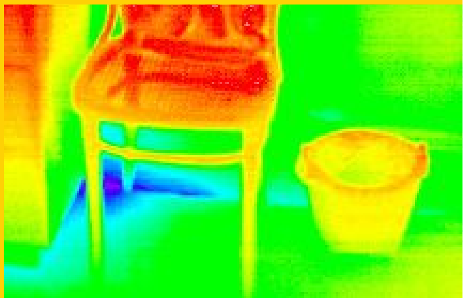
Energy Futures

MIT ENERGY INITIATIVE MIT SPRING 2009

Innovative buildings: Prudent use of energy and materials

IN THIS ISSUE



New tool could aid safe underground storage of carbon dioxide

Nuclear power plants: Shaping new fuels for higher efficiency

Turning waste into clean fuels

Faculty innovation strengthens energy curriculum

MITEI Founding and Sustaining Members

MITEI's Founding and Sustaining members support "flagship" energy research programs or individual research projects that help them meet their strategic energy objectives. They also provide seed funding for early-stage innovative research projects and support named Energy Fellows at MIT. To date, members have made possible more than 40 seed grant projects across the campus as well as fellowships for 40 graduate students in 18 MIT departments and divisions.

Members as of May 1, 2009

FOUNDING MEMBERS

BP Technology Ventures Inc.
Eni S.p.A.

FOUNDING PUBLIC MEMBER

Masdar Institute of Science and Technology

SUSTAINING MEMBERS

ABB Research Ltd.
Robert Bosch GmbH
Chevron U.S.A. Inc.
Enel Produzione SpA
Fundació Barcelona Tecnológica (b_TEC)
Schlumberger
Siemens
Total

SUSTAINING PUBLIC MEMBER

Portuguese Ministry of Science, Technology, and Higher Education

For a list of the MITEI Associate and Affiliate Members, please see the inside back cover.

For information on becoming a MITEI member, please go to: <web.mit.edu/mitei/support/join.html>.

Energy Futures

Energy Futures is published twice yearly by the MIT Energy Initiative. It reports on research results and energy-related activities across the Institute. To subscribe, send your address to stauffer@mit.edu.

Nancy W. Stauffer, editor
stauffer@mit.edu
617.253.3405

ISSN 1942-4671
(Online ISSN 1942-468X)

MIT Energy Initiative
The MIT Energy Initiative is designed to accelerate energy innovation by integrating the Institute's cutting-edge capabilities in science, engineering, management, planning, and policy.

MIT Energy Initiative
Massachusetts Institute of Technology
77 Massachusetts Avenue, E19-307
Cambridge, MA 02139-4307

617.258.8891

web.mit.edu/mitei

Main cover photo: © James Bellamy
Design: Tim Blackburn
Printing: TBD
PSB 09.04.0251

Printed on paper containing 30% post-consumer recycled content, with the balance coming from responsibly managed sources.

Update on the MIT Energy Initiative

Dear Friends,

The work of the MIT Energy Initiative—supporting a large group of faculty, staff, and students engaged in energy-related research and education—has been given additional impetus from a newly energized public dialogue on clean energy and global warming, inspired in part by the high policy priority the Obama Administration has placed on energy security and climate change risk mitigation. Meeting these challenges will require major investments in energy science and technology, informed policy analysis, and the marshaling of talent across the innovation spectrum. All of this is central to the MITEI mission.

Since our last *Energy Futures* newsletter, we have helped bring this important national policy conversation to campus. In October, MITEI and the MIT Energy Club hosted a debate on energy policy between senior advisors to the McCain and Obama campaigns. In April, with the new administration now in place and the congressional debate on climate legislation under way, we hosted a symposium featuring Congressman Edward Markey, chair of the Select Committee on Global Warming; Carol Browner, assistant to the president for energy and climate change; and Dr. John Holdren, science advisor to the president. Forum speakers outlined the tortuous path to reaching domestic and international climate mitigation agreements and engaged MIT students, faculty, MITEI industry partners, the press, and other guests in a robust give-and-take on the policy options for mitigating climate change.

In March, at the Energy Club's annual MIT Energy Conference, Congressman Jay Inslee, an emerging leader of the "green dog" caucus in the U.S. Congress, delivered a keynote speech highlighting the fundamental role new technologies will play in transforming the energy marketplace. At MITEI-hosted symposia, former senior officials such as Secretary of State George Shultz and the first Secretary of Energy, James Schlesinger, provided knowledgeable perspectives on future energy supply, delivery, and use.

Such robust and important policy dialogue was envisioned by MIT President Susan Hockfield in her initial charge to MITEI. It has been gratifying to help facilitate the engagement of the MIT community in this important conversation, as senior policymakers seek to accelerate a clean energy transformation.

As the academic year draws to a close, we are also seeing substantial progress on our core energy research and education missions. The research highlights in this issue of *Energy Futures* focus on innovations for our existing energy systems and infrastructure—carbon dioxide sequestration, nuclear power, and efficient use of buildings and materials. Such innovations are essential for a smooth, affordable, clean transition to a sustainable energy future.

In addition, two more rounds of seed fund awards were issued to researchers across the campus (see page 28). This exciting program supports a range of early-stage innovative research proposals at the same time that it expands the circle of energy-related researchers—nearly half of the awardees are new to energy-related research, and a majority of those funded in the most recent round are junior faculty.

MITEI's Seed Fund Program has supported more than 50 seed fund projects, ignition grants, and planning grants, enabled largely through contributions from MITEI's Founding and Sustaining Members (listed on the inside front cover). But the program has had additional help: the generosity of our alumni and friends has grown this fund such that 30% of the proposals—still fewer than those with very high merit—could gain full or partial support. We expect to see high-impact results from this program over the next several years, providing the foundation for future major MIT energy research efforts.

There are also several exciting developments on the education front. Most of MITEI's first group of Energy Fellows, 40 strong, are finishing their first year of graduate school (a few are at later stages) and are heading for deeper engagement in energy-related research. It has also been an active year for curriculum development, with MIT faculty developing new energy courses that will underpin a proposed novel energy minor program for undergraduates.

All in all, it has been an exciting and productive year in uncertain times. We look forward to hearing from you and to touching base again early in the next academic year.

Sincerely,

Professor Ernest J. Moniz
MITEI Director

Professor Robert C. Armstrong
MITEI Deputy Director

May 2009

Events roundup

Photo: Donna Coveney, MIT

MIT President Susan Hockfield and Rep. Edward Markey (D-Mass.) answer questions from the press after a major MIT forum on April 13. The forum focused on new legislation that aims to spur the development of clean energy and reduce global warming emissions. Other speakers included Dr. John Holdren, President Obama's science advisor; Pulitzer Prize-winning author Dan Yergin; and MITEI Director Ernest Moniz.

Photo: Brian Hammond

Representatives from the two presidential campaigns—R. James Woolsey (left, at podium) for Senator John McCain and Jason Grumet (right, at podium) for then-Senator Barack Obama—face off in a debate on energy policy held at MIT on October 6, 2008. Tom Ashbrook of National Public Radio (third from left) moderated the debate. Also asking questions were (from left) Geoff Carr of *The Economist,* Susan McGinnis of Clean Skies TV, and MIT graduate students Elizabeth McVay Greene, Donald MacKenzie, Curt Fischer, and Christopher Walti. The 90-minute debate was organized by the student-run MIT Energy Club and the MIT Energy Initiative.

Photo: Donna Coveney, MIT

During her keynote address at the April 13 forum, Carol Browner, assistant to the president for energy and climate change in the Obama Administration, stresses that improvements in energy technology often provide great economic opportunities.

Photo: Keith Nordstrom

In a keynote address at the fourth annual student-led MIT Energy Conference on March 7, Rep. Jay Inslee (D-Wash.) says he believes that the clean energy revolution can succeed—and that scientists and engineers rather than politicians will lead the way.

Photo: Donna Coveney, MIT

During a seminar held by MITEI on October 15, 2008, former U.S. Secretary of State George Shultz PhD '49, chair of MITEI's external advisory board, outlines steps that should be taken to reduce U.S. dependence on oil.

New tool could aid safe underground storage of carbon dioxide

To prevent global warming, researchers and policymakers are exploring a variety of options to significantly cut the amount of carbon dioxide (CO_2) that reaches the atmosphere. One possible approach involves capturing greenhouse gases such as CO_2 at the source—an electric power plant, for example—and then injecting them underground.

While theoretically promising, the technique has never been tested in a full-scale commercial demonstration. But now MIT researchers have developed a new mathematical model that can determine how much CO_2 can be sequestered safely in geological formations.

According to the 2007 MIT study, *The Future of Coal*, and other sources, capturing CO_2 at coal-burning power plants and storing it in deep geological basins will mitigate its negative effects on the atmosphere.

However, injecting too much CO_2 could create or enlarge underground faults that may become conduits for CO_2 to travel back up to the atmosphere, says Ruben Juanes, assistant professor of civil and environmental engineering (CEE). "Our model is a simple, effective way to calculate how much CO_2 a basin can store safely. It is the first to look at large scales and take into account the effects of flow dynamics on the stored CO_2," he says.

Juanes and CEE graduate student Michael Szulczewski have applied their model to the Fox Hills Sandstone in the Powder River Basin straddling Montana and Wyoming. They found that the formation would hold around 5 gigatons of CO_2—more than half of all the CO_2 emitted by the United States each year.

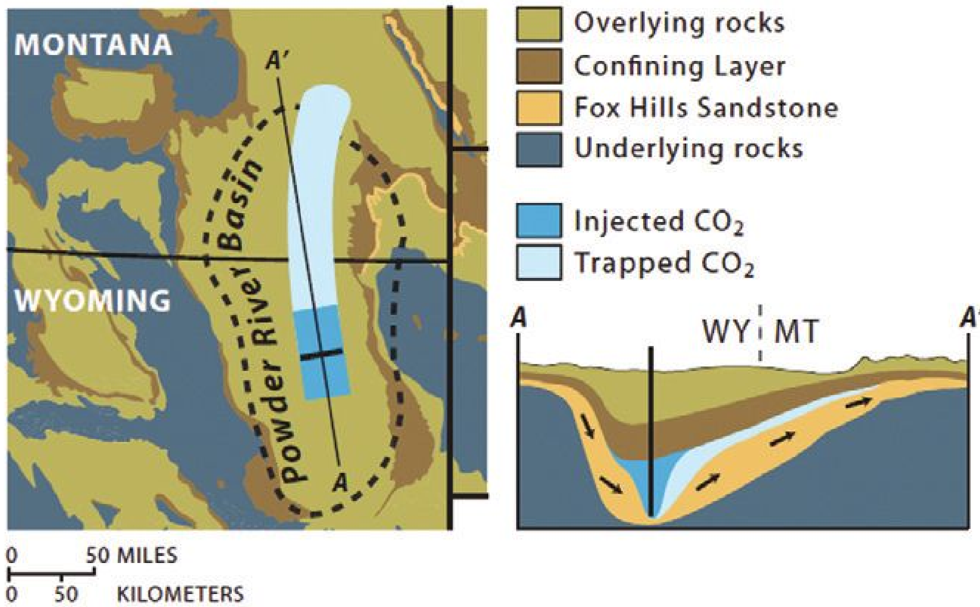


Image: Michael Szulczewski and Ruben Juanes

This schematic illustrates CO_2 sequestration in the Powder River Basin, between the states of Wyoming and Montana. Shown are a plan view (left) and a vertically magnified cross-section of the basin (right). CO_2 is injected from a line-drive array of wells (black line) over decades. The extent of the CO_2 plume at the end of the injection period is shown in dark blue. After injection, the plume continues to migrate in the direction of the regional groundwater flow (indicated by black arrows). During this process, part of the CO_2 is trapped by capillary forces and left behind in the form of immobile blobs. The amount of CO_2 injected into the basin is designed such that the footprint of the plume when all the CO_2 is trapped (light blue) remains within the boundaries of the basin.

A geological basin is a large underground bowl between 100 and 1,000 kilometers wide and 5,000 kilometers deep that has filled over millennia with layers of sand, fine-grained clays, and other sediments that are eventually consolidated into porous rock. Some of the layers contain brine and are called deep saline aquifers. CO_2 would be injected into the aquifers through wells.

The MIT model predicts how much a plume of CO_2 will migrate from its injection well and the path it is likely to take due to underground slopes and groundwater flow.

"A lot of people have done studies at small scales," Szulczewski says. "If we're going to offset emissions, however, we're going to inject a lot of CO_2 into the subsurface. This requires thinking at the basin scale."

"Despite the fact that our model applies at the basin scale, it is very simple. Using only pen and paper, you take geological parameters such as porosity, temperature, and pressure to calculate storage capacity," Szulczewski says. "Other methods suffer from major shortcomings of accuracy, complexity, or scale."

Juanes studies a phenomenon called capillary trapping, through which CO_2, liquefied by the pressure of the Earth, is trapped as small blobs in the briny water (picture bubbles of oil in vinegar). The CO_2 dispersed throughout the basin's structural pores eventually dissolves and may also react with reservoir rocks to precipitate into harmless carbonate minerals.

