rather than neutral water, and they must be hermetically sealed to keep out gases such as carbon dioxide. Nocera is looking for a way to do the same process using natural materials and benign conditions—and sunlight.

But using sunlight to split water isn't so easy—unless you're a leaf. Leaves capture, convert, and store the sun's energy by photosynthesis. "Light that goes into a leaf sets up separated positive and negative charges—an electrical current without wires," explains Nocera. "That current splits the water into oxygen and a form of hydrogen inside the leaf. Then the hydrogen reacts with carbon dioxide to form sugar, which the leaf uses as fuel."

Excluding the last step, photosynthesis is Nocera's blueprint for action. For the past several decades, he has been working to develop a system that mimics the photosynthetic machinery developed by nature more than three billion years ago.

Today's PV systems can do the first two steps: capture and convert. They take in energy from the sun and generate a positive charge at one side and a negative one at the other—as inside the leaf, a wireless current. Getting electricity to flow simply requires connecting the positive and negative ends.

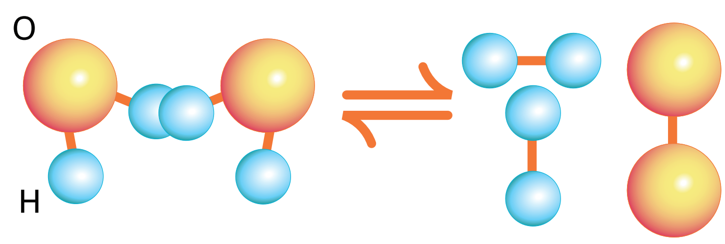
"But that's only half of the story," says Nocera. "Only when the sun is out do you get electricity out of the PV." There has been no good way to convert and store that captured energy, and that shortcoming could ultimately limit the large-scale use of PV systems. Nocera's goal is to figure out how to use the wireless current of the PV to get hydrogen and oxygen out of water—as a leaf does. After decades of research, he and his colleagues now have ways to make those reactions happen.

The grand plan

Nocera's goal is summarized in the chemical equation and schematic below: two water molecules ($2\,H_2O$) must be taken apart and their atoms reconfigured into two hydrogen molecules ($2\,H_2$) and an oxygen molecule (O_2). Instigating that transformation

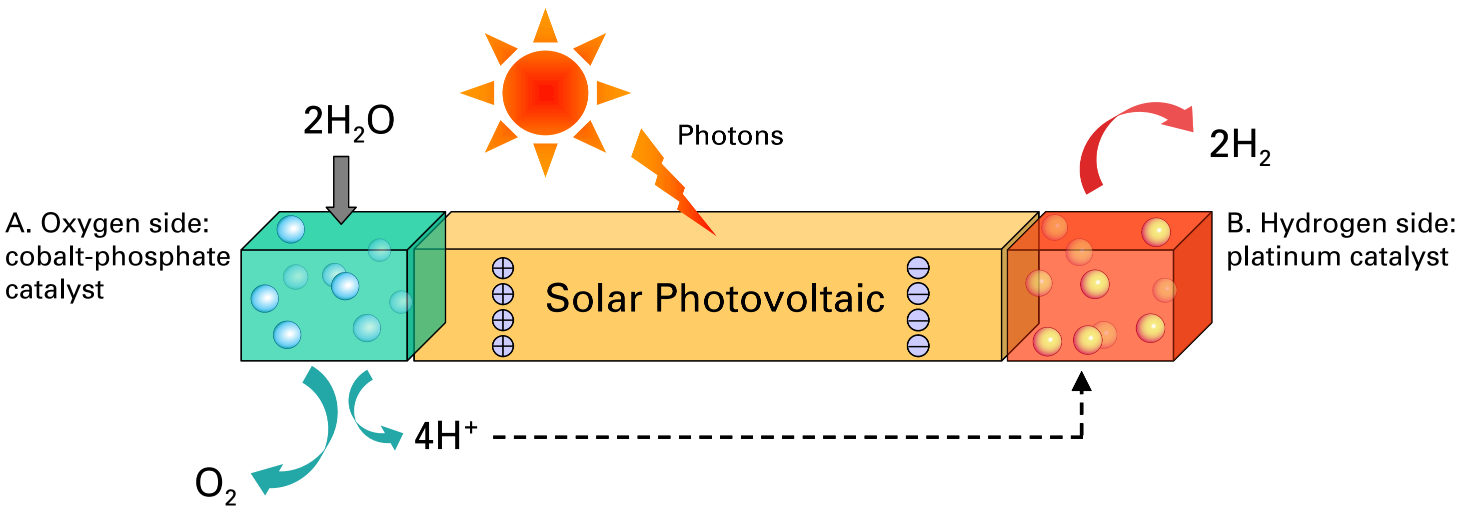
Converting water into storable fuels

$$2\,H_2O \longrightarrow 2\,H_2 + O_2$$



Nocera's goal is summarized in the chemical equation and schematic above: two water molecules ($2\,H_2O$) must be taken apart and their atoms reconfigured into two hydrogen molecules ($2\,H_2$) and an oxygen molecule (O_2).

Solar-powered water-splitting device



In a device envisioned by MIT researchers, photons from the sun hit a photovoltaic cell and are split into positive charges, which go to catalyst A, and negative charges, which go to catalyst B. Catalyst A uses the positive charges to act on two water molecules, forming an oxygen molecule and releasing four positively charged hydrogen protons. Aided by catalyst B, the hydrogen protons capture electrons and transform into two hydrogen molecules. The oxygen and hydrogen produced by the device could be stored and used in an electricity-generating fuel cell, where they would recombine to form water.

requires putting in energy to move electrons from one atom to another so that chemical bonds break and the pieces recombine into molecular hydrogen and oxygen. The chemical equation appears simple, but making it happen easily is not.

The figure above shows the device that Nocera is designing. At the center is the PV cell with electrodes attached at both ends, coated with catalysts and immersed in water. Every time a photon from the sun hits the PV, it makes one negative charge and one positive charge. The negative charge—an electron—goes one way in the PV, and the positive charge—the space left behind, called a hole—goes the other way. The electron jumps into catalyst B and the hole into catalyst A.

Now assume that four photons have come in so that catalyst B contains four electrons and catalyst A four holes. Catalyst A uses those four holes to act on two water molecules, forming an oxygen molecule (O_2) and releasing the four leftover hydrogen protons ($4H^+$), which are now positively charged because they have lost electrons. They head over to the other side, pulled by the four electrons on catalyst B. Aided by that catalyst, the hydrogen protons capture the four electrons and transform into two hydrogen molecules ($2H_2$).

Now the holes and electrons have left both the PV and the catalysts, effectively stored in the chemical bonds of the hydrogen and oxygen molecules. "So the system is reset—it's just as it was when we began," adds Nocera.

The hydrogen and oxygen molecules can be stored and used later—when the sun's not shining—in a fuel cell. "And what does a fuel cell do? It takes the hydrogen plus the oxygen and combines them to make two water molecules—just like we started with—plus an electrical current," he says. "Now you can use that electricity to recharge your electric car or run your house lights when the sun is down."

The hard part

Although Nocera has had this vision for some time, one piece has been missing: the catalyst that would make the oxygen side work in a cheap and efficient way. The hydrogen side can be done with a platinum catalyst, which is expensive but effective. However, if the system is to conserve water, the researchers must get the oxygen out, too, and that has been far harder.

Drawing on the latest knowledge in chemistry, physics, and biology—most notably a new understanding of how the "oxygen-evolving complex" works in plants—Nocera and his colleagues have developed the necessary catalyst. Their new catalyst consists of cobalt metal plus some dissolved phosphate to help out.

Assume that the electrode is immersed in water that contains cobalt and phosphate. When the electrode becomes positively charged (with holes from the PV), a thin layer of cobalt builds up on its surface. The holes in the electrode grab electrons from the cobalt, but the cobalt quickly transfers those holes to the oxygen in the water, and pure oxygen forms. The cobalt is back where it started, ready to do the job again—but some of it has gone into solution. Now the phosphate in the water goes into action. It grabs the dissolved cobalt and takes it back to the surface of the electrode, where the cobalt precipitates, renewing the catalyst. All is prepared for the next batch of holes to arrive from the PV.

The researchers are not sure of every step involved in that transformation. Nevertheless, it is very easy to set up the experiment and observe the process unfold. Immerse a piece of clear conducting glass in a solution of cobalt and phosphate. Nothing happens. But put a positive charge on the conducting glass—just as in the PV electrode—and a thin film immediately starts to form on the glass, and pure oxygen begins to bubble to the surface.

The new catalyst has much in common with natural photosynthesis: it forms spontaneously from abundant nontoxic natural materials in neutral pH water, repairs itself as needed, and operates at room temperature and pressure. Because the catalyst self-assembles, it can be deposited on a variety of substrates, including those that are too delicate to tolerate traditional catalyst preparation techniques.

The next steps

The researchers' work is far from done. So far they have demonstrated their new "oxygen-evolving" catalyst only in the laboratory. Their plan for the coming year is to collaborate with Vladimir Bulović, associate professor of electrical engineering, on integrating the new system of catalysts into advanced PV cells—work being done in the Eni-MIT Solar Frontiers Center, which Bulović co-directs with Nocera. "We'll be building a highly efficient PV-based device that we can put out in the sunlight and watch as it makes water into oxygen and hydrogen," says Nocera.

Other research will focus on determining the precise mechanism by which the holes from the cobalt get transferred to the water to make the molecular oxygen. Knowing all the steps involved should enable them to improve their design and perhaps even develop new catalysts that are more active, selective, and robust. In addition, they plan to develop a catalyst for the hydrogen side that uses earth-abundant materials in place of expensive platinum.

Until he and his colleagues developed the oxygen side, Nocera thought that practical devices would not come soon. "But the oxygen side is so simple and easy to implement that a lot of technology will start flowing from it. Rather than a door closer, this invention is a door opener," he adds. "There's still a lot of science to be done, and researchers from all over the world have already started working on it."

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This research was sponsored by the National Science Foundation (NSF), and is part of a larger solar program at MIT supported by NSF, Eni SpA, and the Chesonis Family Foundation. More information can be found in:

M. Kanan and D. Nocera. "In situ formation of an oxygen-evolving catalyst in neutral water containing phosphate and Co^{2+}." *Science*, DOI: 10.1126/science.1162018. July 31, 2008.

MIT, Eni establish advanced solar center

MIT and the Italian energy company Eni SpA have joined forces to form the Eni-MIT Solar Frontiers Center at MIT.

The Solar Frontiers Center (SFC) is designed to promote and accelerate multidisciplinary research on next-generation solar technologies, including nanotechnologies, advanced materials, and solar hydrogen production.

Paolo Scaroni, CEO of Eni, announced the formation of the center in early July at the Politecnico in Milan, Italy, prior to a technical symposium that drew together key energy researchers from MIT, Eni, and the Politecnico.

Establishment of the SFC came as the strategic next step in the close relationship between Eni and the MIT Energy Initiative (MITEI)—a relationship that was formally launched in February 2008 when Eni became a Founding Member of MITEI.

"The establishment of the Eni-MIT Solar Frontiers Center is an important milestone in the MIT-Eni alliance," says Ernest J. Moniz, the Cecil and Ida Green Professor of Physics and Engineering Systems and director of MITEI. "This designation reflects the strategic focus of our partnership on advanced solar energy research. We are excited about the new opportunities that the center will create."

Reflecting the center's emphasis on multidisciplinary research, its leadership is drawn from two MIT schools: engineering and science. SFC co-directors are Vladimir Bulović, associate professor of electrical engineering, and Daniel G. Nocera, the Henry Dreyfus Professor of Energy and professor of chemistry. An executive director—yet to be named—will play an important role in maintaining the exchange of information between the researchers at Eni and MIT.

The five focus areas of the SFC are nanostructured thin film photovoltaics, self-assembling photovoltaic materials, water splitting, materials for solar energy capture and storage, and maximizing the return on investment for solar thermal plants.

As a Founding Member of MITEI, Eni supports a range of research projects at the Institute, spanning the energy spectrum from advanced solar to traditional oil and gas to methane hydrates to global change to transportation options.

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Photos: Justin Knight

Paolo Scaroni, chief executive officer of Eni, and MIT President Susan Hockfield sign the MIT-Eni Alliance agreement. Eni joined MITEI as a Founding Member.

Left to right, Nicola De Blasio, head of R&D international development at Eni and MIT visiting scientist; MIT President Susan Hockfield; and Leonardo Maugeri, group senior vice president for strategies and development, Eni.

Harnessing sunlight on the cheap: MIT's prototype solar dish

A team led by MIT students has completed and successfully tested a prototype of what may be the most cost-efficient solar power system in the world—one they believe has the potential to revolutionize energy production in both industrialized and developing countries around the world.

The system consists of a 12-foot-wide mirrored dish that team members spent several weeks assembling. Made from a lightweight frame of thin, inexpensive aluminum tubing and strips of mirror, the dish concentrates sunlight by a factor of 1,000—creating heat so intense it can melt a bar of steel.

To demonstrate the system's power, Spencer Ahrens—who in June 2008 earned a master's degree in mechanical engineering from MIT—stood in a grassy field on the edge of the campus one sunny day last spring holding a long plank. Slowly, he eased it into position in front of the dish. Almost instantly there was a big puff of smoke, and flames erupted from the wood. Success!

Burning sticks is not what this dish is really for, of course. Attached to the end of a 12-foot-long aluminum tube rising from the center of the dish is a black-painted coil of tubing that has water running through it. When the dish is pointing directly at the sun, the water in the coil flashes immediately into steam.

Someday soon, Ahrens hopes, the company he and his teammates have founded, called RawSolar, will produce such dishes by the thousands. They could be set up in huge arrays to provide steam for industrial processing or for heating or cooling buildings, as well as to hook up to steam turbines and generate electricity. Once in mass production, such arrays should pay for themselves within a couple of years with the energy they produce.

Photos: David Chandler, MIT

A team led by MIT students has designed and built a prototype of an inexpensive solar dish that concentrates sunlight onto a coil of tubing, causing water inside it to flash immediately into steam. Here team members mount 10-inch by 12-foot mirror panels onto the lightweight frame of the solar dish.

"This is actually the most efficient solar collector in existence, and it was just completed," says Doug Wood, an inventor based in Washington State who patented key parts of the dish's design—the rights to which he has signed over to the team.

Wood credits the students who built this dish, as an independent project that started in January 2008, with significantly improving his original design to make it a practical and competitive energy producer. "They really have simplified this and made it user-friendly, so anybody can build it," he says. "They just leapfrogged ahead of everybody."

Ahrens explains that "making it simple is the trick. Complex is easy." Even something as simple as buying the high-grade bathroom mirror glass proved frustrating and time consuming. The factory that makes the glass is accustomed to dealing with huge construction projects and ordinarily only accepts orders for a full train-car load or more—80,000 pounds worth. But Ahrens persuaded them to make an exception by explaining that this prototype could open up a whole new market for the industrial glass company, which has suffered from the current downturn in housing.