CO_2 has been sequestered in relatively small projects in Norway, Algeria, and elsewhere. In 2004, 1,600 tons of CO_2 were injected 1,500 meters into high-permeability brine-bearing sandstone of the Frio formation beneath the Gulf Coast of Texas. Current proposals call for injecting billions of tons within the continental United States.

• • •

By Deborah Halber, MITEI correspondent

This research was supported by the McClelland Fund (administered by the MIT Energy Initiative) and by the Reed Research Fund. More information can be found in:

M. Szulczewski and R. Juanes. "A simple but rigorous model for calculating CO_2 storage capacity in deep saline aquifers at the basin scale." In *Proceedings*, 9th International Conference on Greenhouse Gas Control Technologies (GHGT-9), Washington D.C., November 16–20, 2008.

Reprinted with permission from the spring 2009 issue of CEE In Focus, *the alumni newsletter of the MIT Department of Civil and Environmental Engineering.*

Nuclear power plants: Shaping new fuels for higher efficiency

MIT researchers have created innovative designs for nuclear fuels that will allow the cooling water inside a nuclear reactor to extract more heat from the uranium fuel. Their new fuels have channels that increase the exposed hot surface area and bumps that churn up the passing water, ensuring that fresh water is continuously brought to the hot surface, thus increasing the cooling effect. These new designs could boost the amount of energy recovered in the same volume of fuel by 30–50%, while reducing the cost of electricity by as much as 7%.

Nuclear power plants now provide about one-fifth of all the electricity used in the United States. Adding more nuclear plants—or getting more power out of the ones we have—could help us meet growing energy demand without adding to greenhouse gas emissions or oil imports.

At MIT, researchers are looking to improve both current and future plants by changing the design—or "geometry"—of the fuel inside the reactor. "We've had many years with the current geometry, so everyone is comfortable with it," says Mujid S. Kazimi, the TEPCO Professor of Nuclear Engineering, professor of mechanical engineering, and director of MIT's Center for Advanced Nuclear Energy Systems. "But we're now trying to redesign it to benefit the efficiency, the economics, and the safety of nuclear power plants."

The payoff will come from a design that enables the extraction of more power from a given volume of fuel. The benefits for new plants would be significant: for a defined power output, the entire plant could be downsized, leading to enormous cost savings.

But since only a few new plants are likely to come online in the near future, the researchers are also looking to use their more efficient fuel in today's nuclear power plants—and soon. "A lot of our calculations were to confirm that the hydraulic behavior of our new fuel will be close to that of conventional fuel so that we can use them together as we gradually shift existing plants to the new fuel," says Dr. Pavel Hejzlar, who worked with Kazimi on fuel design as a principal research scientist in the Department of Nuclear Science and Engineering until January 2009, when he became reactor design lead at TerraPower, LLC.

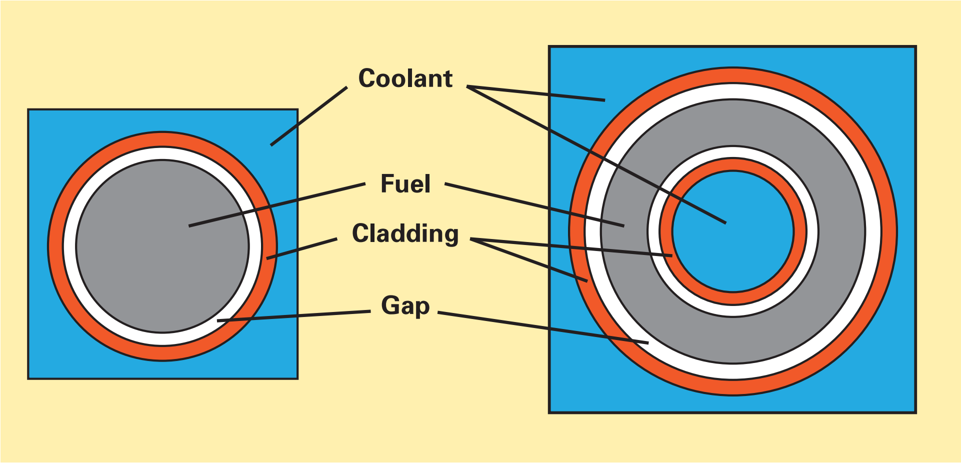
Doughnut-shaped fuel

Roughly two-thirds of the 104 nuclear power plants in the United States are pressurized water reactors (PWRs). In general, PWRs are fueled by metallic rods, or "pins," that are 1 cm in diameter and 4 m long. They are packed with small, hard cylindrical pellets of uranium oxide fuel and are submerged in water inside the reactor. When the reactor runs, fission in the fuel releases huge amounts of heat, which transfers to the water and is subsequently used to make steam for the power-generating turbine.

Most attempts at increasing "power density"—how much energy can be extracted from a given volume of fuel—have involved making the fuel pins smaller to increase the surface-to-volume ratio so that the water can come into contact with more of the hot fuel. But the pins can be only so small before they lose their structural strength.

About five years ago Kazimi, Hejzlar, and their collaborators began work on a novel approach to increasing heat transfer. They designed a fuel that is

New fuel for pressurized water reactors



Cross-sections of a conventional fuel pellet (left) and of MIT's new annular fuel for pressurized water reactors. The conventional fuel is a solid cylinder with a core of uranium fuel encased in protective metal cladding with a small gap in between. The annular fuel is formed into a thick-walled tube with the thin metal cladding on both the outside and inside surfaces. Cooling water surrounds the outside of both types of fuel; but with the annular fuel, it also runs down the center channel, significantly increasing the total amount of heat that can be removed.

annular in shape: instead of being a solid cylinder, each pellet is shaped like a hollow, thick-walled tube, about 1.5 cm tall (see the cross-sections above). To assemble a pin, the annular pellets are stacked up inside a long tube, and then a narrower tube is inserted down the middle. The final product is a fuel pin with an open channel down the center. Inside the reactor, water can flow along the inside wall as well as the outside one. The result: a 50% increase in exposed surface area.

Results of detailed simulations are encouraging. The new fuel should last about as long as conventional fuel does before it needs to be replaced by fresh fuel—but during that time, it will provide 50% more energy.

The new fuel also should improve reactor safety. During hypothetical adverse conditions such as "loss of coolant," the annular fuel should get no hotter than conventional fuel would. Indeed, calculations suggest that the new fuel would operate at a much lower average fuel temperature than a typical solid fuel rod would at the same power output (700°C versus 1300°C) and also at a lower peak fuel temperature (800°C versus 2300°C).

To examine the feasibility and cost of manufacturing the annular fuel pellets, research collaborators at Westinghouse performed test runs in their commercial plant in Columbia, South Carolina. Using commercial fabrication techniques, they were able to manufacture the annular pellets with sufficient dimensional accuracy, little wasted material, and at reasonable cost. They also successfully loaded the pellets into sample 1.2-meter-long pins.

Incorporating the new fuel into today's operating plants should be straightforward. The new pins are larger in diameter than conventional ones are (1.5 cm instead of 1.0 cm). But they can be grouped to form "assemblies" that have the same outside dimensions as assemblies of conventional pins. When a spent assembly in an operating plant needs to be removed, an annular one could be inserted in its place.

However, getting the full benefit of the new fuel in an existing plant would require the installation of larger pumps, different steam generators, and other changes in power-related equipment. Such changes would be costly, so one question is how much extra power could be achieved without large component changes.

The South Koreans are now finding out. They are independently preparing to test MIT's annular design in their existing reactors and are making just one operational change: starting with cooler water at the entrance to the nuclear core, so that a greater temperature increase can occur before the water exits. Their hope is to get a 20% increase in power.

According to the MIT analyses, the effects of using the new fuel—the generation of more energy, the slightly increased manufacturing cost, and the higher cost of the larger pumps, steam generators, and turbines needed to remove 50% more power—should have the net impact of reducing the cost of electricity by 7%.

Twisted fuel

While continuing to develop their annular fuel, the MIT team has also been working on better fuel for the other prevalent type of nuclear plant, the boiling water reactor (BWR). In that design, the water coolant boils inside the reactor core, becomes steam, drives the power-generating turbine, and then condenses and returns to the reactor vessel to go through the cycle again.

To increase heat extraction in a BWR, the researchers designed a novel fuel rod that has a cross-section with four lobes, somewhat like a four-leaf clover. The four-lobed tube is first gently twisted and then filled with matching cross-shaped fuel pellets.

This new design offers several benefits. The cross shape increases the surface-to-volume ratio, and the twisted surface causes the water flowing by to become more turbulent, ensuring that fresh, cool liquid is constantly brought to the hot surface. Also, when gathered into an assembly, the twisted rods touch at intervals, so they support one another without grid spacers—horizontal plates that conventional rods pass through every few feet to keep them stable and separated.

To test their design, the researchers built three sets of 16 rods, each set with a different twist angle, plus a reference set of untwisted rods (see photo at right). They then developed a facility in which they could test water flows through the assemblies under conditions similar to those inside a BWR.

As expected, they found that their assemblies had significantly less resistance to flow than conventional assemblies do, largely due to the absence of the grid spacers. As a result, less power is required to pump the water through. In addition, the open channel ensures that the water and steam can circulate freely around the rods—a critical feature in BWR operation. The increased turbulence also prevents the formation of hot spots on the fuel rods.

According to computer simulations, the combined effects of the new fuel should allow BWRs to operate at 20–25% higher power density. Moreover, during normal operation, the highest centerline temperature of the new fuel should be about 960°C—some 225°C lower than that of a standard cylindrical fuel rod—adding to the ability of the materials to tolerate the effects of sudden changes in operating conditions.

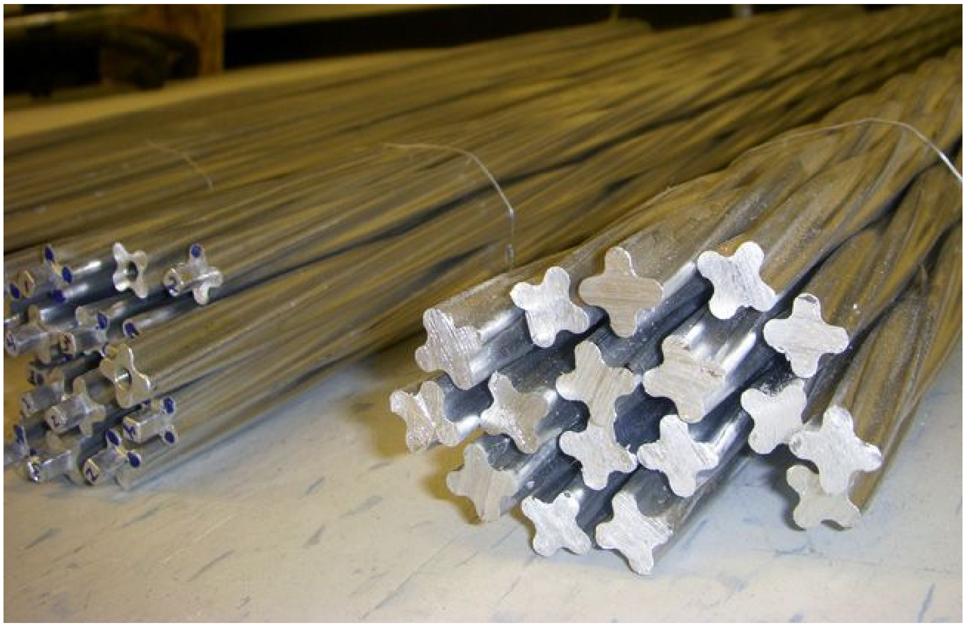


Photo: Thomas Conboy, MIT

Experimental samples of MIT's new fuel for BWRs. In this design, each fuel rod has a cross-section with four lobes and is twisted. The lobes are designed to increase the fuel's hot surface area where the cooling water can extract heat. The twisting causes the passing water to be turbulent, which increases the efficiency of heat transfer through more intensive mixing.

The researchers are continuing to work on both their PWR and BWR fuels. Results to date suggest that the new fuels may provide a means of significantly expanding power generation from today's well-proved nuclear plant technologies while next-generation reactor designs are being developed and demonstrated.

• • •

By Nancy Stauffer, MITEI

This research was supported by the U.S. Department of Energy and Tokyo Electric Power Company. Further information can be found in:

M. Kazimi et al. *Core Design Options for High Power Density BWRs*. MIT Center for Advanced Nuclear Energy Systems report no. MIT-NFC-PR-102, November 2008.

M. Kazimi, P. Hejzlar, et al. *High Performance Fuel Design for Next Generation PWRs: Final Report*. MIT Center for Advanced Nuclear Energy Systems report no. MIT-NFC-PR-082, January 2006.

Nuclear Technology: Annular Fuel Special Issue, v. 160, no. 1, October 2007.

Battery material for rapid recharging of devices

MIT engineers have created a kind of beltway that allows for the rapid transit of electrical energy through a well-known battery material. This advance could usher in smaller, lighter batteries—for cell phones and other devices—that could recharge in seconds rather than hours.