As a result, the factory agreed to sell him 4,000 pounds of the stuff—still 15 times more than he needed. After the students pooled together several thousand dollars to purchase the case of glass, delays in actually getting the glass made, shipped, silvered, and delivered to the site ended up postponing the project's completion, originally hoped for in January, until mid June.

One of the keys to making an inexpensive design was something Wood discovered by accident as he built a variety of solar dishes over the years: smaller really is better. Unlike many technologies where economies of scale dictate large sizes, a smaller dish requires so much less support structure that it ends up costing only a third as much for a given collecting area.

MIT Sloan School of Management lecturer David Pelly, in whose class this project first took shape in fall 2007, says, "I've looked for years at a variety of solar approaches, and this is the cheapest I've seen. And the key thing

Team member Matt Ritter shows steam coming out of the return hose after it forms in the coil above the solar dish.

in scaling it globally is that all of the materials are inexpensive and accessible anywhere in the world."

Pelly adds, "I've looked all over for solar technology that could scale without subsidies. Almost nothing I've looked at has that potential. This does."

The team, led by Ahrens, also includes Micah Sze (Sloan MBA '08), UC Berkeley graduate and Broad Institute engineer Eva Markiewicz, Olin College student Matt Ritter, and MIT materials science student Anna Bershteyn. Various other students also assisted over the course of the semester.

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By David Chandler, MIT News Office

MIT and Chesonis team up for solar revolution

In April 2008, MIT and the Chesonis Family Foundation launched the Solar Revolution Project (SRP) with the ultimate goal of making solar energy America's primary carbon-free fuel.

Funded by a $10 million gift from the foundation, the SRP will explore new materials and systems that could dramatically accelerate the availability of solar energy. The SRP will complement and interact closely with other large solar projects at MIT, creating one of the largest solar energy clusters at any research university.

The Chesonis gift will allow MIT to explore bold approaches that are essential for transforming the solar industry. Specifically, it will focus on three elements—capture, conversion, and storage—that will ultimately make solar power a viable, near-term energy source. The gift's unrestricted funding aims to create a "no holds barred" research environment that will inspire innovations in the field.

Daniel G. Nocera, the Henry Dreyfus Professor of Energy and professor of chemistry at MIT, is the principal investigator of the SRP and is generally responsible for the priorities and operations of the project.

The SRP will initially support 30 energy fellowships for graduate students on a range of solar-related studies, from developing novel materials for energy conversion and storage to using solar energy to produce hydrogen fuel from water. Each fellowship will span five years, allowing for significant continuity and greater impact.

The foundation also contributes to MITEI seed funds for innovative solar projects across the Institute and provides support for the executive director of the Sustainable Energy Revolutions Program. This new program helps coordinate support for renewable energy research at the Institute, including the growing solar research cluster. Among other projects, the solar cluster now includes the SRP and the Eni-MIT Solar Frontiers Center for advanced solar research, Eni's flagship research program with MITEI (see article on page 7).

The gift from the foundation will also help support an integrated study on the future of solar energy (see page 10). The new study builds on the success of two earlier MIT interdisciplinary reports on the future of coal and of nuclear energy in a carbon-constrained world.

The Chesonis Family Foundation is a private philanthropic organization that targets environmental and energy research projects. For more information about the foundation, please go to <www.chesonis.org>.

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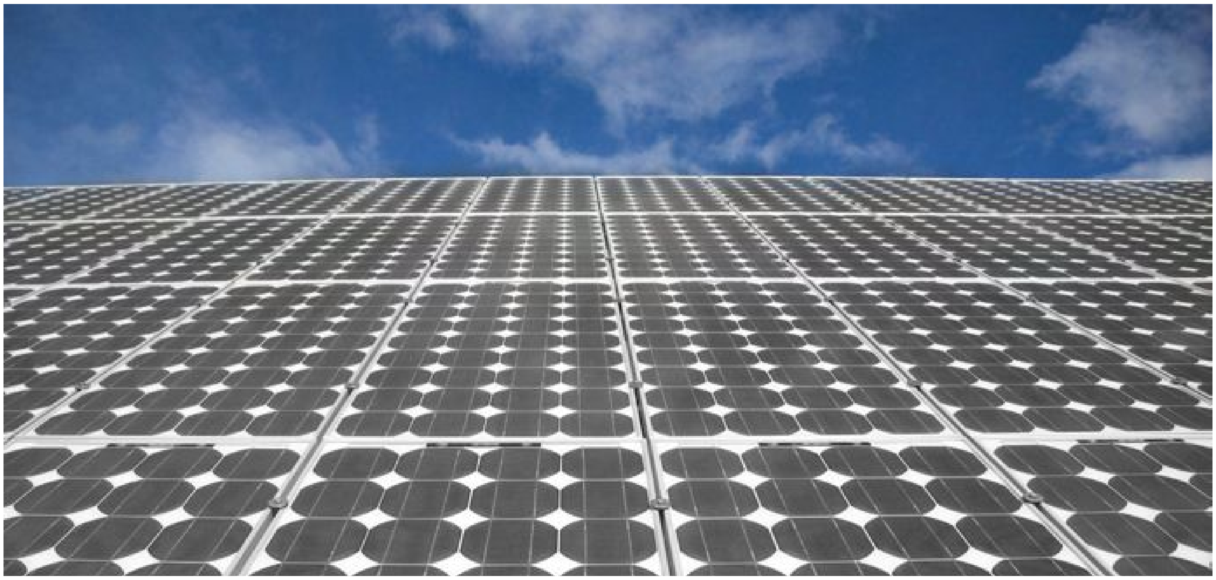
MIT group will chart the course for solar energy



The solar study described below is one in a series of interdisciplinary studies undertaken by MIT faculty to explore the contribution that different energy technologies could make to meet future U.S. and global energy needs. More background and information on two other current studies—focusing on nuclear fuel cycles and natural gas—can be found in the article on page 32.

A team of MIT faculty members is performing a comprehensive study of the technology and economics of a variety of approaches to harnessing the power of the sun. Launched in spring 2008, the MIT Future of Solar Energy Study could ultimately help set the agenda for policymakers, researchers, and industry leaders.

Under the direction of Institute Professor John M. Deutch, the research team will spend about a year and a half analyzing the prospects for solar photovoltaics, solar thermal generating systems, solar water heating, and the use of solar energy to produce fuels, such as hydrogen from water.

The study will consider basic research; resource and materials availability; the engineering and manufacturing needed to meet specific market applications; and the current and projected production costs.

The study will examine prospects for solar energy both in the United States and globally. The team will explore the factors involved in deploying solar technologies in developed countries—the United States, Europe, and Japan—as well as in poorer countries in Africa, South America, and Asia that get a lot of sunlight.

Based on investigations of the technical, economic, and policy factors that will influence the future of solar energy, the team will make recommendations about research, development, and demonstration directions; desirable (and undesirable) government policies; and needed industry action. A comprehensive final report will be issued and made available at no charge on the Internet.

The nine faculty members on the team include specialists in chemistry, mechanical engineering, electrical engineering and computer science, chemical engineering, materials science and engineering, physics, economics, and management. Executive director of the study is Joshua Linn, visiting research scientist at the MIT Energy Initiative and assistant professor of economics at the University of Illinois at Chicago.

Students will participate throughout the study, and it will have an outside advisory committee chaired by Philip Sharp, president of Resources for the Future. The study is being financed by the Chesonis Family Foundation and other foundations.

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Nanoscale layers promise to boost solar cell efficiency

By combining expertise in electrical engineering, nanotechnology, and quantum chemistry, MIT researchers are making novel solar cells that could one day be twice as efficient as current cells are. Their design calls for multiple layers of nanoscale materials that are tuned to capture more of the energy in sunlight and meshed to minimize energy loss within the cell. The layers can be deposited on silicon wafers or plain glass using inexpensive room-temperature processes such as ink-jet printing or silk screening.

These devices are ideally suited for investigating exactly what physical processes contribute to overall performance, with the goal of achieving higher efficiencies. "With the devices we're building we expect to be able to dissect every process we observe cleanly enough to explore one phenomenon at a time and consequently get clear answers on how to optimize performance," says Vladimir Bulović, associate professor of electrical engineering and co-director of the Eni-MIT Solar Frontiers Center.

If photovoltaic (PV) solar power is to compete economically with conventional power sources, PV modules and system installation must become significantly less expensive—a change that can be accomplished by increasing PV power conversion efficiencies and by scaling up the production of PV modules. Bulović suggests that both of those goals can be achieved by using large-area printed thin films of nanoscale materials—tiny chunks of matter measured in billionths of a meter. "We can use thin films of molecules, polymers, or quantum dots," Bulović says. "Such nanoscale forms of matter can be optimally designed to absorb light and generate photoaction."

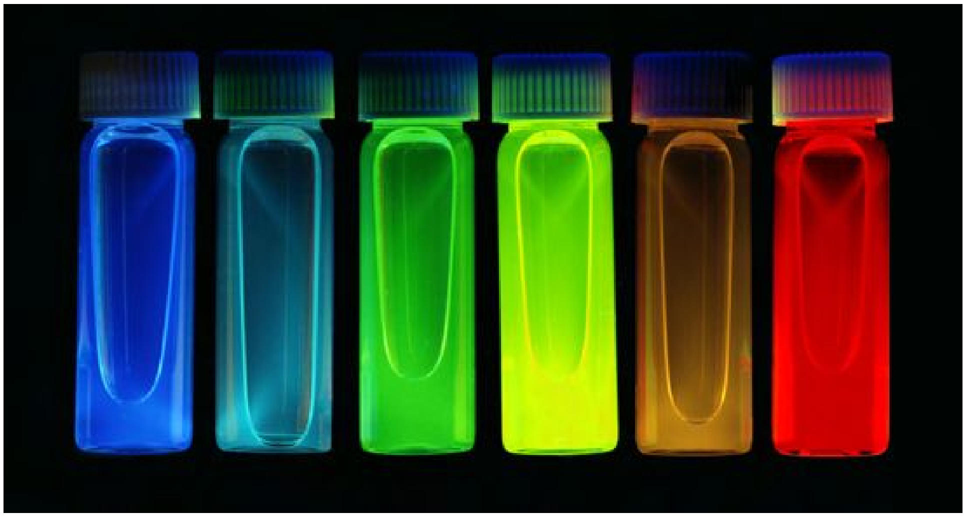

Photo: © Felice Frankel

MIT experts are developing novel solar cells that call for multiple layers of nanoscale materials tuned to capture specific wavelengths, or colors, of light. One way they achieve such tuning is by using quantum dots, tiny chunks of material whose absorption color changes with particle size. To prepare the samples shown above, the researchers chemically synthesized colloidal suspensions of quantum dots in inert solvents. By carefully selecting and controlling the quantum-dot size, they produced samples with markedly different colors.

The challenge is to identify the most appropriate nanostructured materials for PV applications and then to control their precise assembly at the nanoscale while depositing them over the large areas needed for PV modules.

Choosing the right materials

The first step in understanding the benefits of nanostructures is to understand how PV systems work. When photons strike a material, electrons absorb energy and jump from their low-energy "ground" state to their high-energy "excited" state. That process leaves vacancies—called holes—where electrons are missing. The electrons and holes remain loosely bound. In a solar cell, the trick is to separate them so the electrons can flow through an external circuit.

That separation is generally achieved by using a second type of material whose energy level is lower. Arriving at the interface between the materials, the electrons see an opportunity to lose some of their extra energy, so they move into the second material. Over time, holes accumulate in the first material and electrons in the second. Connect the outside edges of the two materials by a loop of wire and the electrons will flow back to the first material, powering a light bulb or other device along the way.

Bulović cites two approaches to material selection that can help optimize the process just described. One key is choosing the correct difference, or "offset," between the energy levels of the electrons in the two materials. The energy dissipated when an excited electron jumps from one material to the other should be just enough to cause the electron to make the move. Any extra dissipation reduces the energy available for powering the light bulb. So fine-tuning the energy offset at the interface between the two materials is one means of increasing efficiency.

Another means is to choose the correct "band gap" for each material, that is, the difference in energy between the electrons' ground and excited states. The band gap determines what color light, or wavelength, the material will absorb and emit. Silicon PV cells—the most widely deployed PV technology—have a band gap that is nearly ideally tuned to maximize the conversion efficiency of the sun's light energy to electrical power, yielding PV modules that are 8 to 14 percent efficient. Because they are optimized to respond to the sun's broad visible light spectrum, silicon PVs do not do well with ultraviolet light or infrared light. (The former is strongly absorbed but also strongly reflected by the silicon PV surface, while much of the latter simply passes through.) A silicon solar cell combined with additional PV cells made from materials that can absorb those poorly utilized wavelengths should capture and convert more of the energy in sunlight.

"The first step in making a good solar cell is to get the right spacing between energy levels within the individual materials and the right positions with respect to the neighbor's energy levels," explains Bulović.

Finding materials that have exactly the right energy levels would be difficult. Bulović therefore turns to his colleague Moungi G. Bawendi, Lester Wolfe Professor in Chemistry and an expert in creating nanomaterials with specially tuned band gaps and energy levels. Bawendi's specialty is the quantum dot, a tiny chunk of material that is just a dozen or so atoms across. In a particle of that size, electrons are unable to move around as much as they'd like to. Because the electrons are confined, they become more energetic. Indeed, the energy levels and band gap are determined by the exact size of the particle. "So with a quantum dot, you can fine-tune its band gap over a very broad range simply by varying the size of the material," says Bulović. And Bawendi is a master at it. "You can name the color you would like to absorb, and his group can make nanocrystals that are precisely tuned to absorb it," Bulović notes.

Depositing the nano layers

The researchers' next job is to deposit those quantum dots—or polymers, organic molecules, metal oxides, or other nanoscale materials—so that they work together to capture as much of the solar spectrum as possible and to separate the photogenerated electrons and holes efficiently. Bulović is not the first to make such combinations. Others have made blended structures in which the different materials are mixed together. But with many blended structures, it is hard to know exactly what physical processes are controlling the performance of the device. Bulović likens the approach to putting salad in a bowl and mixing it all up. "It is easy—and technologically very attractive—to make simple PV devices by mixing two nanoscale materials into a photoactive emulsion, spreading it as a thin film, and then laminating contacts on the top," he explains. "It is, however, challenging to understand how things work inside such devices and what steps to take to improve their performance."

Instead, Bulović, Bawendi, and their colleagues are creating layered structures with distinctly defined interfaces that will allow them to probe and optimize the operating mechanisms of nano-PVs. "We're perfecting the interfaces by making layered-cake-type structures, where you have a layer that does one thing, another layer that does something else, and so on," says Bulović. "Through the careful chemical design of band gaps and interface offsets we can learn about the governing processes in these nano-structured PVs."

Bulović has extensive experience with creating stacked structures of multiple materials. For over a decade, he and his colleagues have been developing multilayered molecular thin films to demonstrate organic LEDs that can be used as paper-thin TV screens and similarly slim photodetector planes of nanoscale thickness. Extending this molecular work to colloidal quantum dots, Bulović and Bawendi recently developed new printing techniques that can deposit thin layers of quantum dots on top of a substrate of choice—just the type of process they now need in their development of nano-PVs.

Using their novel printing methods, the researchers have created stacked nanostructured PVs. They can layer the nanomaterials on flexible substrates such as rollable plastic or metal foils, or they can deposit them on conventional silicon-based PVs to form "tandem" structures with boosted efficiency. Because of the crystalline nature of silicon, meshing it with other crystalline semiconductors is not easy. Nanomaterials, on the other hand, work fine because they are created in an optically active form before being deposited on the silicon. As a result, the researchers can use simple room-temperature processes, such as printing of nano-structured inks, stamping, or silk screening.

Conversion targets

According to Bulović, first-principles calculations suggest that if they do everything exactly right using a single nanostructured layer on top of silicon, they should achieve 15 percent efficient conversion—somewhat better than today's commercial PVs. But if they combine multiple layers that are good at absorbing differing parts of the spectrum, theory says that they should get up to 25 percent power conversion.

Thus far, the efficiencies of their devices are far from that high, but Bulović sees no reason that they cannot get there. "The goal is achievable," he says. "We just need to understand the detailed physical phenomena that govern the operation of these nanostructured photovoltaics." And their layered structures are an ideal "bench top" on which to explore those physical processes and identify the exact parameters that yield the best operation.

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This nanoscale photovoltaic research is part of the research agenda of the Eni-MIT Solar Frontiers Center. The initial part of the research program was supported by the MIT Institute for Soldier Nanotechnologies, a grant from the U.S. Army Research Office, and the Presidential Early Career Award for Scientists and Engineers, which was awarded to Bulović by the White House in 2004. Also, this work made use of the MRSEC Shared Experimental Facilities at MIT, supported by the National Science Foundation. Further information can be found at www.mtl.mit.edu/research/annual_reports/2007/pdf/mn/mn3_17.pdf and in:

D.C. Oertel, M.G. Bawendi, A.C. Arango, and V. Bulović. "Photodetectors based on treated CdSe quantum-dot films." *Applied Physics Letters*, v. 87, no. 21, pp. 213505:1-3 Nov. 2005.

Giant wind turbines, floating out of sight

Wind power is potentially a vast renewable source of energy, but siting wind farms is often difficult. The reason: many people are opposed to the obstruction of ocean views. MIT researchers have a solution to this problem. Inspired by platforms used in deep-sea oil drilling, they are integrating giant wind turbines with "floaters" that can be moored 20 to 30 miles out to sea, where the winds are strong and steady and nobody onshore will see them.

The engineers are now fine-tuning their design and beginning to plan tests of a scale model in a towing tank. If all goes well, project director Paul D. Sclavounos, professor of mechanical engineering and naval architecture, expects that a large-scale demonstration project will take place within the next five years. His ultimate vision? "Over-the-horizon" wind farms, each with several hundred turbines generating enough electricity to power more than 100,000 homes.

According to the U.S. Department of Energy, the potential capacity for wind power generation off the coasts of the United States is more than 900,000 megawatts (MW)—almost as much as the country's current electricity generation capacity. Yet only about 600 MW of offshore wind energy has been installed to date, all of it in Europe. Why so little? Today's offshore wind turbines generally stand on towers driven deep into the ocean floor, and that arrangement works only in water depths of about 20 meters or less. Proposed installations are therefore typically close enough to shore to arouse strong public opposition.

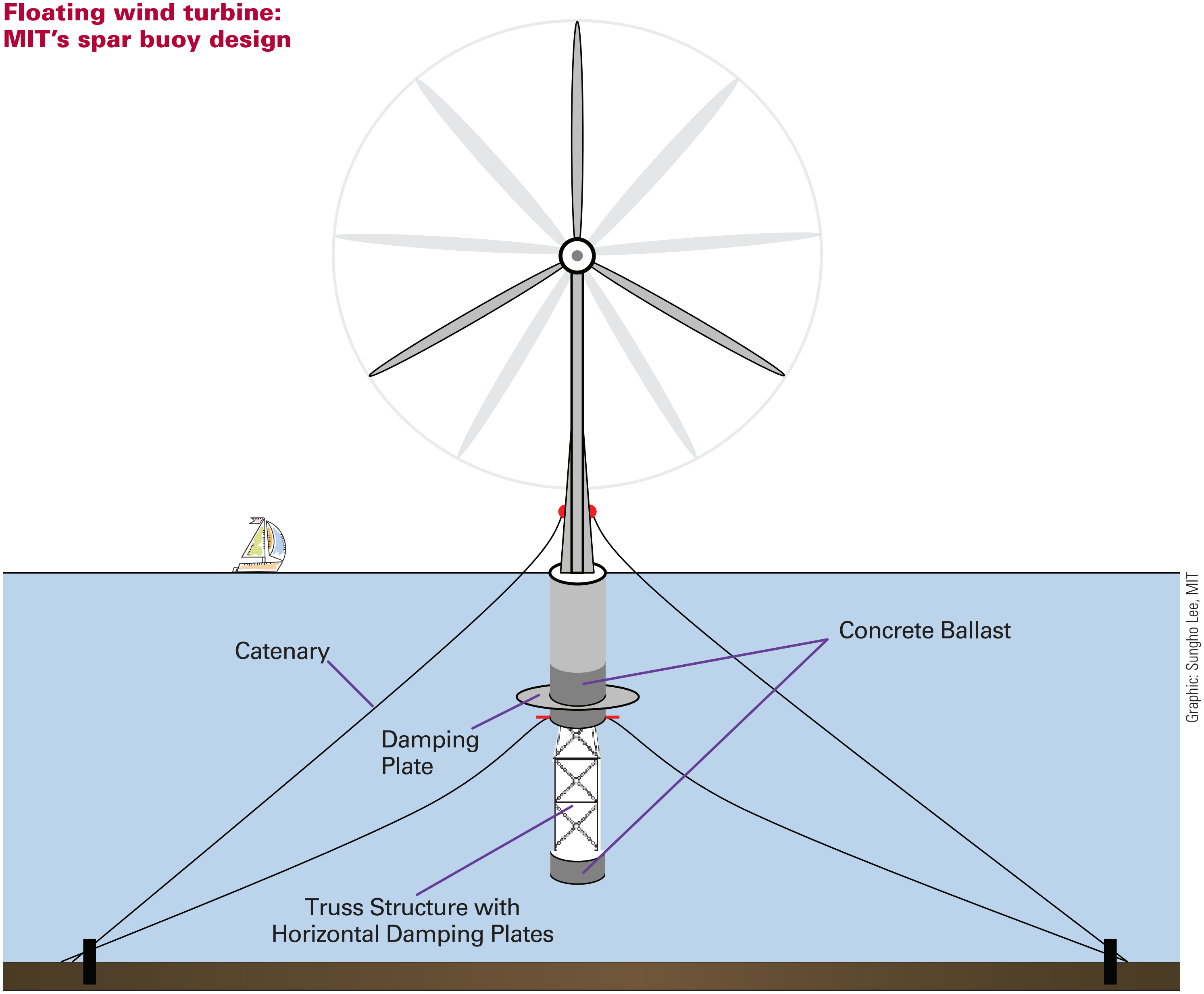
About five years ago, Sclavounos came up with an idea that could solve that problem. For decades, he and his colleagues in the MIT Laboratory for Ships and Platform Flows have been designing and analyzing large floating platforms for oil and gas exploration in water depths exceeding 10,000 feet. Drawing on that experience, he began examining the possibility of mounting giant windmills on similar floaters and deploying them in large-scale wind farms 20 miles or more away from the shore—by his calculation, far enough that people onshore would not see them. This approach has energy benefits as well. Far-offshore winds are strong and persistent, reducing worries about intermittent operation and the need for storing power. Indeed, the floating turbines should produce up to twice as much electricity annually (per installed megawatt) as wind turbines now in operation.

To pursue his idea, Sclavounos teamed up with wind-turbine experts from the National Renewable Energy Laboratory to integrate a wind turbine with a floater. In the wind power business, the bigger the turbine, the better the economics. So they assumed a 5 MW experimental turbine now being developed by industry. (Onshore units are 1.5 MW; conventional offshore units, 3.6 MW.)

The challenge was to find a floater-plus-turbine design that would maximize safety while minimizing cost. Drawing on his studies of oil and gas rigs, Sclavounos developed simulations that—for a given design—could determine how the wind turbine, the floater, and its mooring system would respond both independently and interactively to winds, waves, and currents in weather conditions ranging from calm to severe.

After analyzing several floater designs, Sclavounos concluded that one promising option was the spar buoy. In this

Floating wind turbine: MIT's spar buoy design



This schematic shows a deep-water floating wind turbine now being developed by MIT researchers. The giant turbine is mounted on a vertically slender buoy that extends well below the surface of the water. The low concrete ballast and the damping plates help keep the buoy stable, even in rough weather. The floating turbine is designed to be assembled near the shore, then towed out and tethered 20 miles or more from the shore.

design, the wind turbine is mounted atop a vertically slender cylindrical buoy that extends well below the surface of the water (see the figure above). At the base of the buoy is a vertical extension called a truss, and at the base of the truss is the ballast, which is either concrete or a combination of concrete and steel. Mooring lines, or "catenaries," connect the spar buoy to a concrete block or other mooring system on the ocean floor. The platform and turbine are thus supported not by an expensive tower but by buoyancy. "All you need to pay for is the floating structure, the size of which does not depend on the water depth," says Sclavounos.

Guided by his simulations, he made design choices that increase stability and decrease costs. Placing the ballast as low as possible in the water, for example, shifts the center of gravity well below the surface—and the lower the ballast, the more stable the buoy is in rough weather. That stability makes it possible to decrease the size of the floater, reducing materials and construction costs.

In analyses of various mooring systems, "hybrid" catenaries that are part steel and part polyester gave the best outcome. They can absorb large and repeated impacts better than all-steel catenaries can, and they can absorb compressive loads without buckling. Other key factors include the careful choice of the number of catenaries per floater, their connection point to the spar buoy, and the angle at which they intersect the sea floor.

Because of its small size and elastic moorings, the spar buoy will move up and down in large waves more than a massive oil platform will. To damp that motion, the MIT design includes horizontal plates inserted between the floater and the ballast—a method used by the oil industry. The plates decrease the vertical loads caused by the waves and break up the rapidly circulating water, dissipating energy and significantly reducing the amplitude of the up-and-down motion.

All of those features work together to keep motion at the generator—high up in the hub of the turbine—within acceptable limits. They also significantly reduce the tension, or "pull-up load," on the anchor during severe weather. As a result, the expensive anchors and anchor-installation procedures used by the oil industry may not be needed. In fact, analyses to date indicate that simple "gravity" anchors will do. A block of concrete and steel would be attached to each catenary and then lowered to the sea floor—a very economical system.

While such design details help to cut costs, the biggest cost savings come from how the floating turbines are built. Assembling them out to sea at the wind-farm site would be prohibitively expensive because of their size: the wind tower is 90 meters tall, and the rotors are about 140 meters in diameter. But the MIT design is stable enough that the entire floating turbine could be assembled at a near-shore shipyard and then be towed out to sea by a tugboat.

Attaching the floating turbine at the wind farm would be straightforward. The catenaries—along with the electrical system and the cable to shore—would be pre-installed using well-established methods. The buoy would carry water as added ballast during the trip. Once on site, it would be hooked to the previously installed catenaries. The extra water would be pumped out, and the entire assembly would lift up in the water, pulling the catenaries taut.

Because the floaters are not permanently attached to the sea floor, they can relatively easily be brought back to shore for major maintenance. They can also be redeployed to some other offshore site in need of additional power-generating capacity—another feature that adds to their value.

Sclavounos is now optimizing the spar buoy design for a range of water depths from 50 to 1,000 meters. "The primary limitation on depth is the cost of the mooring system," he notes. Once the design is final, he plans to test the behavior of the floater and catenary system using a small-scale model in a towing tank. Assuming success, a commercial company would then build one or two full-scale prototypes that would demonstrate the concept and also generate income by selling the electricity produced.

With most of the engineering obstacles overcome, the key remaining question concerns the economic viability of floating turbines. Because the design is not yet finalized, exact cost estimates are not available. But Sclavounos predicts that floating wind farms will be cost competitive with combined cycle gas turbine power plants—generators that come on during times of peak demand. "If the U.S. adopts a carbon emissions trading system, electricity generated by wind farms—and by other renewable sources—will gain a significant economic advantage relative to fossil fuel-fired plants," he says.

"If crude oil and natural gas prices continue their upward trend and as carbon-emissions trading markets continue to grow," he adds, "the case for floating offshore wind farms as a significant contributor to worldwide electric power generation becomes quite compelling."

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This research was funded by the National Renewable Energy Laboratory.

Capturing the energy in ocean waves

MIT researchers are working with colleagues in Portugal to design a pilot-scale device that will capture the energy in ocean waves and use it to power an electricity-generating turbine. The MIT team's simulations of the project have shown ways—some unexpected—to tailor the device to catch significantly more of the energy in the incident waves.

Wave energy is a large, widespread renewable resource that is environmentally benign and readily scalable. In some locations—the northwestern coasts of the United States, the western coast of Scotland, and the southern tips of South America, Africa, and Australia, for example—a wave-absorbing device could theoretically generate 100 to 200 megawatts of electricity per kilometer of coastline. But designing a wave-capture system that can deal with the harsh, corrosive seawater environment; handle hourly, daily, and seasonal variations in wave intensity; and continue to operate safely in stormy weather is difficult.

Chiang C. Mei, Ford Professor of Engineering in the Department of Civil and Environmental Engineering, has been a believer in wave energy for decades. "I started working on wave energy at the end of the 1970s—a long time ago, when the gasoline price was only 50 cents per gallon," he recalls. Now with soaring oil prices there is renewed interest in harnessing the energy in ocean waves.

The best means of harnessing that energy is not obvious. As a result, many types of devices are being developed, including simple buoys and oscillating structures that run parallel to the shore or snake out into the ocean. All are designed to extract energy from the surface motion of ocean waves. In general, the force of the waves causes the device to oscillate, and that motion is translated into force to turn an electricity-generating turbine.

To help engineers design such devices, Mei and his colleagues develop numerical simulations that can predict wave forces on a given device and the motion of the device that will result. The simulations not only guide design decisions that will maximize energy capture but also provide data to experts looking for efficient ways to convert the captured mechanical energy into electrical energy.

Designing a pilot plant for Portugal

One country with a good deal of expertise in wave energy research and development is Portugal. For the past three years, Mei has been working with Professors António Falcão, António Sarmento, and Luis Gato of Instituto Superior Tecnico, Technical University of Lisbon, as they plan a pilot-scale version of a facility called an oscillating water column, or OWC. (See the diagram to the right.) Situated on or near the shore, an OWC consists of a chamber with a subsurface opening. As waves come in and out, the water level inside the chamber goes up and down. The moving surface of the water forces air trapped above it to flow into and out of an opening that leads to an electricity-generating turbine. The turbine is a special design in which the blades always rotate in the same direction, despite the changing direction of the air stream as the waves come in and out.