The work could also allow for the quick recharging of batteries in electric cars, although that particular application would be limited by the amount of power available to a homeowner through the electric grid.

The work, led by Gerbrand Ceder, the Richard P. Simmons Professor of Materials Science and Engineering, is reported in the March 12, 2009, issue of *Nature*. Because the material involved is not new—the researchers have simply changed the way they make it—Ceder believes the work could make it into the marketplace within two to three years.

State-of-the-art lithium rechargeable batteries have very high energy densities—they are good at storing large amounts of charge. The tradeoff is that they have relatively slow power rates—they are sluggish at gaining and discharging that energy. Consider current batteries for electric cars. "They have a lot of energy, so you can drive at 55 mph for a long time, but the power is low. You can't accelerate quickly," says Ceder.

Why the slow power rates? Traditionally, scientists have thought that the lithium ions responsible, along with electrons, for carrying charge across the battery simply move too slowly through the material.

About five years ago, however, Ceder and colleagues made a surprising discovery. Computer calculations of a well-known battery material, lithium iron phosphate, predicted that the material's lithium ions should actually be moving extremely quickly.

"If transport of the lithium ions was so fast, something else had to be the problem," says Ceder.

Further calculations showed that lithium ions can indeed move very quickly into the material but only through tunnels accessed from the surface. If a lithium ion at the surface is directly in front of a tunnel entrance, there is no problem: it proceeds efficiently into the tunnel. But if the lithium ion is not directly in front, it is prevented from reaching the tunnel entrance because it cannot move to access that entrance.

Ceder and Byoungwoo Kang, a graduate student in materials science and engineering and coauthor of the *Nature* paper, devised a way around the problem by creating a new surface structure that allows the lithium ions to move quickly around the outside of the material, much like a beltway around a city. When an ion traveling along this beltway reaches a tunnel, it is instantly diverted into it.

Using their new processing technique, the two went on to make a small battery that could be fully charged or discharged in 10 to 20 seconds (it takes six minutes to fully charge or discharge a cell made from the unprocessed material).

Ceder notes that further tests showed that unlike other battery materials, the new material does not degrade as much when repeatedly charged and recharged. This could lead to smaller, lighter batteries because less material is needed for the same result.

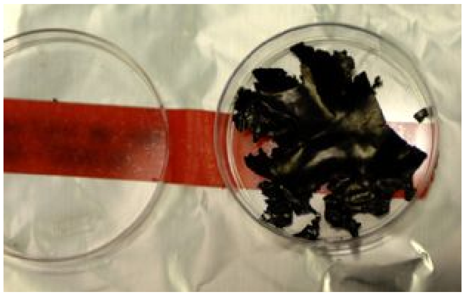


Photo: Donna Coveney, MIT

A sample of the new battery material that could allow quick charging of portable devices.

"The ability to charge and discharge batteries in a matter of seconds rather than hours may open up new technological applications and induce lifestyle changes," Ceder and Kang conclude in their *Nature* paper.

• • •

By Elizabeth A. Thomson, MIT News Office

This work was supported by the National Science Foundation through the Materials Research Science and Engineering Centers program and the Batteries for Advanced Transportation Program of the U.S. Department of Energy. It has been licensed by two companies. More information can be found in:

B. Kang and G. Ceder. "Battery materials for ultrafast charging and discharging." *Nature*, v. 458, pp. 190–193 (12 March 2009), doi:10.1038/nature07853.

Innovative buildings: Prudent use of energy and materials

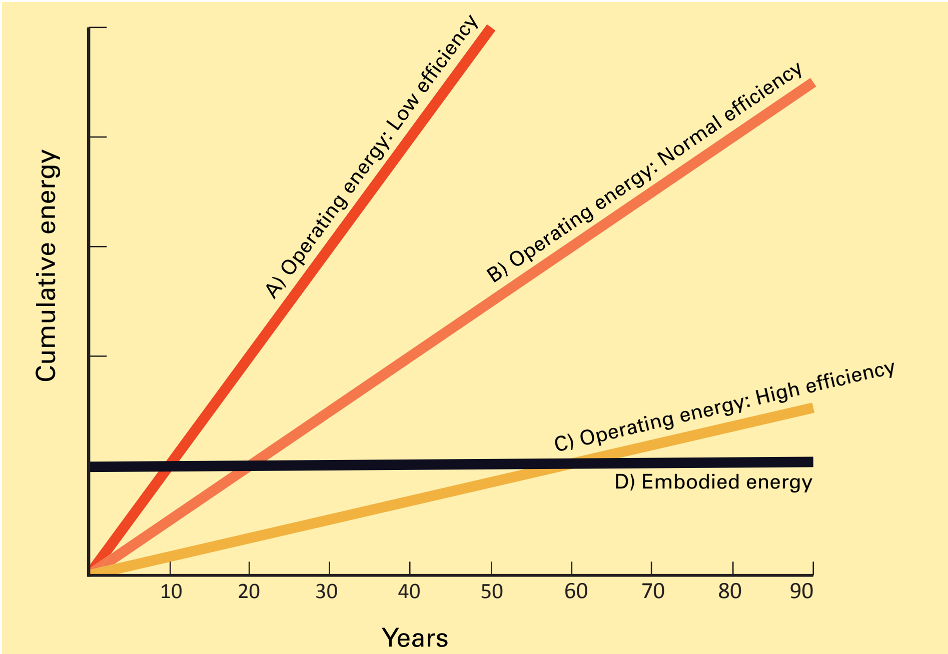
MIT researchers and their collaborators from South Africa and England have demonstrated that it is possible to create elegant, energy-efficient buildings with little energy consumption and essentially no energy-intensive materials.

Their project, located in rural South Africa, used local workers, local materials (mostly soil), a 600-year-old vaulting technology, and a quarter of the energy usually used in materials and in the construction process. The striking new building—which requires almost no energy to run—is a model for sustainable construction worldwide.

As the world struggles to reduce energy consumption and greenhouse gas (GHG) emissions, much attention is focusing on making buildings—both existing and new—operate more efficiently. But John Ochsendorf, associate professor of building technology, thinks mostly about another, less-recognized aspect of the built environment: the "embodied energy" of buildings, that is, the energy consumed in construction, including the entire life cycle of the materials used, from the extraction of raw materials to the manufacture, transportation, and installation of products at the building site.

Most people assume that the embodied energy of a building is small compared to the energy used in operating it over its lifetime. "Conventional wisdom says that the operating energy is far more important than the embodied energy because buildings have a long life—maybe a hundred years," says Ochsendorf. "But we have office buildings in Boston that are torn down after only 20 years." While others may view buildings as essentially permanent, he views them as "waste in transit."

Energy use in buildings: The changing relationship between embodied and operating energy consumption over time



In this illustration, lines A through C show cumulative operating energy in houses with differing energy efficiencies. Line A shows the high energy use of an inefficient house; line C shows the low energy use of an extremely efficient house. Line D shows embodied energy, that is, the energy used in construction and materials. (This simple example excludes future refurbishments and renovations, which would cause cumulative embodied energy to increase slightly over time.) The message: embodied energy can be an important contributor to energy use in the built environment, especially when buildings are torn down after just a few decades or when buildings are extremely energy efficient.

The illustrative graph above conveys his point. The lines labeled A through C show cumulative energy consumption over almost a century assuming varying levels of operating efficiency. Line D is embodied energy. (In reality, embodied energy would rise slightly over time due to refurbishments and renovations.)

Assuming normal operating efficiency (line B), the amount of energy needed to build the house equals the amount used in operating it for about 20 years. In other words, if the house lasts 20 years, the total energy consumed is half from building it and half from operating it. At 40 years, one-third of its lifetime energy goes to building it, two-thirds to operating it. And so on.

A comparison of lines A, B, and C shows that as buildings become more efficient and the energy needed to operate them drops, the embodied energy becomes relatively more important. Line C shows the extreme: a highly efficient house with very low cumulative operating energy. In this case, the embodied energy will be several times the cumulative operating energy for the first 20 years. Indeed, it will be 60 years before the operating energy equals the embodied energy.

Photos: James Bellamy

At the new Mapungubwe National Park Interpretive Centre in South Africa, local workers assemble tiles they have made by compacting soil, a small amount of cement, and water into a form. The building's design uses a 600-year-old vaulting technology with a geometry specially defined to produce a thin, safe shell using the low-strength mud tiles. A model for sustainable construction, the project uses local workers, local materials, little energy, and essentially no energy-intensive materials.

Several construction industry conventions contribute to high embodied energy. Architects and structural engineers are typically taught to design with steel and reinforced concrete—materials that are energy intensive and have high associated carbon dioxide (CO_2) emissions. Currently, about 7% of anthropogenic CO_2 emissions is attributed to the production of cement, the primary ingredient in concrete. And the escalating consumption of cement and steel raises concerns about resource use as well as energy and emissions.

Another problem is the conventional design process in which experts in different disciplines work one after another on a given project. In such a process, designers may make energy-inefficient decisions early on, and then engineers try to improve things by making minor changes afterwards. "It's like having a Hummer and putting solar panels on it or inflating the tires to improve its gasoline consumption," says Ochsendorf. "Every bit helps, but the original design is poor."

A better approach is to have architects, engineers, clients, and others work together from the beginning to come up with a good design—a "whole life" design that takes account of construction, use, and demolition. Materials with high embodied energy can be used, but only when they offer special advantages. Aluminum, for example, has high embodied energy; but if it performs well, does not corrode, lasts for a long time, and can be salvaged and recycled during demolition, then it can be a good choice for certain applications.

A truly sustainable design should aim for what Ochsendorf and others call the triple bottom line: it should make sense economically, environmentally, and socially. Thus, it should cost less; it should minimize carbon emissions, energy use, and resource consumption; and it should fit into and support the local community.

In Ochsendorf's view, those constraints need not stifle creativity; rather, they can create an opportunity for innovative thinking and for finding novel answers and solutions.

Innovative design for the developing world

As an illustration of innovative thinking under extreme constraints, Ochsendorf describes a project in which he and his students have been involved: the construction of the Mapungubwe National Park Interpretive Centre in a World Heritage Site in South Africa.

Many developing nations want modern glass-and-steel buildings designed and built by teams imported from other parts of the world. In contrast, the South African National Park Service—the sponsor of the Mapungubwe project—called for its new interpretive centre to be built by local people using local materials, with minimal environmental impact and low electricity demand. Ancillary benefits should be reducing poverty in the area and empowering the local people with new skills and experience.

In collaboration with colleagues at Cambridge University, England, and architects and engineers in South Africa, Ochsendorf and his students took on the challenge. The team designed and built an innovative building that not only meets the demands of the South African government but also recently won an award from the Holcim Foundation for Sustainable Construction in the region of Africa and the Middle East.

Their project combines a well-known, "humble" material—soil—with a structural system based on historical technology.

Key to their design are bricks, or tiles, made from soil and a little cement (about 5% by mass). The tiles are made by local workers who put the soil-cement mixture plus water into a form and compact it using a long

lever arm. The result: handmade tiles consisting mostly of mud.

For the building's design, Ochsendorf brought to bear his other research specialty: the study of historical design and traditional building methods. He and his colleagues turned to a 600-year-old Mediterranean technique called "tile vaulting," a construction system that uses thin bricks to create lightweight and durable buildings.

But instead of using fired clay bricks (which require a lot of energy for baking), they chose to make the vaults out of the mud tiles, which are relatively weak. If the form of the vaults is not structurally optimal, the weak mud bricks would not be able to support the weight of the building.

So they used new MIT software to define a vault geometry that could produce a thin, safe shell using their low-strength tiles. The final design consists of several vaults and domes, including a vault with a maximum span of 60 feet, using thin shells of mud brick only 4 inches thick. The structure requires no steel reinforcement, which simplifies construction, lowers cost, and reduces the embodied energy—by fully 75% compared to a conventional building.

In addition to the tile vaults, the new centre—scheduled for completion this fall—has sandstone floors, earth block walls, and exterior stone cladding. The design maximizes natural light and natural ventilation, and the high thermal mass of the structure passively cools the space during the day and radiates accumulated heat at night. As a result, little operating energy is required.

The building is structurally sound, elegantly simple, environmentally sustainable, and aesthetically pleasing, blending naturally into the surrounding landscape. "Trying to radically save energy and materials and to minimize environmental impacts may mean challenging some of our assumptions about what we think buildings should look like," says Ochsendorf. "But I do think the new museum is beautiful."

The way forward

Ochsendorf believes that a critical step toward sustainable building is to establish new metrics for the industry. Instead of cost per square foot (or meter), architects, builders, clients, and the public must learn to think in energy consumption—or better still, GHG emissions—per square foot. "Think about the fluency the American public has about the miles per gallon of cars," he says. "They understand that if you get 15 mpg, you've got a guzzler, and if you get 50 mpg, it's great. We need an equivalent metric for buildings that the public understands."