The Portuguese plan is to integrate the OWC plant into the head of a new breakwater at the mouth of the Douro River in Porto, a large city in northern Portugal. Ultimately, the installation will include three OWCs, which together will generate 750 kilowatts. As a bonus, the plant's absorption of wave energy at the breakwater head will calm the waters in the area and reduce local erosion.

OWCs have been installed elsewhere, but tailoring a system to a given site is key to maximizing power output. To help, Mei and graduate student Hervé Martins-Rivas of the Department of Civil and Environmental Engineering formulated a numerical model that shows what happens to the incoming waves, outside and inside the OWC. Millions of calculations simulate how the waves behave in the region; how they interact with the complex surfaces of the breakwater, the head of the breakwater, and the OWC structure itself; how the elevation of the water inside the OWC changes; and how the column of air moves and interacts with the turbine.

Their results show that the distance the water surface inside the chamber rises and falls depends on the frequency of the incoming waves, but the relationship between the two factors is not always the same. "When we chart frequency against change in elevation, there's a peak—a wave frequency that resonates with the chamber, causing an especially large change in elevation," Mei explains. "And the more the water surface moves up and down, the more the air is compressed—and the greater the power for turning the turbine and generating electricity."

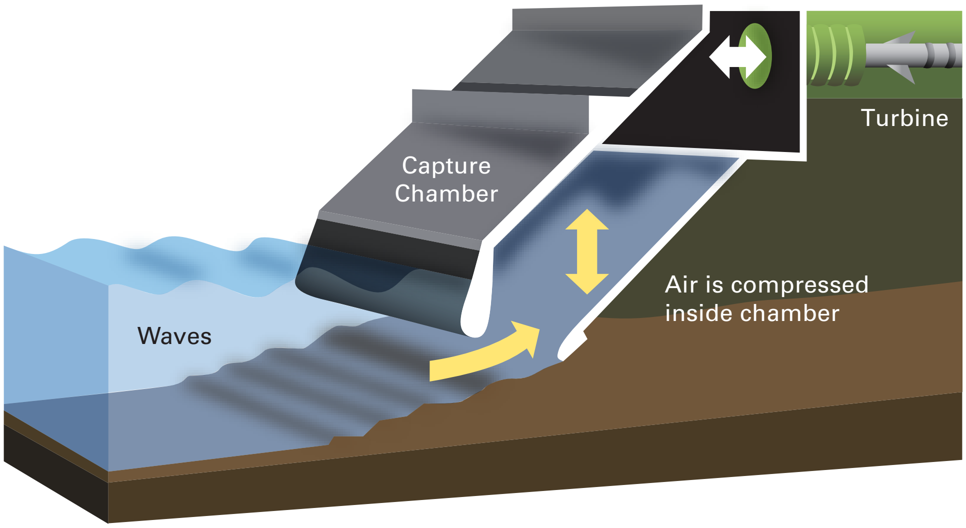
That finding was not a surprise. A wave-energy device always works best when its resonant frequency matches the natural frequency of the incoming waves. Think of pushing a person on a swing: the biggest result comes by pushing in time with the natural interval of the swing.

In reality, however, ocean waves are complex. Despite their appearance, they are not single-frequency waves. Waves form in the open ocean and come toward land from various directions and distances, joining together into a single wave as they approach shallow water. A wave coming onshore is therefore the sum (or superposition) of many waves—waves that have different frequencies. As a result, a device designed to match a narrow peak resonating frequency will fail to capture energy carried by the wave at other frequencies.

The challenge, therefore, is to design a device that resonates at a broad spectrum of wavelengths—and an unexpected finding from the MIT analysis provides a means of achieving that effect. The key is the compressibility of the air inside the OWC chamber. While that compressibility cannot be altered, its impact on the elevation of the water can be changed—simply by changing the size of the OWC chamber. The simulations showed that using a large chamber causes resonance to occur at a wider range of wavelengths, so more of the energy in a given wave can be captured. "We found that we could optimize the efficiency of the OWC by making use of the compressibility of air—something that is not intuitively obvious," says Mei. "It's very exciting."

Also exciting is a memorandum of understanding, signed in late May 2008 by the U.S. secretary of energy and the Portuguese minister of economy, that establishes formal cooperation between the two nations on the "policy, scientific, and technical aspects of wave energy generation and other renewable energy technologies."

Oscillating water column for capturing wave energy



In an oscillating water column, waves enter through a subsurface opening into the chamber with air trapped above. The wave action causes the captured water column to move up and down, pushing the trapped air into a turbine that generates electricity. The turbine turns continuously, despite the changing direction of the air stream as the waves come in and out.

Other approaches and plans

While work on the OWC continues, Mei is also looking at other wave-energy devices and situations. He and graduate student Xavier Garnaud of the Department of Aeronautics and Astronautics recently began working with Professor Ali Tabaei at the Masdar Institute of Science and Technology in Abu Dhabi on a project that focuses on energy-absorbing buoys and their deployment in buoy "farms." The MIT researchers' simulations are helping to optimize the size and spacing of the buoys so that each one will capture the most energy it can—without blocking the waves coming to its neighbors.

Mei continues to be enthusiastic about wave energy, but he is not unrealistic in his expectations about its future role. Although costs have been falling in recent years, wave energy is unlikely to be commercially viable for some time—perhaps several decades. Nevertheless, Mei is adamant that more attention should be given to this clean, renewable source of energy. "Given the future of conventional energy sources, we need lots of research on all kinds of alternative energy," he says. "Right now, wind energy and solar energy are in the spotlight because they've been developed for a longer time. With wave energy, the potential is large, but the engineering science is relatively young. We need to do more research." His vision? A team of MIT experts in different fields—from energy capture and conversion to transmission and distribution—who can work collaboratively toward making large-scale wave energy a reality.

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Research on the OWC was supported by the MIT-Portugal Alliance. Analysis of the wave-energy buoy farm is being supported by the MIT-Abu Dhabi Alliance. Further information can be found in:

E. Martins et al. *Cerdouro Project. Overall Design of an OWC in the New Porto Breakwater.* 6th European Wave and Tidal Energy Conference, Glasgow, United Kingdom, August 28, 2005.

H. Martins-Rivas and C.C. Mei. *Diffraction Effects Near Foz do Douro Breakwater.* 7th European Wave and Tidal Energy Conference, Porto, Portugal, 2007.

MIT Energy Initiative seed grants: Almost $2 million now funding energy projects

From harnessing microbes to developing new materials, from curbing pollution to harvesting wasted watts, a broad array of MIT research projects in solar technology, climate change impact, and power transmission were among those chosen to receive more than $1.94 million in the MIT Energy Initiative's (MITEI) first round of campus seed grants in January 2008.

The grants—which range up to $150,000 and last anywhere from one semester to two years—are intended to help launch new or early-stage projects that, it is hoped, will produce enough results to secure outside funding for further development. In all, 14 projects were selected to receive major grants totaling about $1.7 million, while six other shorter-term grants specifically targeted at junior faculty members were made.

MITEI selected the winners from 54 proposals submitted by members of all of MIT's departments; multidisciplinary projects were especially encouraged. MITEI Director Ernest J. Moniz says that he and his colleagues were pleased by the "overwhelming response" after expecting fewer than 20 proposals.

"The results of our call for proposals were so impressive that we were able to double the funding," Moniz says, by getting additional money from the Chesonis Family Foundation; MITEI's own funding; the MIT-Singapore programs; the deans of science, engineering, and management; and private donors.

Among the novel projects now under way is one aimed at doing basic research that could lead to a whole new approach to the production of biofuels. Sallie "Penny" Chisholm, the Lee and Geraldine Martin Professor of Environmental Studies and professor of biology, is conducting a study of *Prochlorococcus*, the smallest and the most abundant creature capable of photosynthesis. The hope is that this ubiquitous marine microbe could someday be used as a way of harnessing the power of sunlight to grow biofuels on an industrial scale.

Another project using a biological approach is a study of the bacterium *Rhodococcus opacus*, an organism that produces high levels of oils that can be converted into biodiesel and other fuels. The research team—Anthony J. Sinskey, professor of microbiology and health sciences and technology; Alexander van Oudenaarden, Keck Career Development Professor in Biomedical Engineering and associate professor of physics; and Jason Holder, postdoctoral associate in biology—is using the genomic sequence of *Rhodococcus opacus* to direct metabolic engineering to increase the organism's production of biofuels from organic waste streams.

The remanufacturing of products is the subject of a project by Timothy G. Gutowski, professor of mechanical engineering; Stephen C. Graves, Abraham J. Siegel Professor of Management Science; and Elsa Olivetti, MITEI postdoctoral associate. Remanufacturing falls somewhere between recycling (which reduces a product to its raw materials) and reuse (which finds new uses for existing products). In remanufacturing, an item is completely taken apart, cleaned, tested, and refurbished. The researchers are looking at what gets remanufactured, why, what it saves (energy, materials), and how to improve the process.

Another project, headed by Tonio Buonassisi, assistant professor of mechanical engineering, and Gerbrand Ceder, R.P. Simmons Professor of Materials Science and Engineering, is exploring novel materials for making solar cells. The study is focusing on materials that are abundant and could be easily scaled up to widespread production and that could produce low-cost, extremely efficient photovoltaic panels.

One team, pairing two economists and an engineer, is studying the health effects of energy use in rural India—the very smoky indoor combustion of wood and cow dung—and exploring alternatives that could mitigate these effects. Others are looking at various approaches to curbing global warming: harnessing collective intelligence to develop solutions using the model of massive, open collaborative projects like Wikipedia and Linux; utilizing microbially produced enzymes to control pollutants and greenhouse gases—and perhaps produce fuel in the process; and investigating how microbial life will respond if carbon sequestration becomes a major tool for limiting carbon emissions.

Some of the grants are being used to study materials and technologies that could improve electric power systems. These include superconducting transmission systems and the use of nanotubes to produce improved ultracapacitors for energy storage. Another project, colorfully titled "No Watt Left Behind," is developing new technology for minimizing waste in the use of electricity—for example, by using fluorescent lamps to detect the presence of people and adjust lighting accordingly.

In addition to the major seed grants, junior faculty were awarded smaller Ignition grants, which are "a way to kick-start new research for them in the energy area," says Robert C. Armstrong, Chevron Professor of Chemical Engineering and deputy director of MITEI. Those grants are supporting projects aimed at designing more energy-efficient buildings, developing new thermoelectric materials for more efficient heating and cooling, and improving the longevity of advanced nuclear power plants.

"We had outstanding submissions, both in terms of the innovative ideas and in terms of the variety of faculty who applied," Armstrong says. "This has helped us identify new ideas and new people to involve in MITEI as well as valuable collaborations we can foster across campus."

New grants will be awarded twice yearly. Over the course of the next five years, the program will cover the whole spectrum of energy-related research, including environmental research related to energy production, delivery, and use, as well as research that involves not only technology but also science, policy, and systems design issues.

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By David Chandler, MIT News Office

At press time, a committee of MITEI leaders, selected MIT faculty, and representatives from MITEI's Founding and Sustaining Members has finished reviewing the second round of seed fund proposals—51 from across the Institute—and announcements are expected soon.

Recipients of MITEI seed grants for energy research, January 2008

Seed grants

Ultra-high efficiency thin film heterojunction solar cells using earth-abundant, scalable materials
Tonio Buonassisi (Mechanical Engineering) and Gerbrand Ceder (Materials Science and Engineering)

Advancing our understanding of *Prochlorococcus*, the Earth's smallest and most abundant photosynthetic machine
Sallie "Penny" Chisholm (Civil and Environmental Engineering and Biology)

Enzymatic control of pollutants and greenhouse gases
Catherine Drennan (Chemistry)

Foundations for robust and reconfigurable energy networks
Munther Dahleh (Electrical Engineering and Computer Science)

The health consequences of energy consumption in India
Esther Duflo and Michael Greenstone (Economics) and Amy Smith (Mechanical Engineering)

Remanufacturing and energy reduction potential
Timothy Gutowski (Mechanical Engineering), Stephen Graves (MIT Sloan School of Management), and Elsa Olivetti (MIT Energy Initiative)

No watt left behind
Steven Leeb and James Kirtley (Electrical Engineering and Computer Science) and Les Norford (Architecture)

Harnessing collective intelligence to address global climate change
Thomas Malone and John Sterman (MIT Sloan School of Management), Hal Abelson, Mark Klein, and David Karger (Electrical Engineering and Computer Science)

Superconducting DC power transmission and distribution
Joseph Minervini and Leslie Bromberg (Plasma Science and Fusion Center)

Characterization of phonon mean free path and thermal transport in thermoelectric materials
Keith Nelson (Chemistry) and Gang Chen (Mechanical Engineering)

Microbial synthesis of pentanol as a biofuel
Kristala Jones Prather (Chemical Engineering)

Electrochemical cell evaluation and design for MIT nanotube-enhanced ultracapacitor
Joel Schindall and John Kassakian (Electrical Engineering and Computer Science) and Donald Sadoway (Materials Science and Engineering)

Renewable biofuels production in the oleaginous bacterium *Rhodococcus*
Anthony Sinskey (Biology), Alexander van Oudenaarden (Physics), and Jason Holder (Biology)

Investigation of subsurface microbial processes during and after geological carbon sequestration
Janelle Thompson and Roman Stocker (Civil and Environmental Engineering)

Ignition grants

Towards a balance between light, heat, and comfort: angularly and spectrally selective envelopes for energy-efficient buildings
Marilyne Andersen (Architecture)

Semiconductor nanowires for thermoelectric applications
Silvija Gradecak (Materials Science and Engineering)

Nitride-based electronics for high-efficiency power conversion
Tomas Palacios (Electrical Engineering and Computer Science)

Demonstrating biomimetic self-repair in photoelectrochemical energy production systems
Michael Strano (Chemical Engineering)

Structural characterization of organic photovoltaics and fuel-forming catalysts via designer force fields
Troy Van Voorhis (Chemistry)

Nano-structured alloys against corrosion in advanced nuclear plants
Bilge Yildiz (Nuclear Science and Engineering)

Opportunities abound for MIT students keen on energy

Student enthusiasm for engaging in energy activities continues to surge at MIT. Now, avenues to pursue those interests are expanding as well.

Students are joining faculty teams on funded research; they are collaborating with faculty and MIT operations personnel on studies of campus sustainability; and they are working with those who run the campus to implement their ideas for reducing campus energy use and emissions.

"MIT students are creative, energetic, and brilliant," says Dr. Amanda Graham, director of the Education Office of the MIT Energy Initiative (MITEI). "Expanding sources of support for their diverse activities in energy and the environment ensures that their contributions to these critical challenges will continue to multiply."

Undergrads join faculty researchers

MIT's Undergraduate Research Opportunities Program (UROP) has long provided MIT students with a chance to partner with faculty in their cutting-edge research programs or on ideas of their own. MITEI sponsored its first group of UROPs last summer. Eight students worked on topics ranging from the future of natural gas to silicon wafer production. Two of them were funded directly by MITEI Affiliate Members: Nth Power supported work by Nathan Brei '12 on the expanded use of daylighting to reduce energy consumption in buildings, and Marilyne Breslow supported research by Marie Herring '11 on layer-by-layer assembled materials for electrochemical energy devices.

For his project, Brei—an aeronautics/astronautics major and architecture minor—joined a team that is developing software to help architects design buildings that use daylight and sunlight more efficiently. He is working with Siân Kleindienst and Jaime Lee, two graduate students, as part of the LightSolve project run by Marilyne Andersen, head of MIT's Daylighting Laboratory.

"LightSolve is a methodology that accounts for climate and looks at sunlight or daylight over an entire year," explains Andersen, the Mitsui Career Development Assistant Professor of Building Technology. "It can be made into a design tool to help architects create more energy-efficient buildings that are more comfortable and healthier for humans." Among Brei's tasks is programming the "plug-in" that will enable the LightSolve program to interact with models developed by architects using a popular computer-aided design program.

"I am a big fan of building passivity and autonomy, and am fascinated with buildings designed to take advantage of the natural elements specific to their site," says Brei. He plans to apply knowledge gained in his UROP to his aero/astro major and architecture minor. "When I combine this with the skills from my major, I have everything I need to write my own simulators for wind, rain, and water flow—which will open up all kinds of exciting design possibilities for both buildings and airplanes," he says.

Campus-focused UROPs

While some UROP students join faculty-led research projects, others pursue concerns about the energy and environmental footprint of the MIT campus. The Campus Sustainability (CS) UROP Program—developed and coordinated jointly by the MIT Environmental Programs Office (EPO) and the MITEI Education Office—supports projects in which a student collaborates with MIT operations personnel and a faculty member to investigate sustainability challenges confronting the MIT campus.

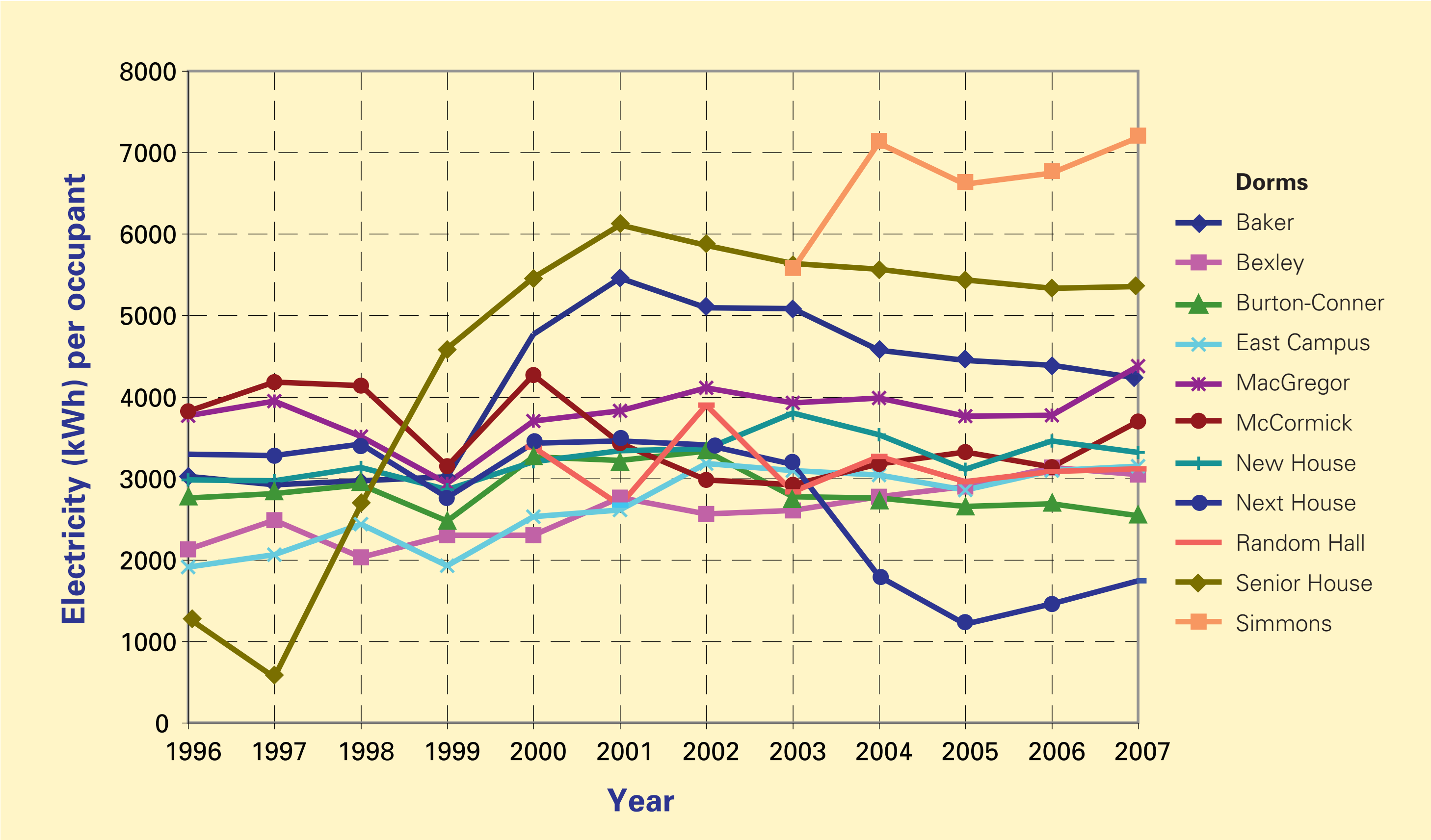
During the past academic year, for example, Tina Lai '09 undertook a CS UROP project in which she compiled data on the consumption of electricity, steam, and water by each MIT dorm between 1996 and 2007. She also documented investments made by MIT in the dorms, such as the switch to compact fluorescent light bulbs, installation of air conditioning, retrofitting of double-paned windows and new insulated roofs, and installation of weather stripping.

The task of gathering consistent data from all the dorms proved challenging, in part because the measurements are taken in a variety of ways. In some dorms, for example, electricity meters are read manually once a month; in others, continuous readings are taken electronically. Steam for heat is metered in some dorms but estimated in others.

"Much of my research dealt with extracting detailed information from a jumble of numbers and then analyzing the results," notes Lai. A sample of her results is the figure on page 21, which shows electricity use per occupant in each of the undergraduate dorms. In general, consumption is fairly level over time, but a few notable changes are evident. For example, consumption in Senior House rose in 1997, just after air conditioning was installed. Consumption in Next House began to drop in 2002, when double-paned windows were installed.

Leslie K. Norford, professor of building technology and Lai's CS UROP faculty supervisor, is most struck by the spread

Electricity consumption per occupant in MIT's undergraduate dorms



With funding from the Campus Sustainability UROP Program, Tina Lai '09 compiled these graphs of the per-person electricity consumption in each MIT undergraduate dorm between 1996 and 2007. The next step is to understand what caused the observed changes over time and why the per-person consumption levels vary so much from dorm to dorm.

between the lowest and the highest per capita values. "To me, the real story here is that while we're housing people in somewhat similar accommodations—they're all dorms—there's a huge range in the electricity use per capita," he says. "With that big a range, you'd think there would be some conservation opportunities to be found."

Norford hopes to have another UROP student work with the MIT Department of Facilities and the Housing Office on further analyses of Lai's data to try to understand what has caused changes over time and why the per-person consumption levels vary so much from dorm to dorm. Partnering with operations units allows for enhanced access to data and insight into management practices that can help both student researchers and the MIT administration.

As part of her project, Lai examined electricity use during the 2008 Dorm Electricity Competition—a project funded in part by MITEI in which undergraduate dorms compete to cut electricity use over a two-month period. This year's competition brought a total electricity savings of 13.6 percent from the baseline. "Clearly, student behavior can make a notable impact on campus energy use," concludes Lai. "And the installation of real-time electricity meters with web-based live feedback, for example in MacGregor Hall, will allow students to monitor and improve on their energy-related actions." (See the article on page 29.)

Grants for student groups

Another opportunity for students to get support for campus energy and environmental activities is through the MITEI Student Campus Energy Project Fund, which twice a year awards grants to student groups with ideas for promoting sustainable energy and environmental practices on campus. Current grants are enabling student groups to examine energy-saving retrofits for campus buildings, develop a solar thermal dish concentrator, and find ways to encourage energy-saving habits like two-sided printing.

In one campus project, a team of students is looking to harness waste heat at MIT's cogeneration plant, which provides most of the electricity, heat, and air conditioning for the campus. The plant is already a model of energy efficiency—but the students aim to make it even more so.

Andy Muto and Daniel Kraemer, graduate students in mechanical engineering, and Bryan Ho, a graduate student in materials science and engineering, have been working on a thermoelectric system that can be installed in a hot-water pipe or in exhaust flues at the cogeneration plant to get some extra electric power from heat that is currently going to waste. The temperature of the waste heat is too low to drive the electricity-generating turbine but plenty high to run a thermoelectric device—a solid-state heat engine that produces electricity from a difference in temperatures, without using any moving parts.

Working in collaboration with Facilities, the students have installed a small test module on one of the plant's rooftop flues. They check it periodically to collect data on its performance and durability after exposure to the weather. The students are also performing a cost/return analysis for implementation of this technology at MIT and in similar industrial settings. If the technology proves viable, it could over time reduce the total fuel consumption of the cogeneration plant by about 5 percent while delivering the same amount of power to campus.

The students believe that the MIT thermoelectric installation could provide a model for other cogeneration plants in operation or under construction around the world. Ultimately, Kraemer says, "this could work anywhere—even on a home furnace—anywhere where there's excess heat."

Benefits to all

During the past academic year, MIT students have undertaken dozens of innovative energy projects supported and funded by MITEI. The diversity of ways for students to engage in energy projects not only enriches their educational experience but also showcases the breadth of professional and scholarly opportunities in this field—and the campus benefits in lasting ways as well.

"Students inject a tremendous amount of new thinking and perspective into our work," says Steven M. Lanou, deputy director for environmental sustainability in the EPO and a CS UROP co-sponsor. "They have become a driving force in helping MIT shape and act on its campus sustainability agenda."

• • •

MITEI launches Society of Energy Fellows at MIT

In late August, the MIT Energy Initiative (MITEI) announced the first class of MIT Energy Fellows. Sponsored by the industry partners in the Initiative, these 39 graduate students are the inaugural members of the Society of Energy Fellows at MIT, an organization within MITEI established to foster a network of students dedicated to meeting the world's future energy needs.

Professor Ernest J. Moniz, director of MITEI, notes, "We are excited about this outstanding group of energy fellows—the next generation of energy innovators, scientists, engineers, policy leaders, and entrepreneurs who will help transform our global energy systems."

The first group of Energy Fellows is very diverse. Its 13 women and 26 men range in age from 21 to 50 years. Twenty of the fellows hail from at least 11 different states in the U.S. Because energy issues are global in nature, developing the fundamental science, technologies, and strategies to build a sustainable energy future will require worldwide adaptation and cooperation. Accordingly, in the first class of MIT Energy Fellows, 19 individuals come to MIT from 14 countries outside the United States, namely Belgium, Bulgaria, Canada, China, Croatia, Germany, Hong Kong, India, Italy, Mexico, Russia, Spain, Ukraine, and Yugoslavia.

The MIT Energy Fellows program is designed to attract and support graduate students with a special interest in energy, to build MIT's research capacity, and to foster a robust community of faculty, students, and staff engaged in energy research, education, and campus activity. Current MITEI members have a five-year commitment to the fellowship program and will support nearly 200 graduate students in energy over the course of their initial membership agreements.

MITEI assigns the fellowships to academic units with input from the supporting members. The MIT department and division heads then select the "named" fellows, for example, the Eni-MIT Energy Fellows. Fellows are encouraged to become acquainted with their sponsoring organizations—leading energy firms that are engaged with MITEI. Visiting scholar Dr. Nicola De Blasio, representative of MITEI Founding Member Eni, says that his company "is proud to support the next generation of innovators and leaders in the energy field. The Energy Fellows program is an important part of Eni's research partnership with MIT." This year, 11 Founding, Sustaining, and Associate members of MITEI are sponsoring fellows. (See below.)

Professor Robert C. Armstrong, deputy director of the Energy Initiative, praised the support of MITEI's industry partners. "We deeply appreciate the commitment of MITEI members to energy education at the Institute," he says. "Their support represents a major investment in the world's intellectual infrastructure, and will help enable

Named MIT Energy Fellows, 2008–09

ABB
Benjamin Cannon Electrical Engineering and Computer Science
Mar Reguant-Rido Economics

b_TEC
Evelina Polyzoeva Electrical Engineering and Computer Science
Tea Žakula Architecture

Bosch
Joseph Sullivan Mechanical Engineering
William Woodford Materials Science and Engineering

BP
Lina Bird Biology
Yi Chen Mechanical Engineering
Regina Clewlow Engineering Systems Division
Raoul Correa Chemistry
Neil de Laplante Earth, Atmospheric, and Planetary Sciences
Tatyana Deryugina Economics
Andrew Horning Chemistry
Xun Huan Aeronautics and Astronautics
Sean Kessler Chemical Engineering
Kyle Peet Civil and Environmental Engineering

Chevron
Yulia Agramakova Earth, Atmospheric, and Planetary Sciences
Betar Gallant Mechanical Engineering

Enel
Bruno Bueno Unzeta Architecture
Todd Ferguson Chemical Engineering

Eni
F. John Burpo Biological Engineering
Ingrid Heilke Urban Studies and Planning
Apurv Jain Sloan School of Management
Brian Kardon Physics
Jason Kovacs Chemical Engineering
Bonnie Lam Electrical Engineering and Computer Science
Kenneth Lotito Chemistry
Alejandra Quintanilla Terminel Earth, Atmospheric, and Planetary Sciences
Elizabeth Rapoport Materials Science and Engineering
Emiliano Renzi Civil and Environmental Engineering
Brandon Russell Biological Engineering

Ford
Nicholas Martin Political Science
Hiram Samel Sloan School of Management

Ormat
Andrej Lenert Mechanical Engineering

Schlumberger
Di Chen Materials Science and Engineering
Bren Phillips Nuclear Science and Engineering

Total
James Berry Economics
Geoffroy Hautier Materials Science and Engineering
Michael Marshak Chemistry

a cleaner, more affordable, and more sustainable energy future."

The MIT Energy Fellows have far-ranging interests. Fellows have been assigned to all five schools at MIT, across 18 departments and divisions. Many are engaged in traditional energy fields such as engineering, chemistry, and materials science; others are pursuing studies in areas such as energy economics and business, energy policy and politics, and the energy implications of urban planning and architecture. Although most of the new fellows are incoming first-year doctoral students, a handful are in their second or third years, depending on the specific needs and requirements of their schools and departments.