His goals for his MIT students? To be the first generation of designers to internalize those metrics into their design process and to be able to talk comfortably about the energy and emissions associated with constructing and operating their buildings.

• • •

By Nancy Stauffer, MITEI

This work was supported by the International Masonry Institute and the Cambridge-MIT Institute. Further information can be found at the following website: web.mit.edu/masonry.

Cutting energy use in commercial buildings

A new MIT analytical system can help operators of large commercial buildings dramatically reduce both energy use and costs by informing them when, for example, a specific boiler or air handler is beginning to malfunction or when heaters and air conditioners are running at the same time—a surprisingly common occurrence that goes unnoticed because occupants are not uncomfortable.

In tests on one MIT building, the system examined thousands of measurements gathered by the building's controls and identified both low-cost and no-cost changes that should reduce the building's electricity consumption by fully 30%.

Much focus is now on developing solar cells, windmills, and other options for displacing traditional sources of energy. But in the near term, major savings can come from increasing the efficiency with which we use energy—and a good place to look is in the commercial buildings sector. Nearly 20% of all U.S. energy consumption is used by that sector, half of it in 250,000 large commercial buildings—buildings that are also responsible for about 12% of the nation's total greenhouse gas emissions.

The opportunity for savings is huge. "Experts agree that we should be able to reduce energy consumption in commercial buildings by 20–30% just by making sure that things still work as they did when they were installed and by implementing a handful of energy-efficiency strategies—in many cases with little or no investment," says Stephen Samouhos, a Hertz Fellow and graduate student in the Department of Mechanical Engineering. Moreover, many large buildings continuously generate evidence of their problems. Automated systems control heating, ventilating, and air conditioning (HVAC) operations based on detailed data on temperatures, pressures, airflows, and so on; and those data can contain signs of drifting system performance, machine degradation, and other clues that something has gone wrong or could go better.

But the quantity of data is overwhelming. On the MIT campus, for example, hundreds of thousands of data points are collected every 15 minutes from the automatic systems that control HVAC equipment in about 150 campus buildings. "We just don't have the resources to monitor all that information to see which fans aren't operating correctly or which chillers are going down," says Leon Glicksman, professor of building technology and mechanical engineering, one of Samouhos's advisors, and co-chair of the MIT Energy Initiative's Campus Energy Task Force. "If we could, we might be able to make major reductions in our energy use in buildings, which makes up 70% of MIT's total energy consumption."

To that end, Samouhos set out to create a system that could parse through the huge volume of available data, find the bits and pieces of interest, and provide them in manageable form to human experts who can take action. One approach that previous scientists have taken is to create what Samouhos calls an "engineer in a box," a detailed system that will figure out not just that a fan is misbehaving but also exactly which belt on that fan needs to be repaired.

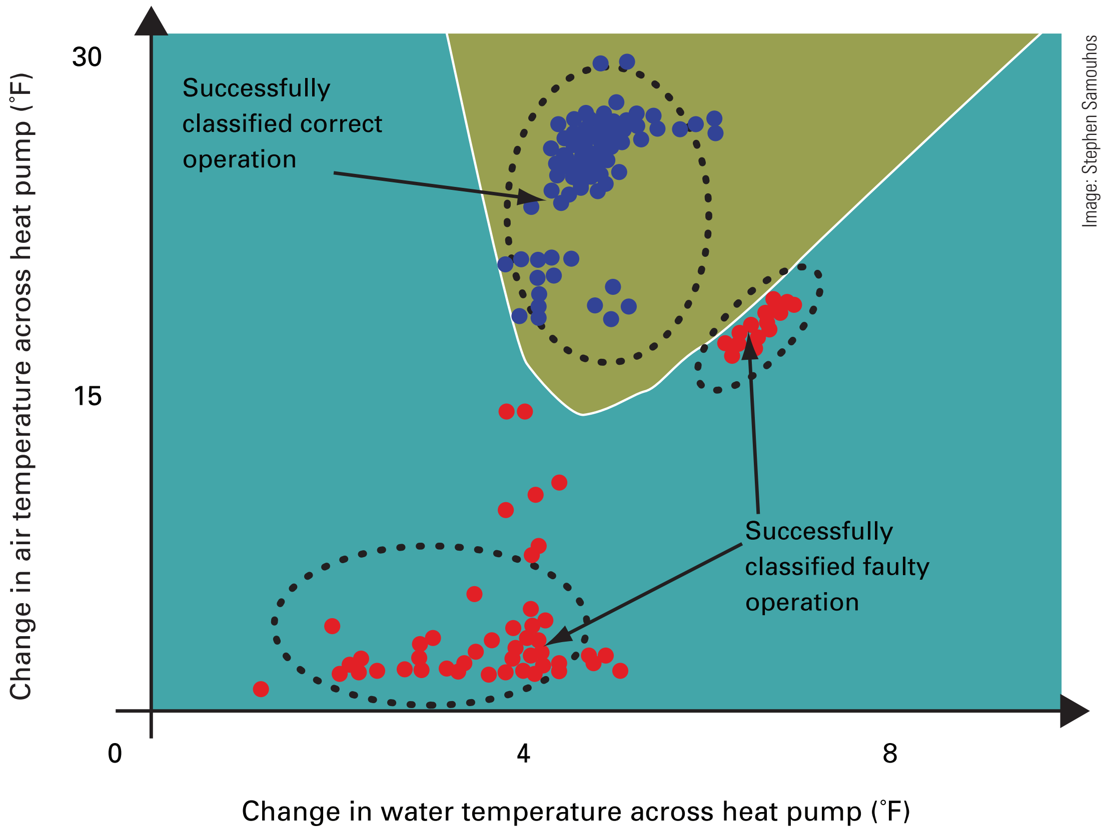
"But I don't need to replace the human expert," says Samouhos, who grew up in a "construction family" and has worked on buildings his whole life, including during his nine years on the MIT campus. "Contractors and facilities engineers are very good at their jobs. They just need to know that something is not right on the fan. So we keep our system simple, which makes it usable on many types of equipment, both small and large. The over-complexity of prior approaches is partially to blame for why we don't see such things in use today."

Samouhos began his project using "neural networks," a common approach to data analysis based on artificial intelligence (AI). A neural network can be "trained" based on an initial data set; it can then analyze a second data set and identify any changes from the first. While Samouhos's neural networks could detect operational changes over time, he found that developing the networks—a process based largely on trial and error—did not produce consistent results and became increasingly difficult as the data sets got bigger.

So he recently switched to "support vector machines" (SVMs), another AI technique that is more mathematically rigorous and can be better designed and tuned to do a particular task. SVMs are now used for handwriting and facial recognition and other tasks that involve classifying and comparing data in huge data sets—just what Samouhos needed to do with the buildings data.

Key to the operation of an SVM are multidimensional graphs that can represent multiple characteristics of a piece of equipment as a single point. To monitor a geothermal heat pump, for example, the SVM would receive measurements of electricity consumption plus the temperature and flow rate of air entering and leaving the device. In its training phase, it would learn what the relationships among those measurements can be, establish-

Heat pump performance classifier



This figure is a simplified demonstration of a new MIT tool that monitors the performance of HVAC equipment. The data points are measurements of water and air temperatures taken in a residential geothermal heat pump over the course of a month. The tool uses artificial intelligence techniques to learn to classify those operating points as representing correct or faulty heat pump operation. Based on the data, the tool draws a demarcation line (shown in white) so that measurements taken after its learning period can immediately be classified as indicating correct or incorrect heat pump operation.

ing a baseline for the heat pump's performance. It would then perform the same analysis with data taken the following month and compare the outcome with the established baseline, identifying any shift that has occurred. The figure above shows a simplified example of establishing a baseline using actual measurements taken in a residential geothermal heat pump over the course of a month.

Of course, if a device—or a building—has strayed from its original specifications, such a baseline will not reflect optimal operation. Samouhos therefore developed "if/then" logic rules that search the baseline data for five common problems: HVAC systems running unnecessarily, lights left on unnecessarily, competing cooling and heating systems, leaky ducts, and imbalanced airflow (when one space overheats while others remain cold).

Whether used on individual devices or an entire building, Samouhos's new methods produce quantitative results. For an individual device, the findings include the statistical significance of the change in operation, thus whether it warrants attention. For a whole building, the results include rough estimates of the potential energy savings—information of great value to entities such as the MIT Department of Facilities, which owns and operates many buildings. "Facilities knows that lots of problems and opportunities exist, but with so many buildings it's difficult to know where to start," says Glicksman. "In which building would retrofits and other investments give us the greatest gains?"

Case studies

Early tests of Samouhos's system took place on MIT buildings—in keeping with the MITEI goal of using the campus as a "learning laboratory." One study focused on N42, the building that houses MIT's Information Services and Technology Office. Working closely with MIT Facilities and occupants of the building, Samouhos installed instruments to collect data, then used his system to analyze the thousands of data points that were gathered.

The most significant—and surprising—finding was that the building's HVAC systems turned on at 4:00 a.m., even though nobody was in the building until 8:30 or 9:00 a.m. Since no one was present to observe the unnecessary space conditioning, the building operators remained unaware of it. Given the ventilation rates for the building, that unnecessary heating and cooling increased the building's total energy bill by about 5%. Samouhos's study also showed that lights in the building—on all three floors—were left on all the time. Rescheduling the HVAC (by simply unchecking one box in the building's control system) and putting occupancy sensors on the lights together should save 30% of the total electric bill.

An off-campus test demonstrated that even with all the latest energy-saving equipment and the best intentions, getting everything right can be difficult. The tests took place in a new Cape Cod home that incorporated solar panels, geothermal heat pumps, and other measures intended to make it a zero-energy building. Even so, the owners got a one-month electricity bill of $500.

Samouhos's analysis showed that the geothermal heat pumps were running around the clock every day, even though the owners were only there on weekends. Moreover, the automatic controls were turning on the heat pumps as air conditioners and then 10 minutes later reversing them so they generated heat. Simple changes in programming fixed both problems.

Expanded monitoring

In other work, Samouhos collaborates on developing new methods of gathering data in smaller commercial buildings that have no means of generating measurements. (Some four million such buildings are spread across the United States.) He works with Professor Neil Gershenfeld, director of MIT's Center for Bits and Atoms, on a novel system called Internet 0. This low-cost, easy-to-deploy instrumentation package can be placed on HVAC and other devices to give them IP addresses, making each one into a little web server that sends a stream of information directly onto the web in real time. The research team is now testing Internet 0 at a number of locations at MIT and elsewhere.

Photo: Tim Blackburn

In early tests, the researchers used their new analytical system on data they gathered in MIT's building N42 (above). Results of the analysis pointed to low- and no-cost changes that should reduce the building's electricity consumption by 30%.

Technologies similar to Internet 0 are being deployed for electrical metering that supports the growing "smart grid" across the United States. When integrated with the smart grid, Internet 0 and Samouhos's methods will enable a new smart grid that not only turns off electrical equipment during periods of high demand but also works year-round to identify opportunities for increasing the energy efficiency of buildings.

According to Samouhos, the combination of new methods for collecting and analyzing building data will enable dramatic changes in the building industry. "We can provide a data-driven third party that identifies, quantifies, and communicates efficiency opportunities," he says. "With this new information, building owners, managers, engineers, and contractors can all collaborate to develop objective and targeted strategies for fixing buildings."

• • •

By Nancy Stauffer, MITEI

This research was supported by the Hertz Foundation, the MIT Department of Facilities, MIT Information Services and Technology, and Schneider Electric-TAC. Publications are forthcoming.

Turning waste into clean fuels: Commercial devices rooted in fusion research

An MIT researcher and his colleagues have developed a system that can make liquid fuels from an abundant, familiar, and troublesome source: trash.

The system can convert municipal and nonhazardous industrial waste into valuable products including ethanol, methanol, and synthetic diesel at an affordable cost, in part because the starting materials come at a negative cost: people pay to have them taken away.

"In the ideal case, if we processed all U.S. municipal and industrial waste this way, we could produce up to 50 billion gallons of alcohol fuel, which is equivalent in energy to around a fifth of the gasoline used in this country," says Daniel R. Cohn, senior research scientist at the MIT Plasma Science and Fusion Center and the MIT Energy Initiative. "At the same time, we'd reduce the amount of material in landfills, which are now a major source of methane, a very potent greenhouse gas."

The work is a striking demonstration of how basic research on a long-term technology—nuclear fusion—can lead to commercial products with significant near-term impacts, in this case, protecting the environment and reducing U.S. dependence on foreign oil.

Thinking outside the box

In the late 1980s, Cohn and his collaborators were working to understand the behavior of plasmas, ionized gases that play a key role in fusion energy devices. The goal of fusion research is to harness the same energy—nuclear fusion—that powers the sun to serve as a sustainable power source on Earth, and a key challenge is finding a way to contain the hot, dense plasma long enough for fusion reactions to occur.

Plasmas also form at lower temperatures, for example, when lightning cuts through the air, breaking apart molecules in its path into a mixture of free electrons and positive ions. Sometimes called the fourth state of matter, plasmas have characteristics that are not seen in ordinary gases, and they have become a valuable tool in materials processing.

Recognizing that practical fusion energy was still well in the future, the research team began to think about nearer-term applications for plasma technology. "We decided that the environmental area was in need of new approaches and that plasma technology could make a real difference," says Cohn. "In particular, it seemed well suited to waste disposal because it can simply disintegrate or vaporize even the nastiest of materials."

Their first target for destruction was "mixed waste," a combination of chemical and nuclear waste that the U.S. Department of Energy (DOE) must dispose of. Taking advantage of the huge space and high power supply available at the MIT Plasma Science and Fusion Center, Cohn and his collaborators—including a group from the Battelle Pacific Northwest National Laboratory (PNNL) led by Jeffrey Surma—designed and built a large-scale plasma furnace in that MIT facility. They then demonstrated its ability to deal with simulated waste, specifically, hazardous chemicals mixed with dirt and metals (which stood in for the radioactive component in nuclear waste). Later PNNL tests in an actual radioactive environment were successful. Those tests were carried out at the PNNL facility in Richland, Washington, near the DOE Hanford site.

Cohn and his colleagues next thought about using plasma technology for a wider range of waste materials and finding ways to make it more effective. They came up with the idea of adding a second stage to the plasma furnace. This second stage—a "joule-heated melter"—is a technology that had been developed at PNNL and used by DOE to isolate the most hazardous radioactive components of nuclear waste. Key to the melter is a molten glass bath, kept hot by a current passing between two submerged electrodes. Inorganic material from the hazardous waste is incorporated into the glass bath. When the glass is removed and cooled, it traps the waste within its solid matrix.

In 1995, Cohn, Surma, and two other partners founded a company called InEnTec to commercialize the two-stage device, the Plasma-Enhanced Melter, or PEM. Small demonstration and commercial units were installed in the United States, Japan, and Taiwan. These units achieved a high degree of waste destruction, converting the waste into a valuable hydrogen-rich gas while surpassing environmental regulatory requirements.

In fall 2008, InEnTec and Dow Corning Corporation announced an agreement under which a larger PEM unit would be built at the Dow Corning facility in Midland, Michigan. The unit would process chemical hazardous waste and produce valuable products that could be reused within the plant. "None of this chemical waste needs to be shipped out of the plant," says Cohn. "The concept is a sustainable process whereby the chemical industry uses the waste it produces."

The Dow Corning unit is now being constructed and will be operated by InEnTec Chemical, a joint venture

Liquid fuels from municipal waste using plasma-melter gasification

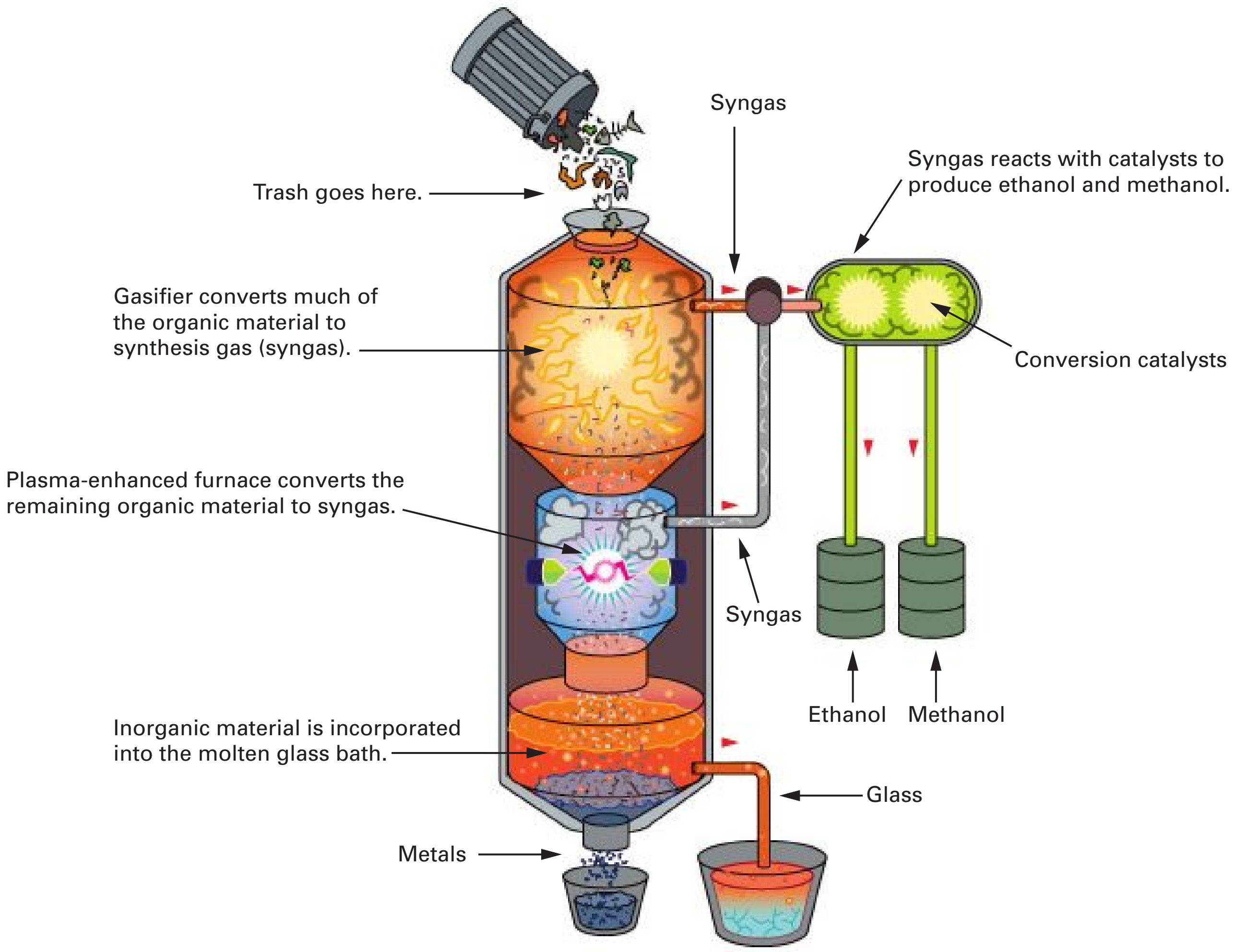


Illustration: © Jeffrey West Design. www.jwestdesign.com

between InEnTec and Lakeside Energy LLC. It is the first in a series of units that InEnTec plans to build for the chemical industry using a project financing fund of up to $150 million provided by Lakeside Energy.

Converting trash to liquid fuels for cars and trucks

About two years ago, InEnTec began to set its sights on municipal waste, a feedstock with several advantages. It is available in huge quantities just about everywhere; people pay to have it taken away; and—best of all—it is rich in biomaterials, so it should be ideal for producing fuels, in particular, liquid fuels needed for transportation.

Cohn notes that turning garbage into energy is not a new idea. "But present technology involves incineration, which burns the waste, generates hard-to-handle toxic pollutants such as dioxin, produces potentially hazardous ash—and in the end generates heat, which is then used to raise steam to run a power-generating turbine," he says. "Our system uses plasma-enhanced gasification, which converts the waste directly into clean fuel and essentially eliminates the production of dioxin and ash." Added environmental benefits come from diverting material from landfills, which can contaminate soil and groundwater and—as materials decompose—generate huge amounts of methane, a greenhouse gas that is 20 times more potent than carbon dioxide.

To optimize their system for destroying municipal waste, engineers at InEnTec added one more stage to their setup: a conventional gasifier that acts as a preprocessor. This simple, inexpensive technology handles the abundant easy-to-treat part of the waste, leaving just the difficult-to-treat parts to move on to the next stages.

The figure to the left shows the three-stage system. Trash is shredded into pieces about six inches long and dumped into the gasifier at the top. There, the material is heated and mixed with just enough oxygen to cause chemical reactions but not enough to burn the waste as in an incinerator. Much of the organic content (waste made of hydrogen and carbon) reacts to produce a combination of hydrogen and carbon monoxide called synthesis gas, or syngas. The syngas is sent to a catalytic system that converts it to ethanol and methanol or other liquid fuels or chemicals.

The inorganic material and remaining organics—now in the form of char—enter the second stage, the plasma furnace, where they are subjected to the electric arc that turns them into high-temperature plasmas. The remaining organics are converted to syngas, which is sent to the catalysts.

The inorganic waste drops into the molten glass bath in the joule-heated melter. When the glass is removed and cooled, it traps the inorganics, forming a material that can be safely landfilled (without decomposing or leaching) or used as construction material or sandblasting grit. Metals in the molten mix that are not incorporated into the glass separate from the bath and drop to the bottom, where they are removed and—depending on their composition—are recycled or safely discarded.

InEnTec has built a demonstration unit—one-fifth commercial scale—of the waste conversion system that uses municipal waste diverted from a landfill in Richland, Washington (see the photo at the right). The unit has processed 12 tons per day of Richland's municipal waste, with a goal of 25 tons per day.

Cohn believes that their "plasma-melter gasification system" could provide the first significant non-corn-based renewable fuel replacement for liquid fuels. "Because it uses known technologies, it's likely to come ahead of cellulosic ethanol, which requires more biochemistry research to develop an economically viable process," he says. And the price is right. Given the negative cost of the feedstock, the system should produce alcohol fuels for less than $1.00 per gallon, which translates into the energy equivalent of less than $2.00 per gallon of gasoline.

Finally, the quantities involved are substantial, potentially replacing up to 20% of all the gasoline used in the United States. "That's a lot of fuel that doesn't come from food or from oil—and it's a lot of money that doesn't go overseas," says Cohn. "It looks like the MIT fusion program has spun off one of the most promising near-term technologies for replacing gasoline and reducing greenhouse gas emissions at the same time."

• • •

By Nancy Stauffer, MITEI

Research on the plasma furnace at the MIT Plasma Science and Fusion Center was supported by the U.S. Department of Energy.

Photo: courtesy of InEnTec

InEnTec's demonstration unit for converting up to 25 tons per day of municipal waste into syngas. The unit is located in Richland, Washington. Shredded waste is transported to the top through the diagonal white pipe at the upper left and is then processed in the various stages of the unit.

Documenting energy-wasting blues in Technicolor®

The images look like something out of a color-shifting alternate universe, or maybe an Andy Warhol print. They help residents and homeowners save energy.

Using a thermal video camera owned by the MIT Department of Civil and Environmental Engineering (CEE) and a still camera from MIT's Environment, Health, and Safety Office, Laura E. Mar and two other MIT graduate students taking Design for Sustainability (1.819) last semester did a case study of heat loss from a 100-year-old clapboard duplex in Somerville, Massachusetts.

The project, launched when Mar learned about thermal energy audits at the October 14, 2008, MIT Generator event, ended up as a serendipitous collaboration between MIT students and the Cambridge Energy Alliance (CEA). The project could lead to more routine use of thermal imaging in energy audits and more MIT-CEA interchanges.

With U.S. buildings consuming 72% of the nation's electricity and 39% of energy overall, that is a good thing. A thermal camera audit is an easy and noninvasive way to pinpoint building envelope defects that result in energy losses.

"It was a fun project," says Mar, who teamed up with fellow CEE graduate student Kate Kerigan and Michael Johnson, a PhD student in chemical engineering. "I really enjoyed talking to people at CEA and on the MIT campus."

The camera, which gauges heat loss from temperature profiles of objects in relation to their surroundings, is a fun gadget, says Mar. The size and shape of a circa-1980s camcorder, it uses a color scale that turns its subjects into images worthy of modern art. Windows and doors, typically cooler areas, become a startling tableau of neon greens and bright Crayola® blues edged with turquoise, while warmer areas such as interior walls are depicted in sunset oranges and reds.

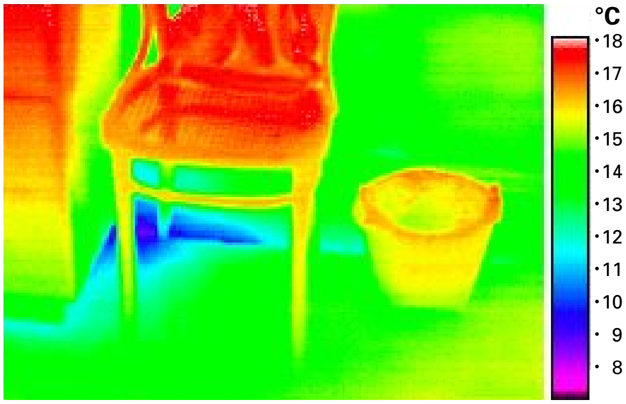


Photo taken with a thermal imaging camera during an energy audit of a 100-year-old clapboard duplex in Somerville, Mass. The camera uses a color scale that shows warm areas in oranges and reds and cooler areas in blues. This image suggests possible heat loss in the joint between the wall and the floor.