During a reception at the MIT Museum in late August, the new fellows were welcomed by MITEI and MIT leadership, MIT faculty, and MITEI members. The Society of Energy Fellows was formally launched in September at an all-day symposium opened by MIT President Susan Hockfield. The symposium showcased MIT energy faculty research as well as the work of MITEI sponsors in the energy arena.

Dr. Amanda Graham, director of MITEI's Education Office, is the Initiative's coordinator for the Society of Energy Fellows. "I am looking forward to an exciting year of working with this outstanding group of graduate students," Graham says. "We want to facilitate relationships among the students, the faculty, and their industry sponsors to show them a range of opportunities in the energy arena. We hope that the society will provide the students with a sense of community and enrich their experience at MIT."

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Luce Fellows look to a larger role for women scientists

The Clare Boothe Luce Postdoctoral Fellows in Energy at MIT are taking the pioneering spirit of their fellowships' namesake to heart: through their research to find solutions to society's energy demands, they also will enhance the presence of women in science and engineering.

During their two-year Luce Fellowships, Bonna Newman will be studying the physics of black silicon for potential use in solar photovoltaic (PV) cells, and Carolyn Seto will be developing models for monitoring carbon sequestration.

The prestigious postdoctoral fellowship program of the Henry Luce Foundation's Clare Boothe Luce (CBL) Program aims to open the door for women in science, engineering, and mathematics, areas where they continue to be underrepresented. It is the largest private source of funding for women in those fields. The CBL Program was created through a bequest to the Henry Luce Foundation of Clare Boothe Luce (1903–1987)—playwright, journalist, U.S. Ambassador to Italy, and the first woman from Connecticut elected to the U.S. Congress.

"From my own experiences in the petroleum industry, female role models who had fulfilling technical careers and healthy work-life balance were few and far between," says Seto, who holds a PhD in petroleum engineering from Stanford University. "This fellowship is a unique chance to explore an interesting, topical research subject while serving as a role model for other women in my technical field." She and Newman both plan to explore academic research careers.

Lindley Huey, associate director of MIT's Office of Foundation Relations responsible for managing the relationship with the Henry Luce Foundation, said the CBL postdoctoral fellowships are intended to help put women on a more level playing field when looking for academic positions. Two previous CBL postdoctoral fellows were at MIT from 2005 to 2007 in the Department of Electrical Engineering and Computer Science. Following their CBL fellowships, one went to the Toyota Technological Institute at Chicago as a research assistant professor, and the other joined the faculty of the University of Maryland's Department of Electrical and Computer Engineering, coincidentally as the Clare Boothe Luce Assistant Professor. "We see these outcomes as evidence of the effectiveness of the CBL postdoctoral fellowships in achieving the Luce Foundation's goals," says Huey.

Newman hopes for a similar opportunity. "The fellowship will allow me to pursue a career in academia or outside of academia in applied physics or the energy industry," says Newman, who earned a PhD from MIT in experimental atomic physics shortly before her fellowship began in September.

For Newman, the fellowship is also a chance to switch fields. "For the past few years I've tried to do extra things at MIT to move from basic fundamental physics to applied physics," she says. Having a postdoctoral fellowship at the same institution where she earned a PhD should make the transition to a new field easier. "More important, the MIT Energy Initiative is here," she adds. "Having that kind of organization available will help." One of her recent projects was helping to create a new undergraduate class, the Physics of Energy, which started this fall. Development of the class was supported by MITEI.

Newman is researching aspects of photovoltaics ranging from the fundamental efficiencies of silicon to processes for manufacturing PV systems. Her particular focus is black silicon, which absorbs light below the infrared level that is not taken in by a regular silicon-based solar cell. Developing a means of capturing that light could increase the efficiency of solar photovoltaic cells. "I'll try to understand the properties of black silicon and adapt that knowledge to photovoltaic cells," she explains. "I'm also interested in working on energy storage devices. There are a few projects on campus working on this, and I might try to get involved. The Luce fellowship gives you free time because you are not working for one specific professor."

Seto was drawn to the interdisciplinary research environment at MITEI, which complements her professional experience as a reservoir engineer. She is working to develop efficient and effective monitoring strategies for carbon sequestration, an enabling technology for the continued use of fossil fuels in a carbon-constrained environment. Carbon sequestration involves capturing carbon dioxide (CO_2) at stationary emission sources such as power plants and then injecting it into large geological formations for long-term storage. Seto is developing models of how CO_2 flows below ground to predict where it may migrate.

"My proposed research hopes to reconcile the multiple scales, and associated uncertainty, in CO_2 sequestration," she says. "Insights gained from this research will help shape policy and practice in deploying CO_2 sequestration as a means of providing a safe and effective low-carbon solution to meet society's energy needs."

Photo: Mark Morelli

Carolyn Seto (left) and Bonna Newman have been awarded two-year Clare Boothe Luce Postdoctoral Fellowships in Energy at MIT. Newman is studying black silicon for potential use in solar photovoltaic cells, and Seto is developing models for monitoring carbon sequestration.

Huey said the type of research the women will conduct and their disciplinary backgrounds fit well with the CBL Program goals. "The Luce Foundation wants to increase the number of women in science and engineering," she notes, "particularly in areas where the numbers are especially low, such as physics. These CBL fellows will be working on one of the world's greatest challenges and will serve as important role models for other young women."

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MIT Class of 1960 supports curriculum development in energy

The MIT Energy Initiative is pleased to announce a generous donation from the MIT Class of 1960 to support the formulation and development of MIT's energy education curriculum.

Reflecting the multidisciplinary nature of energy studies, three faculty members—one each in Engineering, Science, and Management—have been designated "Class of 1960 Fellows." Support is also being provided by the Class of 1960 to a lecturer in the School of Architecture and Urban Planning.

Vladimir Bulović, associate professor of electrical engineering, and Donald R. Lessard, the Epoch Foundation Professor of International Management at MIT Sloan, are combining their Class of 1960 awards to support their joint efforts to coordinate multidisciplinary energy curriculum development. Among their goals is the development of an Institute-wide energy minor as well as the identification of opportunities to improve graduate-level energy education.

Bulović and Lessard are currently the co-chairs of the MITEI Energy Education Task Force. Both have been involved in MITEI since its inception. Bulović was a member of the Energy Research Council (2005–06) convened by President Susan Hockfield to lay the groundwork for MITEI. He has been involved in undergraduate education and has helped to initiate the campus energy "walk the talk" component of MITEI.

Lessard has been a member of the MITEI Energy Education Task Force since it was formed in April 2007. He served as chair of the Curriculum Subcommittee, leading the development of the task force's "Statement of Principles" and core competency descriptions for energy science, social science, and engineering.

The third Class of 1960 Fellow is Washington Taylor, professor of physics and a member of the MITEI Energy Education Task Force since its formation. During the past year, Taylor collaborated with Robert L. Jaffe, Jane and Otto Morningstar Professor of Physics, to develop a new subject called the Physics of Energy (8.21). Launched in fall 2008, the subject is designed to help students from across the Institute understand the physical processes that govern all aspects of energy production, transmission, conversion, storage, and consumption.

Class of 1960 funds are also supporting the appointment of Harvey Michaels (MIT, SB '74, Civil Engineering; SB '75, Urban Studies; MCP '75) as a research scientist and lecturer; he will be co-located in the Department of Urban Studies and Planning and MITEI. Michaels has extensive private-sector experience in advancing technology and policy for enhanced efficiency in electricity delivery and use. He will teach the new subject Enabling an Energy Efficient Society (11.194/11.953/ESD.931) in fall 2008 and 2009.

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Turning bricks and mortar green

The limestone and glass walls of MIT's Brain and Cognitive Sciences Complex (BCSC) glint white and silver in the sun. But actually, the complex, also known as Building 46, is green.

The world's largest center for neuroscience research, BCSC opened in 2005. Its high-performance building envelope, gray water reuse, exhaust-fan heat recovery, and daylight-balanced lighting have earned it a coveted ranking by the U.S. Green Building Council (USGBC), making it one of the greenest buildings on the MIT campus.

"Sustainable buildings pay for themselves. Sustainable buildings please their occupants," says Leon R. Glicksman, professor of building technology and mechanical engineering and co-chair of the Campus Energy Task Force of the MIT Energy Initiative (MITEI). "We are working hard to make them more widespread at MIT and use this as an example to other organizations."

Photo: Andy Ryan

MIT's Brain and Cognitive Sciences Complex, opened in 2005, is one of the greenest buildings on campus. Among its features: a high-performance building envelope, gray water reuse, exhaust-fan heat recovery, and daylight-balanced lighting.

Almost a century after architect William W. Bosworth applied cutting-edge European concepts of efficiency to MIT's Cambridge campus, environmental imperatives such as global warming are spurring a renewed interest in sustainable architecture. MIT is increasingly applying its own architectural and engineering expertise, such as virtual building design and energy-saving technologies, to its own infrastructure, making the Institute an emerging leader in green campus buildings.

In 2001, MIT's Green Building Task Force (GBTF) set Institute-wide goals and standards aimed at conserving energy and reducing greenhouse gas emissions. "MIT was an early adopter of a green building policy and goals, and our expertise has evolved and strengthened over time," says Steven M. Lanou, deputy director for environmental sustainability. "Our newest buildings—the MIT Sloan School of Management, NW35 (the new Ashdown House), and the David H. Koch Institute for Integrative Cancer Research—are expected to be the greenest to date."

"There has been impressive collaboration among faculty, students, and staff in developing features to improve energy efficiency in our project planning," says MIT Executive Vice President and Treasurer Theresa M. Stone, who is co-chair of the MITEI Campus Energy Task Force.

"In the case of the Koch building, for example, Professors Leon Glicksman and Leslie Norford [professor of building technology] worked with the MIT Department of Facilities' engineering and project management teams, as well as experts from the Environment, Health, and Safety Office, to refine the Institute's approach to fume hood standards to improve energy usage while assuring proper safety standards," explains Stone.

Walter E. Henry, director of Facilities' Systems Engineering Group, and others modeled and tested airflow in laboratory fume hoods, which suck out noxious chemical fumes, to determine whether a drop in the velocity of the air entering the hoods would maintain their effectiveness. They found that a 20 percent reduction would keep the fume hoods safe while drastically reducing their energy use.

Another significant marker of change is MIT's commitment to hold all its new construction and renovation up to

William Rawn Associates, Architects, Inc.

An architectural model of the new Ashdown House, a series of connected buildings situated around two courtyards that serve as private outdoor gardens for the residents. The recently opened building includes many green features and is expected to receive a gold or silver LEED designation.

scrutiny by the USGBC's Leadership in Energy and Environmental Design (LEED®) Green Building Rating System. LEED certifications of platinum, gold, and silver aim to encourage and accelerate global adoption of sustainable green building and have become a benchmark for green building design and construction.

It is a little-known fact that all new construction and major renovations undertaken by MIT after 2001 are expected to meet or exceed the LEED silver standard, Lanou says.

Through use of targeted technology and a system called integrated design, MIT's newest buildings could end up using a third less energy than their conventional counterparts do. And because buildings are responsible for more than a third of our national energy consumption, says Glicksman, that is a significant number.

The MIT Sloan project is unlike any building project MIT has undertaken. From the start, a high level of green design was set as a goal; and in order to achieve that goal, the team adopted a version of the integrated design process, according to Henry. In the typical design process, work is linear, so that the different disciplines work one after the other. The integrated process includes all of the architects and engineers from the beginning so they can more effectively work as a team. From this new process, the designers for the MIT Sloan project were able to develop what is probably the greenest building at MIT.

The design team of the Koch Institute, under construction on Main Street, also incorporated aspects of integrated design. In addition to the low-flow fume hoods, the building will filter its stormwater en route to the Charles River, use reflective roof material, recover heat in the HVAC system, and recycle or salvage at least 75 percent of construction waste. In addition to these features, shared by the MIT Sloan building, the landscaping around Building E56 was saved before it was demolished and then moved to a new park next to Building E33.

Among the features of NW35, the new graduate student housing at Pacific and Albany streets, are a stormwater management system, use of recycled materials, a reflective roof with provisions for future solar panels, and low-VOC paints and adhesives. MIT Sloan, the Koch Institute, and the graduate dorm are expected to receive gold or silver LEED designations.

Green building was still largely a novelty when MIT alumnus Marc Rosenbaum founded the New Hampshire-based sustainable building company Energysmiths in 1979. While green practices have become more common in the industry, Rosenbaum told participants at a recent sustainable real estate symposium at MIT that perceived barriers, such as cost, time, and risk, still prevent green building from becoming standard practice. It is important for building professionals to learn about green building, he noted, and for consumers to demand it.

"As an institute built around innovation," says Lanou, "MIT has an obligation to demand and uphold the highest standards in environmentally friendly infrastructure."

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By Deborah Halber, MITEI correspondent

New web-enabled meters may reduce electric bill shock

On any given night in a typical semester, students are burning the midnight oil—or more to the point for MIT's carbon footprint, burning the midnight electricity. A student team seeking to monitor and reduce dormitory electrical consumption found that peak use occurs from midnight to 1:00 a.m.

Photo: Mark Morelli

Mechanical engineering graduate student Bryan J. Urban, left, inspects a web-enabled electric meter with Rich Lucas, senior electrical engineer at the MIT Department of Facilities. Urban, Lucas, and others are spearheading the installation of these devices in dorms to raise student awareness of day-to-day electricity use.

Energy consumption in buildings accounts for the vast majority of campus energy use and produces more than 90 percent of MIT's greenhouse gas emissions, but occupants do not tend to get any feedback about their patterns or rate of use, says Steven M. Lanou, deputy director of environmental sustainability for MIT. The goal of a student-run project, one of 20 funded in the past year by the MIT Energy Initiative's (MITEI) Student Campus Energy Project Fund, is to make that feedback available.

Austin L. Oehlerking, who graduated in June with double undergraduate degrees in management science and mechanical engineering; mechanical engineering graduate student Bryan J. Urban; and 2008 MIT Sloan Fellow Michael A. Chiu started working with student groups and the MIT Department of Facilities in spring 2008 to install real-time electricity meters in all undergraduate dorms.

Once the project is completed next year, the meters will provide the first accurate web-based data on how much electricity is consumed in individual buildings; provide a way for students to access that information; and—it is hoped—motivate individuals to cut back on their energy use. "People will be able to log on to a website and see in real time how much electrical energy is being used per person," explains Urban.

The team so far has received funding from MITEI; the Chesonis Family Foundation; Total, a multinational energy company; and the MIT Undergraduate Association Sustainability Committee. Although not inexpensive—it costs $1,000 to $5,000 in equipment and labor to install the commercially available, web-enabled meters in each of the 11 undergraduate dorms—the biggest challenges so far have been largely logistical, Urban says.

Rich Lucas, senior electrical engineer at Facilities, has been spearheading installation, which in some dorms requires a complete electrical shutdown. Quirky electrical wiring differs from building to building, and more pressing needs often demand Facilities' attention. "It's challenging to make it all come together," notes Oehlerking, who became interested in sustainable energy after taking an Independent Activities Period course on the subject in 2007.