Partners in time

The project began when the CEA's Josh Hassol pitched the idea of using thermal imaging on Cambridge buildings at the October Generator event. The Generator, co-founded by Jason Jay, a doctoral candidate at the MIT Sloan School of Management, unites and catalyzes student groups working on local energy, environment, and sustainability projects with a campus focus. CEA was established in 2007 as a nonprofit organization to reduce Cambridge's carbon footprint by working with homeowners, businesses, and institutions.

In addition to Mar, representatives from the MIT Energy Initiative (MITEI), the MIT Department of Facilities, and the MIT Building Technology Program followed up with CEA on a possible collaboration. CEA was not sure whether it wanted to invest in the expensive equipment that MIT already owned, so a pilot project appealed to Hassol.

One of the instructors of 1.819, E. Eric Adams, CEE senior research engineer and senior lecturer, suggested that students attend the Generator meeting to uncover potential class projects. This was one of several times a Generator project has been paired with class credit, and Mar thinks that the idea makes sense because it allows MIT students to kill two birds with one stone.

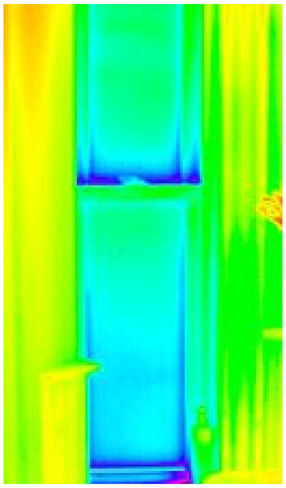
"It's great to pair class projects with Generator projects," says Jay. "If professors who teach project-based classes know about Generator events, they can help spawn collaborations, including projects involving Cambridge, not just the MIT campus."

Sealing gaps

When Mar, Johnson, and Kerigan videotaped and photographed the Somerville duplex owned by an MIT staff member, the resulting images revealed heat-escaping gaps around windows and in the seal around the front door. Even though the two-story structure had had insulation added, ductwork sealed, and storm windows installed since 2003, settling insulation and gaps in the floor and foundation were causing heat loss.

Suggested upgrades included blown insulation, spray foam insulation, weather stripping around the door, and shrinkable plastic over the windows. The

Photos: MIT Thermal Imaging Team



Thermal image of a window with curtains. The blue areas show gaps where heat is escaping.

student team identified payback periods for the upgrades. The students also developed a "toolkit" to guide a typical building owner in making repairs.

The team presented its findings to the class at the end of the fall 2008 semester. Next steps and ideas for similar studies using two MIT-affiliated Independent Living Groups (ILGs) and a fraternity were pitched at a February 2009 re-Generator event and posted to the Generator's online forum, Bazaar O'Ideas at <sustainability.mit.edu/projects/about-the-bazaar>.

"CEA is interested in continuing to work with MIT partners to implement a Cambridge-wide thermal imaging initiative," Hassol says. As part of its community outreach efforts, CEA is considering buying a camera and training people to use it to document energy waste in Cambridge.

"This is a great example of what can happen when MIT students rise to a community challenge to help solve energy problems while actively and creatively engaging the broad campus sustainability community," says Steven Lanou, deputy director for environmental sustainability and a member of the MITEI Campus Energy Task Force.

• • •

By Deborah Halber, MITEI correspondent

Energy Futures Week kicks off "greeningMIT" campaign

During MIT's Independent Activities Period (IAP) in January, the MIT Energy Initiative (MITEI) in collaboration with several student and staff groups organized a week of activities to engage student, staff, and faculty participation in "walking the talk" at MIT—taking action to reduce energy use and to promote sustainable practices on campus. A highlight of the week was the premiere of the "greeningMIT" logo to build awareness of MIT's many activities focusing on campus sustainability.

The event marked the continuing development of the Campus Energy program within MITEI. During the past two years, the program has focused on engineered opportunities for reducing MIT's energy footprint—utility system upgrades, lighting retrofits, improved building operations management, installation of high-efficiency heating and cooling systems in renovations, and use of green energy technologies in new buildings. The next phase of the program, led by the Campus Energy Task Force, focuses on engaging the broader MIT community in making personal energy-use choices to save energy and advance sustainable practices in offices, labs, and dorms.

MIT community members turned out in force at Energy Futures Week activities, with more than 500 people attending the week's events. Throughout the week, participants demonstrated a persistent desire to "do our part" to increase MIT's energy efficiency and reduce the Institute's greenhouse gas emissions.

MIT's Executive Vice President and Treasurer Theresa Stone and MITEI Deputy Director Robert Armstrong helped kick off the week's events at a "community rally" that drew several hundred participants. Stone and Armstrong emphasized MIT's institutional commitment to wise energy management, including at least $1 million spent to date on investments in energy conservation and efficiency. Steven Lanou, deputy director of environmental sustainability, and Jason Jay, doctoral candidate at the MIT Sloan School of Management, illustrated a wide array of simple actions that people can take, from shutting off the lights to using the revolving doors to turning on the power management features on their computers.

Other activities included panel discussions on climate policy and technologies for efficiency, a career panel, and a "sustainability in action" workshop. The workshop drew more than 70 participants, some of whom signed up to join a new network of "green ambassadors" to serve as change agents, information resources, and nodes of outreach within their units. The network now numbers more than 80 students, staff, and faculty.

For more information, visit the MITEI Campus Energy Activities website at <web.mit.edu/mitei/campus>.

• • •

By Amanda Graham, MITEI

Faculty innovation strengthens energy curriculum

Faculty from departments across MIT are collaborating to revise existing energy-related classes and to develop new ones. The fruits of their labor are helping prepare MIT students to become energy technology innovators, designers, entrepreneurs, and policy-makers in the future.

This surge of creativity and cross-disciplinary work is coordinated by the MIT Energy Initiative's (MITEI) Energy Education Task Force. Vladimir Bulović, KDD Associate Professor of Communications and Technology, and Donald Lessard, Epoch Foundation Professor of Management, co-chair the task force. The classes described here significantly enrich the under-graduate energy curriculum and will serve as key offerings within the undergraduate minor in energy studies that is now being developed.

Energy classes under revision

- A multi-departmental team led by Professor Michael Golay (Nuclear Science and Engineering) is preparing an undergraduate version of ***Sustainable Energy***, a highly successful graduate class on energy technology options that has been taught for more than a decade. A major goal is to develop under-graduates' understanding of the nature and limitations of the set of available and potential energy technologies.

- Chemistry faculty Robert Silbey, Moungi Bawendi, and Andrei Tokmakoff are updating the content of ***Thermodynamics and Kinetics,*** adding new lectures on energy as well as demonstrations of fuel cells, batteries, and heat pumps.

- Professors Henry Jacoby (Management) and Ronald Prinn (Earth, Atmospheric, and Planetary Sciences, EAPS) are providing extra support for undergraduates who are taking the graduate class, ***Climate Change: Economics, Science, and Policy.***

New energy classes under development

- ***Energy Decisions, Markets, and Policies*** will explore energy regulation, forms of social control in relation to energy, and the role of energy markets and prices in U.S. domestic and global policies. Professors Richard Schmalensee and Donald Lessard (Management) and Susan Silbey (Anthropology) are collaborating on this team-taught class.

- ***Earth Science, Energy, and the Environment***, being developed by EAPS faculty Samuel Bowring and Bradford Hager, will cover the chemistry, biology, physics, and geology of fossil fuels and the physics of ocean and atmospheric circulation.

- In ***The Politics of Energy and the Environment***, students will learn how public policy decisions are made about energy and the environment, with a primary focus on U.S. policymaking in both the domestic and international arenas. Professor of Urban Studies and Planning Judith Layzer is preparing the class, which will be jointly listed in the Department of Political Science.

- Professor Karen Polenske (Urban Studies and Planning) will be teaching ***Infrastructure in Crisis: Food and Energy Security***. In this class, students will obtain a comprehensive picture of energy and food systems in their social, environmental, and political contexts in the United States and in developing economies.

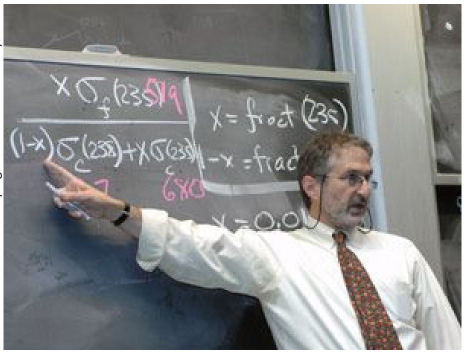
- Building technology faculty Marilyne Andersen, John Fernandez, Leslie Norford, and Leon Glicksman are creating a new seminar, ***Sustainable Futures***, which will be taught in a workshop format. The class will introduce students to current thinking regarding global climate change, ecological economics, and performance-driven building system design and assessment.

- Sheila Kennedy, professor of practice in architecture, will explore innovative materials that can generate and store energy in the new class, ***Design for Distributed Energy: Body, Building, and City***. In this hands-on class, students will explore design parameters of selected materials, possibly through proof-of-concept prototypes.

These activities are supported by a gift from the Dirk (SB 1975) and Charlene (SB 1979) Kabcenell Foundation to the MIT Energy Initiative.

Physics class teaches fundamentals of energy

Photos this page: Donna Coveney, MIT



In an MIT class taught for the first time last fall, 32 undergraduates learned to use fundamental physical principles and quantitative analysis to evaluate the promise and limitations inherent in energy alternatives.

The class—called ***Physics of Energy*** (8.21)—was developed by Professors Robert L. Jaffe (shown above) and Washington Taylor of physics, with support from the MIT Energy Initiative.

Physics of Energy tackles the subject in terms of the basic underlying mechanisms involved in every aspect of generating and using energy. "The laws of thermodynamics, and basic physics, draw lines around what you can and can't do" in terms of harnessing various sources of energy, says Jaffe. In the class, students examined those fundamental constraints and learned to use analytical tools to understand options for energy production, transmission, conversion, storage, and consumption. In the future, they will be able to draw on sound scientific principles as they face decisions on difficult political, economic, and social issues relating to energy.

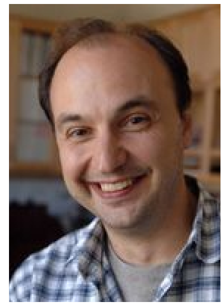
Summer opportunities for energy professionals

MIT Professional Education—Short Programs offers courses of two to five days in length on the MIT campus during the summer. Short Programs are geared to working professionals in engineering and science, and they attract a worldwide student body with many different interests. Students from industry, government, and academia come to learn from MIT experts and bring actionable information back to their organizations. Short Programs reach a broad spectrum of students who can communicate industry perspectives. In keeping with the strong interest in energy on as well as off campus, Short Programs will offer the following courses for summer 2009:

- Biofuels from biomass: technology and policy considerations (G. Stephanopoulos)
- Design of motors, generators, and drive systems (J. Kirtley, S. Leeb)
- Energy in the context of climate policy: strategic challenges and opportunities (M. Webster)
- Geological carbon sequestration: science, technology, and policy (R. Juanes, H. Herzog)
- Modeling and simulation of transportation networks (M. Ben-Akiva)
- Nuclear plant safety (M. Kazimi, N. Todreas)
- Organic, molecular, and nanostructured electronics—physics and technology (V. Bulović, M. Baldo)
- Present and future internal combustion engines: performance, efficiency, emissions, and fuels (J. Heywood, W. Cheng)
- Risk-informed operational decision management (G. Apostolakis)
- Solar energy: capturing the sun (D. Nocera)

For a complete list of topics and course descriptions, go to <shortprograms.mit.edu>.

Bulović honored for excellence in teaching



Vladimir Bulović, the KDD Associate Professor of Communications and Technology, has been named a Margaret MacVicar Faculty Fellow in recognition of his innovative teaching practices and accomplishments. The honor was formally announced by Provost L. Rafael Reif at a faculty reception on March 5.

Bulović is recognized for his ability to take complex ideas and present them in a manner that makes them especially clear and intuitive. According to colleagues, Bulović uses both artistic skills and extraordinary technical acumen in the classroom, inspiring students to new heights.

At the MIT Energy Initiative, Bulović is a member of the Energy Council and co-chair of the Energy Education Task Force. He is also co-director of the Eni-MIT Solar Frontiers Center, which is designed to promote and accelerate multidisciplinary research on next-generation solar technologies.

MacVicar fellowships recognize faculty who have made exemplary and sustained contributions to the teaching and education of undergraduates at MIT. MacVicar Faculty Fellows serve 10-year terms. The program was named to honor the life and contributions of the late Margaret MacVicar, professor of physical science and dean for undergraduate education at the time of her death in 1991.

Meet Amy Glasmeier, new head of urban studies and planning

Amy Glasmeier, the new head of MIT's Department of Urban Studies and Planning (DUSP), is an expert in economic geography, regional planning, and spatial statistics. Previously a professor of geography and the John Whisman Scholar of the Appalachian Regional Commission at Pennsylvania State University, Glasmeier served as director of Penn State's Center for Policy Research on Energy, Environment, and Community. She was also director of the university's environmental inquiry minor, which is sponsored by the Penn State Institutes of Energy and the Environment.

Glasmeier recently became a member of the MIT Energy Initiative's (MITEI) Energy Education Task Force—the first representative from DUSP. She brings to the task force a distinctive combination of leadership, scholarly excellence, and experience with regional planning in energy.

"We are thrilled to have Professor Glasmeier join the MIT faculty and the Energy Education Task Force," said MITEI Director Ernest J. Moniz. "Her expertise in economic geography will add a new and important voice to the MIT conversation on energy and environmental policy."

Glasmeier spoke with MITEI on March 10 from her office in Building 7. A former whitewater rafting guide, she was practically breathless at the Institute's "getting to know you" pace, she said.

Q: Your career has bridged the fields of economics and geography and applied them in the energy context. Could you explain how these areas are linked?

A: Economic geography is geographic reasoning applied to economic problems. Geography is essential to our understanding of why certain industries—especially energy industries, such as coal and natural gas—are located where they are. When you know where resources are located, then you can predict where a company's headquarters or production facilities will be and what impact that will have on local labor, infrastructure, and the environment. My own work focuses on development as it affects regions, economics, energy, and the environment.

Q: Would you cite a successful case for energy policy and development?

A: Wilmington, Delaware, succeeded with their wind power project. They had an existing coal plant, but to meet rising energy requirements, they had to expand the plant or find alternative energy sources, such as wind power.

Q: It's hard to imagine that expanding a coal plant had public support.

A: There were many complaints about the impact of the plant's gritty particulate matter on the environment and on public health. Also, the plant could not keep up with increasing energy demands. But the image of 60 large turbines in the water off Rehoboth Beach was a hard sell. The Wilmington planning process worked because the planners used simulations and modeling to show everyone involved in the project how the turbines would look in the bay. They assessed and included the public's response. The wind farm was accepted in June 2008.

Photo: Judith M. Daniels/SA+P

Amy Glasmeier, the new head of MIT's Department of Urban Studies and Planning and a member of the MIT Energy Initiative's Energy Education Task Force.

Q: You have long worked with the Appalachian Regional Commission (ARC), the group that advocates for sustainable development in the 13-state Appalachian region. What is your focus there?

A: I work on health economics, the environment, and energy, particularly in the distressed counties in Ohio, Kentucky, West Virginia, and Virginia. Appalachia itself is an energy and economic geography lesson: coal mines, the region's largest employer, switched from bituminous coal to cleaner reserves over the past 40 years. A million or more jobs were lost. Runoff and deposits from mining brought pollution.

Like many vulnerable rural areas, Appalachia is where natural energy resources are located, where pollution is produced, and where poverty is dire. As a planner, I believe we should return something equivalent to what we take from those areas.

Q: How could we, as a nation, "return something equivalent" to people in Appalachia for the coal we extracted?

A: We could start with analyzing who benefits from that coal industry and make sure the local economy is on the list. When construction workers are needed in a rural area to pave roads or support bridges or retrofit buildings for energy efficiency, we can assess local employment and wages before importing carpenters and other trades to do the work. Local labor should benefit from these "green" jobs.

Q: Any thoughts on how that might work?

A: Every licensed carpenter or plumber who is hired to work in a vulnerable community could be required to serve as a mentor to a local person, so the project produces both infrastructural improvement—like a new road or sewer—and more skilled workers.

Q: What direction do you see your own work taking at MIT?

A: I'm glad to be in a strong policy environment. One of my goals is to participate aggressively in the debates about globalization, economic development, and inequality; another is to collaborate with MIT engineers, scientists, and humanists in tackling global issues like climate change. We need strong multidisciplinary teams to address the world's grand challenges.

Glasmeier holds a BS in Environmental Studies and Planning from Sonoma State University and an MA and a PhD in City and Regional Planning from the University of California, Berkeley.

• • •

By Sarah Wright, MITEI correspondent

Student leaders network, exchange ideas

In a dinner held each semester, the MIT Energy Initiative's Education Office gathers leaders of energy, environment, and sustainability student groups to share information, alert each other to upcoming events, and discuss challenges and opportunities for collaboration. At the spring 2009 event on February 23, students started their conversation with visual images illustrating the mission of each of their organizations.

Groups represented at the event were Biodiesel@MIT, Closing the Loop, Dorm Electricity Competition, Electric Vehicle Team, MIT Energy Club, MIT Food Initiative, Net Impact, Sloan Energy and Environment Club, Impact Career Fair, Solar Electric Vehicle Team, Students for Global Sustainability, Sustainability@MIT, MIT Generator, and the Undergraduate Association's Sustainability Committee.

Jeff McAulay G (left) represents the Energy Club's aims by displaying a "bingo" board image showing 25 common icons and graphs related to energy. McAulay explained that the Energy Club wants to help students understand these concepts when they encounter them.

Josh Siegel '11 (right) of the Electric Vehicle Team and Jason Jay G of the MIT Generator describe the needs and challenges their groups face, including leadership development and space on campus.

Photos: Justin Knight

Lily Xu '12 (right) of the Undergraduate Association's Sustainability Committee higlights several spring events. Listening in are Samantha Fox '10 (center) and Sara Barnowski '10 from Biodiesel@MIT.

Catharina Lavers G (left) discusses the vision of the Sustainability@MIT group, which strives to inspire, educate, and empower people to help shape a sustainable world, while Christina Ingersoll G of Net Impact looks on.

Face time: Slower air saves energy

A device that sucks up noxious fumes also devours almost $1.4 billion worth of potential U.S. energy savings each year. Fume hoods help keep researchers from breathing harmful chemical vapors, but a typical fume hood consumes three times more energy than an average house, according to Lawrence Berkeley National Laboratory.

The MIT Department of Facilities is exploring ways to keep researchers safe while cutting the cost of running the Institute's 1,000-plus fume hoods. Closing sashes when they are not in use has already helped the Department of Chemistry save money and energy. The latest initiative involves altering some hoods' "face velocity"—the speed of the air moving through the unit.

"The rule of thumb in the past was that you needed a high velocity of air in fume hoods to protect users' health," says Walter E. Henry, director of the Department of Facilities' Systems Engineering Group. "But research and demonstrations on campus have shown that we can reduce the air velocity through the hoods by 20% and maintain safety."

In Building 18, the chemistry building, a significant number of fume hoods can operate at a lower level. Collaborating with MIT's Environment, Health, and Safety Office (EHS), "we experimented with seven hoods in an unused laboratory to find the lowest velocity at which we could get them to operate safely," says Peter L. Cooper, manager of sustainability engineering and utility planning at Facilities. "Eighty feet per minute met EHS's stringent safety standards."

After the lab's occupants moved in, EHS followed up with air sampling for some of the more volatile, potentially hazardous chemicals that the chemists were using. "The air sampling confirmed that no exposure was occurring due to the reduced face velocity," says Pamela Greenley, deputy director of EHS's Industrial Hygiene Program.

Fume hoods have a sash that slides open or closed. When open, air travels through the opening at up to 100 feet a minute. Fume hoods designed in the past 10 years are made to operate effectively at lower velocities. A survey is in progress to determine how many Institute hoods can safely operate at the lower velocities.

Altering face velocity requires adjustments by the manufacturer to modify controls, resetting air valves at the supply and exhaust ends, measuring airflow, and running a safety test to make sure the hood continues to meet American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards. While the work is "not trivial," Henry says the Institute is pursuing funding for the project, which would require a $430,000 up-front expenditure to retrofit several hundred hoods. The investment would be recouped in less than three years.

"Given that a fume hood uses as much energy as three homes, if you can cut that significantly, that's a big number," Henry says. "We're among the leaders in exploring options to reduce the carbon footprint of fume hoods."

• • •

By Deborah Halber, MITEI correspondent

Photo: Greg Hren Photography/Research Laboratory of Electronics at MIT

MIT is working to reduce the energy consumed by more than 1,000 fume hoods used by researchers across the campus. Above, graduate student Jianglong (Gerry) Chen of materials science and engineering works in a fume hood as he prepares glass substrates for the growth of nanostructured optoelectronic devices. His faculty advisor is Professor Vladimir Bulović, associate professor of electrical engineering and co-director of the Eni-MIT Solar Frontiers Center.

Chilled beams hit the roof

Employees in a handful of MIT buildings might notice what look like slim, fin-tubed radiators in ceiling cavities. These cooling devices are a relatively recent innovation to make its way to the U.S. market. Called chilled beams, they use water, not air, to remove heat from a room.

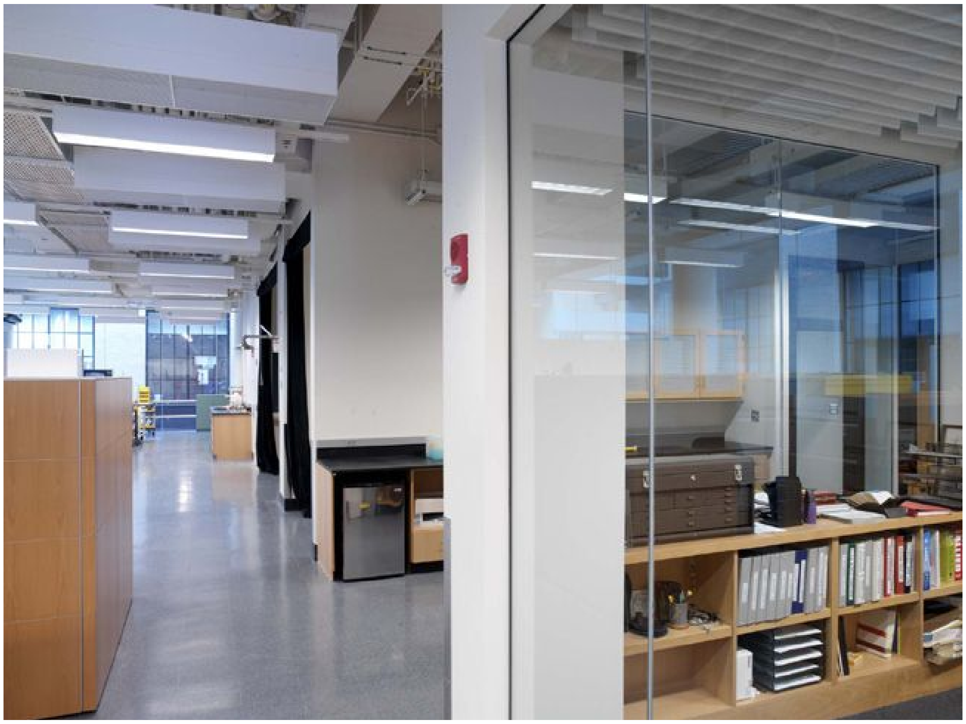


Photo: Andy Ryan

Passive chilled beams are used in the recently completed 49,000-square-foot physics department space built within the Building 6 courtyard. In the photo above, the chilled beams are the rectangular boxes between the light fixtures.

If you peek under the cover of a baseboard heater, you will see a pipe studded with many thin fins, looking like a car radiator. Chilled beams are based on a similar design, except instead of one long straight pipe, their pipes snake back and forth like the security line at the airport. And instead of heating air with hot water, they cool it with cold water.

The potential energy reduction of using chilled beams instead of a traditional air conditioning system ranges from 20% to 50%, depending on the type of system, climate, and building.

The recently completed expansion and renovation to the Main Group—the 49,000-square-foot physics department space infill project of the Building 6 courtyard—is one of the recipients of chilled beams. This energy-efficient air-conditioning system also has been successfully installed in buildings 4, 6, and 8. "One of its advantages over conventional air-conditioning is that it can be retrofitted in buildings that can't accommodate conventional air-conditioning equipment," says Peter L. Cooper, manager of sustainability engineering and utility planning for the Department of Facilities. "There was not enough ductwork in the existing building and not enough space for new ductwork."

MIT will incorporate two types of chilled beams: active and passive. Active systems tie into the building's air supply ducts, mixing supply air with cooled air and distributing it through diffusers. Passive technology relies on warm air rising to the beams to be cooled. It then descends without the assistance of fans. In both cases, water cooled to 59–65°F is pumped from a chilled water system to the coiled piping inside the beam.

"Chilled beams cool the people and dehumidify the air in the room. They take one-tenth the volume of fresh air needed for traditional A/C, far less ductwork, smaller ducts, and smaller fans," says Cooper.

The new MIT Sloan School expansion and the David H. Koch Institute for Integrative Cancer Research also will take advantage of some chilled-beam cooling. According to Cooper, the beams are useful in offices, laboratories, and other spaces where equipment and sunlight generate a significant amount of heat.

"There's a factor of eight improvement in cost of moving a Btu of air cooled by water versus air. If you can get the cooling energy into the space through water, you're way ahead," says Cooper. "The eight times factor is a very attractive alternative from an energy point of view."

• • •

By Deborah Halber, MITEI correspondent

MIT faculty and students enliven AGS annual meeting

The United Nations estimates that by 2050, 6.4 billion people—two-thirds of the world's population—will live in cities. Can that dramatic demographic change be harnessed to ensure progress toward sustainability?