The team is convinced that the project will be worthwhile. "One of the things we found exciting is that when Oberlin College adopted a similar system and ran an electricity competition, the dorms with more sophisticated metering performed much better," Urban says. "We hope to use this as a platform for experiments in changing behavior. People can see how much electricity they're using and what they can do to change that."

"I like the idea of providing incentives to reward dorms or individuals for reduced energy consumption," Oehlerking adds. "Students don't pay directly for electricity, but reductions in this age of rising energy costs translate into savings for everyone."

The team is working with campus groups such as the Undergraduate Association Campus Sustainability Committee and the Energy Map Project, which is developing a prototype map that displays energy-use intensity in various MIT buildings with a color scale "to see which buildings are the real energy hogs," says Urban, who has been developing, with MIT's Building Technology Program, a web-based tool to help architects design energy-efficient buildings.

Urban and Oehlerking are looking forward to getting the meters installed and the data flowing.

"We'll provide open access to the data on our website and make direct access to the data available to others who want to develop further applications for it, such as notifications downloaded to cell phones," Oehlerking says. "Our main purpose is to put the data out there and hope the creativity of MIT takes over."

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By Deborah Halber, MITEI correspondent

Deploying a student army to battle wasted energy

When a small crew of energy-conscious students came up with the idea of enlisting like-minded comrades in an MIT energy brigade, they pictured a small army swarming throughout campus, leaving newly retrofitted buildings in its wake.

Their vision turned out to be pretty accurate.

Originally a one-time, hands-on Energy Week activity—part of the third annual MIT Energy Conference organized by the MIT Energy Club and the Sloan Energy & Environment Club in April 2008—the Energy Brigade is growing by leaps and bounds.

To the delight of RetrofitMIT organizers—Adam M. Siegel, an MIT Sloan graduate student; Carrie A. Brown, an architecture graduate student; and Chris P. Kempes, a technical assistant with the Earth System Initiative who began his doctoral studies in September—more than 30 students showed up April 7 to get a crash course from the MIT Department of Facilities on occupancy sensors and Vending Misers, which shut down lights and vending machines, respectively, when they are not in use.

The students embarked on a kind of campus treasure hunt to seek out vending machines equipped with or lacking the device, or with ones that needed adjusting. They were able to fix some on the spot or mark down ones that needed more attention. Other students worked in Building 18, the Dreyfus Chemistry Building, to fine-tune occupancy sensors. Department of Chemistry administrators supported their efforts, arranging their visits to various laboratories.

"When you add up the energy savings from all vending machine misers per year, it comes to $30,000 to $40,000, which is pretty cool," Kempes says. The student volunteers also received a warm welcome from chemistry graduate students and laboratory technicians, who patiently stood motionless while sensors were calibrated and suggested possible locations for additional sensors.

Based on the event's success, Siegel, Kempes, and Brown decided to make the Energy Brigade ongoing. Students will have an opportunity to join the brigade in the fall. They will take part in a training session about available retrofit technology and the savings such technologies can generate.

With funding from the MIT Energy Initiative's Campus Energy Task Force and the help of the MIT Generator, which works with student groups trying to green the campus, the Energy Brigade is expanding its focus to a lighting study in Building 54, monitoring energy use, and helping to retrofit dorms.

"We want to give students the tools and equipment they need to actually retrofit campus buildings," explains Siegel, who became involved himself after finding the level of campus enthusiasm for environmental sustainability infectious. "The great thing is that a lot of students are very interested and very excited with the technologies we implemented. We also hope to research additional technologies, identify new retrofits for campus, and understand the energy- and cost-saving implications of those technologies."

For Kempes, retrofits are "something I've been aware of for awhile. Fifty percent of the buildings that will be standing in 2030 already exist today, so we have to think about retrofitting the existing infrastructure."

After talking with Peter L. Cooper, manager for sustainable engineering and utility planning in Facilities, Kempes, Siegel, and Brown became aware that students who are smart and willing, but not licensed electricians, could provide effective service by performing surveys, testing, adjustments, and certain maintenance that would otherwise be labor-intensive and expensive. The April 7 student volunteers, for instance, provided the equivalent of $5,000 to $7,000 in labor.

To Kempes, the Energy Brigade is a win-win: "It saves money, educates people about what energy efficiency looks like, and creates an energy-conscious culture on campus," he says.

"It is just this type of student and staff collaboration that the MITEI campus energy program envisioned by opening our campus as an energy learning laboratory. We can find new solutions to old problems by creatively engaging fresh perspectives—while also opening new avenues for student learning and leadership," says Steven M. Lanou, deputy director for environmental sustainability in the Environmental Programs Office and a Campus Energy Task Force member.

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By Deborah Halber, MITEI correspondent

Photo: Mark Morelli

Eric R. Beaton, center, senior engineer for the MIT Department of Facilities' Systems Engineering Group, displays a Vending Miser, which reduces energy consumption in vending machines. Architecture graduate student Carrie A. Brown, left, and Earth System Initiative technical assistant Chris P. Kempes, right, recruited a student Energy Brigade to install the devices on machines around campus.

Major MIT studies examine the future of solar energy, nuclear fuel cycles, and natural gas

Meeting global energy demand in a low-carbon environment will require informed policy, technology, and investment decisions supported by critical and objective analysis. To provide such analysis, MIT teams have begun new studies on the future of solar energy and the future of natural gas as well as an update of MIT's 2003 nuclear power study, with a focus on the nuclear fuel cycle. When completed in mid 2010, these studies will deliver recommendations for high-priority research, development, demonstration, investment, and policy actions that would lead to the best possible outcome.

The current analyses are the latest in a series of major studies that a group of MIT faculty began in 2001 to explore the contribution that different energy technologies could make to meet future U.S. and global energy needs in a carbon-constrained world. All of the studies have a broad interdisciplinary focus that encompasses technology, economics, and policy (see the Future of Nuclear Power Study at <web.mit.edu/nuclearpower> and the Future of Coal Study at <web.mit.edu/coal>).

The new studies on nuclear fuel cycles and natural gas are described below. The Future of Solar Energy Study is described on page 10.

Identifying promising nuclear fuel cycles for future development

Nuclear power is an important option for meeting future energy needs without emitting carbon dioxide and other atmospheric pollutants. Indeed, the expectation of a significant price on carbon dioxide emissions and a growing commitment to new nuclear power programs in various developing economies suggests the possibility of a large scale-up of nuclear power.

In 2003, the MIT study on the Future of Nuclear Power identified key issues requiring timely action if nuclear power is to contribute to climate change risk mitigation. Among the recommendations was a call for statutory financial incentives for a small number of "first-of-a-kind" new nuclear power plants within the United States. The first-mover incentives took life with the Energy Policy Act of 2005, and the U.S. Department of Energy launched a new research program focused on fuel cycles that could mitigate long-term waste management challenges without exacerbating proliferation concerns.

In response, the Electric Power Research Institute and the Nuclear Energy Institute commissioned another major interdisciplinary MIT study that is updating key parts of the 2003 report, such as the analysis of nuclear energy economics, but also has a sharper focus on advanced fuel cycles and waste management.

The optimum choices for nuclear fuel cycle development entail a complex tradeoff among diverse interconnected issues—economics, safety, short-term versus long-term exposures of both the workforce and the public, management of spent nuclear fuel versus multiple waste streams, fissile resource availability, and nuclear proliferation. In the Future of the Nuclear Fuel Cycle Study, an MIT group is analyzing these issues in an integrated fashion for various reactor/fuel cycle systems (with and without irradiated fuel reprocessing) and for various nuclear power deployment scenarios. The product of the study will be recommendations for fuel cycle development within an overall risk management framework.

The fuel cycle working group is chaired by Mujid S. Kazimi, professor of nuclear engineering and mechanical engineering and director of the MIT Center for Advanced Nuclear Energy Systems, and Ernest J. Moniz, professor of physics and engineering systems and director of the MIT Energy Initiative (MITEI). Executive director of the study is Charles W. Forsberg, who comes to MIT following a distinguished career at the Oak Ridge National Laboratory. The fuel cycle advisory committee is chaired by Philip Sharp, president of Resources for the Future and a former Indiana congressman who was influential in energy legislation.

Understanding the role of natural gas in a carbon-constrained world

Nearly a quarter of all the energy used in the United States is in the form of natural gas. It fuels 20 percent of all U.S. power generation (second only to coal), supplies 41 percent of the energy used by industry, heats a large percentage of residential and commercial buildings, and is an essential industrial feedstock. This flexible domestic resource can play a critical role in reducing greenhouse gas emissions as we transition to renewable, low-carbon energy sources: for example, carbon emissions from natural gas combustion are generally about half those from coal combustion.

An MIT team has undertaken a two-year interdisciplinary study aimed at better understanding the current and future role of natural gas in a carbon-constrained environment, with a specific focus on the U.S. market. The Future of Natural Gas Study will begin with objective reviews and analyses of existing information, data, and studies on natural gas supply and resources, end uses, and infrastructure for import, distribution, and storage.

The study team will also evaluate the status of natural gas research and development in both the private and public sectors. Finally, the team will use the MIT Emissions Prediction and Policy Analysis model—adjusted and expanded to reflect U.S. regional differences—to analyze the role of natural gas as a transition fuel under various scenarios, defined by different policy frameworks and other key inputs. By examining critical technical, institutional, and public policy factors, the team will identify the highest priority needs for analysis, research, development, and demonstration as well as a range of policy options to support and advance the outcomes of various scenarios.

The natural gas study is co-chaired by Henry D. Jacoby, professor of management, co-director of the MIT Joint Program on the Science and Policy of Global Change, and director of the MIT Center for Energy and Environmental Policy Research; Tony Meggs, MITEI visiting scholar and retired technology group vice president at BP; and Ernest J. Moniz, professor of physics and engineering systems and director of MITEI.

The external advisory committee—now in formation—will be chaired by Mack McLarty, former gas utility executive and chief of staff to President Bill Clinton. Members include J. Bennett Johnston, former Louisiana senator and former chair of the U.S. Senate Energy Committee; Frank Keating, former governor of Oklahoma; and Ralph Cavanagh of the Natural Resources Defense Council. The study is funded by the Clean Skies Foundation.

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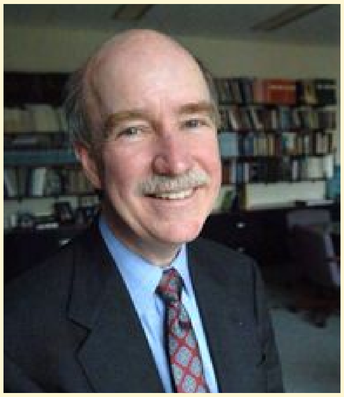
Armstrong elected to National Academy of Engineering



Robert C. Armstrong, deputy director of the MIT Energy Initiative, has been elected to the National Academy of Engineering. Armstrong, the Chevron Professor of Chemical Engineering, was honored for "conducting outstanding research on non-Newtonian fluid mechanics, co-authoring landmark textbooks, and providing leadership in chemical engineering education."

Academy membership honors those who have made outstanding contributions to "engineering research, practice, or education" and to the "pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education."

Armstrong has been a member of the MIT faculty since 1973 and served as head of the Department of Chemical Engineering from 1996 to 2007. His research interests include polymer fluid mechanics, rheology of complex materials, and energy. Armstrong received the Professional Progress Award in 1992 and the Warren K. Lewis Award in 2006, both from the American Institute of Chemical Engineers, and the 2006 Bingham Medal from the Society of Rheology, which is devoted to the study of the science of deformation and flow of matter.

Upcoming international conference on greenhouse gas control technologies

The 9th International Conference on Greenhouse Gas Control Technologies (GHGT-9) will be held November 16–20, 2008, at the Omni Shoreham Hotel in Washington, D.C. This event is recognized as the principal international meeting on greenhouse mitigation technologies, in particular carbon capture and storage (CCS).

The conference is being organized by MIT in collaboration with the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG), with major sponsorship from the U.S. Department of Energy (DOE). Howard Herzog, principal research engineer in the MIT Energy Initiative, is chair of the GHGT-9 Organizing Committee and of the GHGT-9 Program Committee.

CCS is increasingly viewed as a key enabling technology for coal and other fossil fuel combustion in a carbon-constrained world, and interest in it is growing rapidly. The previous GHGT conference—held in 2006—attracted roughly 950 delegates; some 1,200 are expected this year.

At GHGT-9, distinguished keynote speakers will present overviews of the status of CCS and related climate change issues to give a broader context. Invited papers will set out the challenges and issues that must be addressed for global implementation of CCS to be realized, while panel sessions addressing key topics relating to CCS implementation will promote debate and attendee participation.

Almost 270 technical papers will be presented orally during parallel sessions spanning four days. In addition, more than 500 authors were invited to present posters. Among the topics to be addressed are the technology and economics of carbon capture, transportation, and long-term storage; geological storage, including novel options, best practices, and risk assessment; retrofitting of power plants; infrastructure issues; policy and regulatory development; incentives and financing; pilot and demonstration projects; public acceptance and the role of information; and issues involved in moving forward to large-scale deployment of CCS.

In the closing session, participants will consider what they have learned from the conference and what they see as the challenges ahead. They will thus set the scene for GHGT-10, which will be held in Amsterdam in 2010.

The three lead conference sponsors—IEA GHG, DOE, and MIT—are joined by 27 corporate sponsors. More detailed information about GHGT-9 can be found at <mit.edu/ghgt9>.

The GHGT conferences are held every two years in IEA GHG's member countries. The conference series rotates among North America, Europe, and Asia.

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Green Islands: Developing robust sustainable energy strategies for the Azores

The volcanic island of São Miguel in the Portuguese Azores has abundant geothermal resources. Operational constraints, however, severely limit the local utility, Electricidade dos Açores, from expanding the use of this renewable energy resource beyond the island's minimum demand for electricity.

This is one of the many challenges—and opportunities—that the new MIT-Portugal "Green Islands" project is designed to address. The Azores, a cluster of Portuguese islands in the mid Atlantic, faces daunting challenges as it seeks to transform its energy sources, infrastructures, and related resources into new, sustainable, and environmentally friendly systems. The MIT-Portugal Program's flagship Green Islands project is finding ways to tap into local resources and overcome locally binding constraints in a technologically robust and economically viable manner. Using new methodologies, the team of MIT and Portuguese collaborators is working to identify cost-effective, sustainable energy solutions and options that will be designed to take full advantage of the Azores' indigenous natural resources.

Photo: Stephen Connors, MITEI

MIT and Portuguese collaborators are now working to identify cost-effective, sustainable energy options for the Azores, a cluster of Portuguese islands in the mid Atlantic. The innovative tools and methods developed in the project will be applicable to other remote island communities and nations trying to make their energy systems more sustainable while taking full advantage of their indigenous natural resources.

For the past year, the MIT-Portugal Program has been developing a diverse set of research, educational, and outreach activities that are both "green" and "smart." Researchers at MIT and its partner universities in Portugal are engaged in "brown to green" activities—developing tools that can transform regional and local infrastructures to work in concert with the environment. To ensure that the transformation of the islands' integrated energy systems is both robust and cost-effective, the researchers are developing "smart" planning techniques that capture the dynamics of energy supply and demand. Included are the design of efficient houses, buildings, and neighborhoods; clean, safe, and convenient transportation systems; integrated local energy supplies and energy networks; and the new businesses that will develop and deploy them.

The Green Islands initiative seeks to apply these tools in ways that both respect and take advantage of local energy needs, consumption patterns, and resources. The project will collect detailed information on how the islands of the Azores currently use energy, how they might use energy in the future, and the characteristics of the islands' numerous indigenous energy resources. The integration of such information will enable the researchers to identify cost-effective options for change that would have minimal impact on people's way of living and would promote new business opportunities for economic growth and development.

To maximize local knowledge and expertise, the Green Islands project is partnering with the government of the Autonomous Region of the Azores, its people, and interested businesses to explore sustainable options for the Azores. The initial focus of the project will be the islands of São Miguel and Flores.

The work will proceed in three phases: initial "scoping scenarios" will lead to detailed "design scenarios" and, whenever possible, innovative "demonstration and pilot projects" supported by industrial partners and aimed at assessing the viability of the research's more interesting options.

On the issue of geothermal energy at São Miguel, for example, the Green Islands team is exploring a number of options and will develop recommendations on how best to overcome the limitations of the power generation and distribution system of the island. One possibility is to shift some electricity use to nighttime—when demand is lowest—through a combination of energy storage technologies, plug-in vehicles, and strategic investments to reduce electricity demand.

Each of the nine islands of the Azores is unique, so feasible energy options will differ from one to another. However, the innovative regional methodologies developed in this Green Islands project are largely transferable and are capable of identifying sustainable pathways for transforming energy systems at the local level. The project also can provide a template for other remote island communities and nations.

The MIT-Portugal Program is a major initiative that was undertaken by the Portuguese Ministry of Science, Technology, and Higher Education in 2006 to significantly expand research and education in engineering and management across many of Portugal's top national universities. The collaboration includes four focus areas: sustainable energy systems, transportation systems, engineering design and advanced manufacturing, and bioengineering systems. Four of MIT's five schools—Engineering, Science, Architecture and Planning, and Management—are currently involved, along with more than half a dozen Portuguese research universities.

In March 2008, the activities of the MIT-Portugal Program were significantly enhanced when Portugal became the inaugural Sustaining Public Member of the MIT Energy Initiative (MITEI). As such, Portugal will have a seat on MITEI's governing board, will support graduate energy fellows and/or postdoctoral fellows at MIT, and will support MITEI's energy research "seed funds" to promote the development of a broad range of novel energy technologies and concepts from innovators across the Institute.

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Celebrating ten years of Martin Fellowships

For the past decade, the Martin Family Society of Fellows for Sustainability (MFSFS) has supported some 20 MIT graduate students each year. As a result, 227 MIT alumni are now part of a growing network of Martin Fellows working in industry, academia, government, and NGOs around the world.

To celebrate the 10th anniversary of the MFSFS, MIT held a series of activities on May 1, 2008. A luncheon hosted by President Susan Hockfield was followed by visits to several MIT laboratories, a reception and poster session with the 2007–08 Martin Fellows, and finally an induction dinner for the 20 Martin Fellows for 2008–09. The new fellows will work on a wide range of topics including environmental protection and equitable development, novel designs for thermophotovoltaic cells, recycling and reclaiming of materials from products, and ecology of marine cyanobacteria and viruses.

The Martin Family Society was established at MIT in 1996 by Lee '42 and Geraldine Martin to foster opportunities for multidisciplinary cooperation and team building among MIT's top graduate students in environmental studies. Since 2006, the Martin Foundation has also been providing support for MIT undergraduates, each of whom collaborates with a Martin graduate fellow and a faculty supervisor on a sustainability-related research project.

Photo: Justin Knight

At a poster session preceding the induction dinner, Elizabeth Basha (Martin Fellow 2007–08), right, explains her research to Meredith Silberstein (Martin Fellow 2008–09), left, and Mary C. Boyce, the Gail E. Kendall Professor of Mechanical Engineering and head of the Department of Mechanical Engineering. Basha is designing sensor networks for early-warning flood detection systems for developing countries.

Photo: Justin Knight

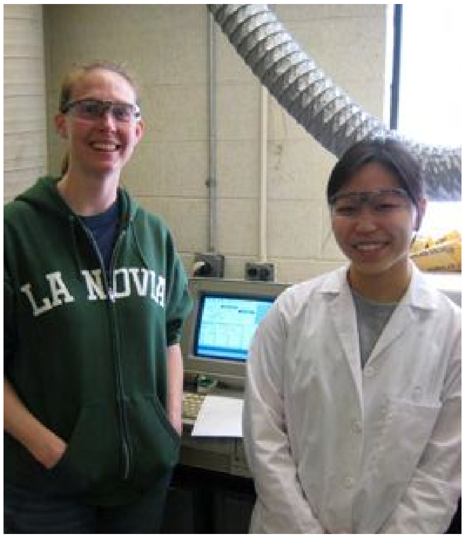
Mrs. Geraldine Martin was guest of honor at the Martin Fellows induction dinner and celebration of the 10th anniversary of the Martin Fellows program, which she and her husband Lee Martin '42 established to foster graduate-level research, education, and collaboration on issues relating to sustainability.

Cyprus Fellows to apply MIT research at home

Photo: Beth Conlin, MITEI

In spring 2008, Jennifer Chao '09, right, received funding from the Martin Foundation to work with Jing Tang, a graduate student in chemical engineering and a Martin Fellow for 2007–08. They were developing a new laboratory technique that can uncoil single DNA into a linear strand and then fix it in a polymer solution for analysis. The technique should help in determining how toxic chemicals damage human health.

Photo: Beth Conlin, MITEI



With support from the Martin Foundation, Maria A. Duaime '09, right, an undergraduate in chemical engineering, worked with current Martin Fellow Sarah Jane White, graduate student in civil and environmental engineering, to characterize the concentrations of the metal gallium in the sediment of the Charles River. The ultimate goal is to determine the environmental impacts of industrially important metals to support sustainable technology development.

The first three Cyprus Fellows at MIT are on a big mission: to conduct research into various aspects of energy, water, and the environment for two years as postdocs, and then to take that knowledge back to Cyprus. There, they will spend another two years as researchers at a new institute that aims to develop graduate-level research opportunities in the Mediterranean island nation and the region and to solve some of its energy and water challenges.

"There is a need in Cyprus for a major research-based science and technology graduate educational and research institution," says Professor David H. Marks, director of MIT's Cyprus Institute Program for Energy, Environment, and Water Resources (CEEW) and the Morton and Claire Goulder Family Professor of Civil and Environmental Engineering and Engineering Systems at MIT. "This new institute is focused on meeting that need. It will build up an MIT-like institution in Cyprus, starting with research and then adding teaching." He said that most Cypriots seeking advanced degrees in science or technology study abroad, mainly in the United States and England. The new institute will give them an alternative for education and a place for doing advanced research.

The three fellows are Cypriots Nick Polydorides and Constantine Hadjistassou, and Canadian Jan Franklin Adamowski, who has a keen interest in Cyprus. The fellows were chosen in part because of their links to Cyprus: all will be motivated to return to Cyprus after the fellowship and continue their research, which can be used to help build a knowledge economy. Cyprus experiences serious shortages of both energy and water and relies heavily on fossil fuels, even for desalinating water. At MIT, the fellows will focus their research on energy and water issues of global significance and special impact on the eastern Mediterranean region.

The Cyprus fellowships resulted from an idea by Professor Ernest J. Moniz, director of the MIT Energy Initiative (MITEI), and his friend and former MIT PhD student Costas Papanicolas, who now is president of the new Cyprus Institute, a private, nonprofit organization focused on science, technology, and management. Through the fellowships, MIT is helping to prepare new faculty for the Cyprus Institute. Up to three Cyprus Fellows could be funded per year, with most of the money coming from the Cyprus Institute.

Cyprus derives about 78 percent of its gross domestic product (GDP) from services such as tourism, financial services, and real estate. When Cyprus joined the European Union (EU) in 2004, it had the lowest research and development expenditure as a percentage of GDP. It remained the lowest in 2006 at 0.40 percent of GDP, well below the EU's overall rate of 1.84 percent, according to Eurostat, the Statistical Office of the European Commission. Cyprus Institute President Papanicolas said last year that the government is committed to turning the Cypriot economy into a knowledge-based economy and to making the island a regional center of excellence for educational services.

"The Cyprus economy is trying to get to the level of the technologically advanced countries of the world," says Cyprus Fellow Polydorides. "Technology education is one aspect to look at, but there should be an equal emphasis on getting industry established. We need to employ people who graduate." Polydorides holds a PhD in electromagnetic inverse problems from the University of Manchester in England.

Photo: Mark Morelli

Constantine Hadjistassou (left) and Nick Polydorides are two of MIT's first postdoctoral Cyprus Fellows. They and a third fellow, Jan Franklin Adamowski, will spend the next two years at MIT performing research relating to energy and water issues of global significance and special impact on the eastern Mediterranean region. All three will subsequently return to Cyprus to continue their research at the new Cyprus Institute.

He is collaborating with MIT's McAfee Professor of Electrical Engineering Dimitri P. Bertsekas on a methodology for large-scale, energy-related computational problems, especially issues relevant to underground carbon sequestration techniques.

Cyprus Fellow Hadjistassou, an MIT graduate (SM '04) who completed a doctorate in engineering science at the University of Oxford in England, is working with MIT Professor Alex Slocum of mechanical engineering on developing new and improving existing concentrated solar energy technologies for harnessing solar energy. The motivation is to generate affordable electricity from the sun that can also be used to power seawater desalination. "I'm looking into areas with high societal impact like solar energy, which has no emissions," Hadjistassou says.

Cyprus Fellow Adamowski, who holds a PhD in environmental engineering from the Warsaw Technical University in Poland in conjunction with the École des Hautes Études Commerciales in Paris, will focus on general issues of water resource management. He is working with Marks and MIT Professors Lawrence E. Susskind and Herman Karl of urban studies and planning on adaptive management of water resources in the Mediterranean Basin, as well as on time series forecasting. "For one project, I am using wavelet analysis and neural networks to develop forecasting models for peak water demand for the city of Nicosia to help optimize the water supply system," he says.

Marks is excited about the synergies that the fellowship already is sparking. "We're tying Cyprus into some work in MITEI funded by industry," he says. "So already the linkages between government and industry are building up there. I think it's on its way to being a real success story."

The CEEW was started last year within MIT's Laboratory for Energy and the Environment. It is a sister program to the Energy, Environment, and Water Research Center (EEWRC) in Cyprus. The EEWRC, which opened in December 2007, is the first research center at the new Cyprus Institute in Nicosia. For information about the Cyprus Institute, go to <www.cyi.ac.cy>.

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Events roundup

Photo: Justin Knight

During a lecture at MIT on April 25, U.S. Senator Jeff Bingaman (D–New Mexico), chairman of the Senate Committee on Energy and Natural Resources, called for immediate government action in response to today's energy challenge. Among his recommendations: adopt consistent tax incentives for renewables and establish a cap-and-trade system to stimulate private-sector development of clean energy technologies.

Photo: Donna Coveney

Massachusetts Governor Deval Patrick told an enthusiastic crowd at Kresge Auditorium on April 22—the 39th anniversary of the first Earth Day—that clean energy has the potential to bring about an economic bonanza for the Commonwealth at the same time that it improves the planet's well-being.

At a colloquium held by MITEI on February 26, Carl O. Bauer, director of the U.S. Department of Energy's National Energy Technology Laboratory, stressed the rapidly growing worldwide demand for energy, especially electricity, and predicted possible shortfalls within the United States.

MITEI Seminar Series, Fall 2008/Spring 2009

September 9, 2008
Profitably reducing greenhouse gas emissions
Thomas R. Casten, Chairman, Recycled Energy Development

October 7, 2008
Energy services for the poor
H. Harish Hande, Co-founder and Managing Director, SELCO-India

November 18, 2008
Zero energy buildings: potentials and realities
Stephen Selkowitz, Department Head, Building Technologies Department, Lawrence Berkeley National Laboratory

December 2, 2008
The sustainable energy challenge
George Crabtree, Materials Science Division, Argonne National Laboratory

February 10, 2009
Recent advances, new trends, and future challenges within the Li-ion battery energy storage system
Jean-Marie Tarascon, Professor, Université de Picardie Jules Verne; Member of the French Academy of Science

March 10, 2009
Sunlight-driven hydrogen formation by membrane-supported photoelectrochemical water splitting
Nate Lewis, George L. Argyros Professor of Chemistry, California Institute of Technology

April 14, 2009
Revising limits in energy conversion using nanostructures
Arun Majumdar, Almy and Agnes Maynard Professor of Mechanical Engineering and Materials Science and Engineering, UC Berkeley; Director, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory

May 5, 2009
Meeting U.S. energy and climate challenges with rational policy
Severin Borenstein, E.T. Grether Professor of Business Administration and Public Policy, Haas School of Business, UC Berkeley; Director of the University of California Energy Institute

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The Tremont Group

On September 22, MITEI members met the first group of Named Energy Fellows at the Inaugural Fall Fellows Symposium in Cambridge. MIT President Susan Hockfield opened the event with an address emphasizing the importance of partnering with industry to advance both energy research and education. More than a dozen MIT faculty members then described research ranging from new developments in building technology, to prospects for solar technologies and biofuels, to the emerging contributions of materials science and engineering to the energy field.

From left, Ford-MIT Energy Fellows Nicholas Martin (Political Science) and Hiram Samel (Sloan School of Management) and Ford Director of Environmental Policy and Special Projects Ronald Westby.

Eni Group Senior Vice President for Strategies and Development Leonardo Maugeri (second from right) with Eni-MIT Energy Fellows (from left) Emiliano Renzi (Civil and Environmental Engineering), Alejandra Quintanilla Terminel (Earth, Atmospheric, and Planetary Sciences), and Ingrid Heilke (Urban Studies and Planning).

Photos: Justin Knight

From left, Executive Director of BP-MIT Conversion Research Program Randall Field, BP Conversion Reactor Modeling Advisor and MIT Campus Champion George Huff, BP-MIT Energy Fellow Neil de Laplante (Earth, Atmospheric, and Planetary Sciences) and (facing away from camera) BP Chief Scientist Steven Koonin.

Ormat-MIT Energy Fellow Andrej Lenert (Mechanical Engineering) and Ormat Chairman of the Board and Chief Technology Officer Lucien Bronicki.

MITei MIT Energy Initiative

Photo: David Chandler, MIT

From left, Olin College student Matt Ritter, inventor Doug Wood, Micah Sze (MBA '08), and Spencer Ahrens (SM '08) assemble their prototype solar dish. Made from a lightweight frame of thin, inexpensive aluminum tubing and strips of mirror, the dish concentrates sunlight by a factor of 1,000—creating heat so intense it can melt a bar of steel. The students and their teammates believe that their new solar dish may be the most cost-efficient solar power system in the world (see story on page 8).

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