To address that question, the 2009 annual meeting of the Alliance for Global Sustainability (AGS) examined "Urban Futures: the Challenge of Sustainability." The meeting was held January 26–29 at the Swiss Federal Institute of Technology (ETH) Zürich.

Organizers of the conference focused on two propositions. First, cities can be transformative arenas in which natural resources are used more efficiently. Second, designing future cities as an integral part of the local environment is an effective way to improve "social sustainability" as well as reduce human impacts on local, regional, and global ecosystems.

The presidents of all four AGS universities—the Massachusetts Institute of Technology, the University of Tokyo, Chalmers University of Technology, and ETH Zürich—met and also joined industry and civic leaders at an executive forum to discuss how the AGS might improve outreach and the impact of the AGS's sustainability research.

MIT faculty and staff members contributed their expertise in several areas. Professor Ernest J. Moniz (Physics and Engineering Systems), director of the MIT Energy Initiative (MITEI), called for close cooperation among research, industry leadership, and the public on carbon dioxide reduction. He concluded, "We are not very serious now. Let's get serious!"

Among other MIT presenters were Professors Leon Glicksman (Architecture), director of the MIT Building Technology Program; Nazli Choucri (Political Science); Bish Sanyal (Urban Studies and Planning); John Fernandez (Architecture); and Steven Lanou, deputy director for environmental sustainability in MIT's Office of Environment, Health, and Safety.

Student participation

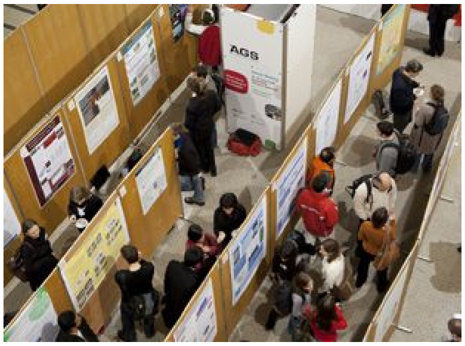
MIT students were well represented at both the AGS meeting and the meeting of the World Student Community for Sustainable Development held concurrently with the AGS event. This year, the MIT-Portugal project sponsored the participation of 15 of its affiliated Portuguese graduate students.

The 2009 Student Summit for Sustainability (S^3) was integrated into the AGS meeting through co-sponsored and shared events and the common theme of urban futures. This year, students from 39 nations were on hand. An always-impressive feature of every AGS annual meeting is the student poster session, which this year included well over 200 exhibits. An AGS panel awards prizes to the most outstanding projects.

In addition to students from the four AGS schools, presenters came from a global range of research institutions. Examples include Monash University (Australia), the University of Cape Town (South Africa), the Tashkent Medical Academy (Uzbekistan), the University of Nairobi (Kenya), Silpakorn University Nakornpathom (Thailand), and the Ashoka Trust for Research in Ecology and Environment (India).

Photos: Cristian Köpfli

An AGS annual meeting panel including (from left) Professor Keisuke Hanaki from the University of Tokyo; Professor Ralph Eichler, president of ETH Zürich; and Professor Ernest Moniz, director of the MIT Energy Initiative, discussed the role of research institutions in developing pathways to sustainable energy systems.



The poster session, a regular feature of AGS annual meetings, brought together participants in the annual meeting and in the Student Summit for Sustainability (S^3). Prizes are awarded for the best presentations.

AGS and industry: common interests

Following the formal closure of the annual meeting, AGS coordinators and staff met with representatives of the World Business Council for Sustainable Development (WBCSD). This group is currently working on a document describing how a sustainable world might look in 2050. Two WBCSD projects—one on sustainable food, water, and fiber regimes and the other on energy—map onto two current AGS Pathways projects. The AGS and the WBCSD also share a programmatic interest in the future of urban areas.

Now 12 years old, the AGS is a partnership of the four major scientific and technological universities plus their extensive regional networks of research universities that enhance the range of AGS projects. The alliance encourages collaboration among these and other institutions on sustainability-related projects of immediate interest to industry and civil leaders.

Since its inception in 1997, the AGS at MIT has contributed over $60 million in support for MIT fellowships, research, and education. AGS seed funding has built long-term links among MIT faculty members as well as between MIT faculty and researchers at other universities. AGS activities at MIT are led by AGS coordinator Professor David H. Marks (Civil and Environmental Engineering and Engineering Systems).

• • •

By Teresa Hill, MITEI

Graduate fellows share their work

At the Annual Martin Fellows Research Exchange, held on March 2 at the MIT Energy Initiative, advanced graduate fellows met informally to learn about each other's research. Martin Fellows, Linden Fellows, and fellows from the new Solar Revolution Project (SRP) were in attendance to network and participate in animated discussion.

Photos: Justin Knight

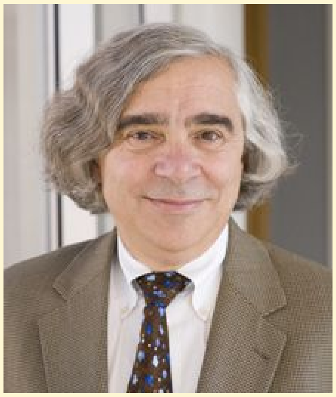
Sarah Jane White of civil and environmental engineering, a Martin Fellow for 2007–08 and a Linden Fellow for 2005–06, explains her research to Philipp Reist of electrical engineering and computer science, a current Linden Fellow. White is investigating the potential impacts on hydrologic systems of novel metals that may be used in the processing of new high-efficiency semiconductors.

Vikram Mittal of mechanical engineering, a current Martin Fellow, shows results from his study of the standard tests used to determine research and motor octane numbers for fuels. He found that the tests—established in 1928—involve temperatures far higher than the operating temperatures of today's engines.

SRP Fellow David Bradwell of materials science and engineering is working to evaluate and characterize a liquid battery for grid-scale energy storage. Here, he describes his research to SRP Fellows (left to right) Prithu Sharma, Johanna Engel, and Vaibhav Somani, all of materials science and engineering.

Moniz named to presidential advisory council

Photo: Justin Knight



Ernest J. Moniz, director of the MIT Energy Initiative, is among the 20 leading U.S. scientists and engineers selected to serve on President Barack Obama's Council of Advisors on Science and Technology (PCAST). PCAST will advise the president and vice president on science issues and help formulate policy.

In a statement issued Monday, April 27, Obama said, "This council represents leaders from many scientific disciplines who will bring a diversity of experience and views. I will charge PCAST with advising me about national strategies to nurture and sustain a culture of scientific innovation."

Moniz, the Cecil and Ida Green Professor of Physics and Engineering Systems, served as undersecretary of the Department of Energy (1997–2001) and associate director for science in the White House Office of Science and Technology Policy (1995–1997). His research centers on energy technology and policy, including the future of nuclear power, coal, natural gas, and solar energy in a low-carbon world.

In December, Obama announced MIT Professor Eric S. Lander, director of the Broad Institute, as a co-chair of PCAST. For a complete list of PCAST members, go to < www.ostp.gov/cs/pcast >.

MITEI seed grants for energy research

Recipients of MITEI seed grants for energy research, September 2008

PACEM: cooperative control for citywide energy management
Harold Abelson (Electrical Engineering and Computer Science)

Bioinspired hierarchical thermal materials
Markus Buehler (Civil and Environmental Engineering)

A high-throughput computational approach to finding novel thermo-electric materials
Gerbrand Ceder (Materials Science and Engineering)

Self-powered electronic systems
Anantha Chandrakasan (Microsystems Technology Laboratories)

Energy Initiative computational science: an interdisciplinary, high scale computing and algorithmic approach
Alan Edelman (Mathematics) and Stephen Connors (MIT Energy Initiative)

A regionally integrated systems dynamics and energy and material flow model for the Ica region of Peru
John Fernandez (Architecture), Michael Flaxman (Urban Studies and Planning), and John Sterman (MIT Sloan School of Management)

Scalable thermoelectric power with novel thin film technology
Eugene Fitzgerald (Materials Science and Engineering) and Mayank Bulsara (Materials Processing Center)

Solar PV-thermal hybrid for renewable energy generation in developing countries
Harold Hemond (Civil and Environmental Engineering) and Ahmed Ghoniem (Mechanical Engineering)

Photonic crystals: enabling efficient energy generation
John Kassakian (Laboratory for Electromagnetic and Electronic Systems) and Marin Soljacic (Physics)

Do urban energy initiatives actually reduce cities' carbon footprints?
Judith Layzer (Urban Studies and Planning)

Carbon nanotube super-springs for energy storage
Carol Livermore (Mechanical Engineering)

The social and economic impact of micro-scale hydroelectric power: design for a randomized experiment in rural Indonesia
Benjamin Olken (Economics)

Solar thermoelectric generator for the developing world
Rajeev Ram (Electrical Engineering and Computer Science)

Supervalent battery
Donald Sadoway (Materials Science and Engineering)

Offshore renewable energy system for generation and storage
Alexander Slocum (Mechanical Engineering) and James Kirtley (Electrical Engineering and Computer Science)

Engineering tolerance in yeast for improved biofuel production
Gregory Stephanopoulos (Chemical Engineering)

Millimeter wave deep drilling for geothermal energy, natural gas, and oil
Paul Woskov (Plasma Science and Fusion Center) and Daniel Cohn (MIT Energy Initiative)

MITEI Associate and Affiliate Members

Recipients of MITEI seed grants for energy research, April 2009

Seed grants

Supramolecular self-assembly of photosynthetic materials: towards design principles for more efficient light harvesting systems
Alfredo Alexander-Katz (Materials Science and Engineering)

Assessment of the energy savings potential of leading edge façade technologies with new performance metrics
Marilyne Andersen (Architecture)

Neodymium for infrared luminescent solar concentrators
Marc Baldo (Electrical Engineering and Computer Science)

Understanding the effect of nano-scale surface structures on bubble nucleation and boiling heat transfer
Jacopo Buongiorno (Nuclear Science and Engineering) and Karl Berggren (Electrical Engineering and Computer Science)

Investigation of an inexpensive surface alloy catalyst for hydrogen fuel cells and the role of a novel excited proton in the oxidation reduction reaction
Sylvia Ceyer (Chemistry)

Design of novel biofuels: biosynthesis and predicted fuel performance
William Green and Kristala Jones Prather (Chemical Engineering)

Bio-inspired underwater adhesion system for deep-sea oil mining
Sangbae Kim (Mechanical Engineering)

Electrocatalytic carbon dioxide reduction using intramolecular secondary interactions
Jonas Peters (Chemistry)

MIT Enernet: matching horsepower with brainpower
Carlo Ratti (Urban Studies and Planning), Neil Gershenfeld (Media Arts and Sciences), and Harvey Michaels (Urban Studies and Planning)

Heterostructured oxides for energy storage
Caroline Ross (Materials Science and Engineering) and Yang Shao-Horn (Mechanical Engineering)

Optimization of coherent energy transfer in photosynthetic systems
Robert Silbey and Jianshu Cao (Chemistry)

Polychromatic diffractive concentrators for ultra-high efficiency photovoltaic cells
Henry Smith (Electrical Engineering and Computer Science)

Nanoengineered surfaces for enhanced phase-change heat transfer for applications in energy and desalination systems
Kripa Varanasi (Mechanical Engineering)

Planning grants

SOFT CITIES: design of thin-film solar textile systems for the sustainable retrofit of dense urban fabric
Sheila Kennedy (Architecture)

Integrated modeling for sustainable metropolitan mobility
P. Christopher Zegras (Urban Studies and Planning), Moshe Ben-Akiva (Civil and Environmental Engineering), and Carlo Ratti (Urban Studies and Planning)

MITEI's Associate and Affiliate members support a range of MIT energy research, education, and campus activities that are of interest to them. Current members are now supporting various energy-related MIT centers, laboratories, and initiatives; fellowships for graduate students; research opportunities for undergrads; campus energy management projects; outreach activities including seminars and colloquia; and more.

Members as of May 1, 2009

Associate Members

Ormat Technologies, Inc.

Affiliate Members

AMSO Corporation
Angeleno Group LLC
Berkeley Investments, Inc.
Marilyne G. Breslow
Cambridge Energy
  Research Associates (CERA)
CIDS – DCS Energy Savings
EnerNOC, Inc.
Fischer Francis Trees & Watts
Forge Partners, LLC
Gabelli Capital Partners
Natalie Givans
Globespan Capital Partners
Moore & Van Allen
NGP Energy Technology Partners, LP
Nth Power
Patriot Renewables
Philip Rettger (OptiSolar)
Rockport Capital Partners
Steptoe & Johnson LLP
The Tremont Group

For a list of the MITEI Founding and Sustaining Members, please see the inside front cover.

For information on becoming a MITEI member, please go to: <web.mit.edu/mitei/support/join.html>.

MIT Energy Initiative

Massachusetts Institute of Technology
77 Massachusetts Avenue, E19-307
Cambridge, MA 02139-4307

Return service requested

Nonprofit Organization
U.S. Postage
PAID
Cambridge, MA
Permit No. 54016

MIT Energy Initiative

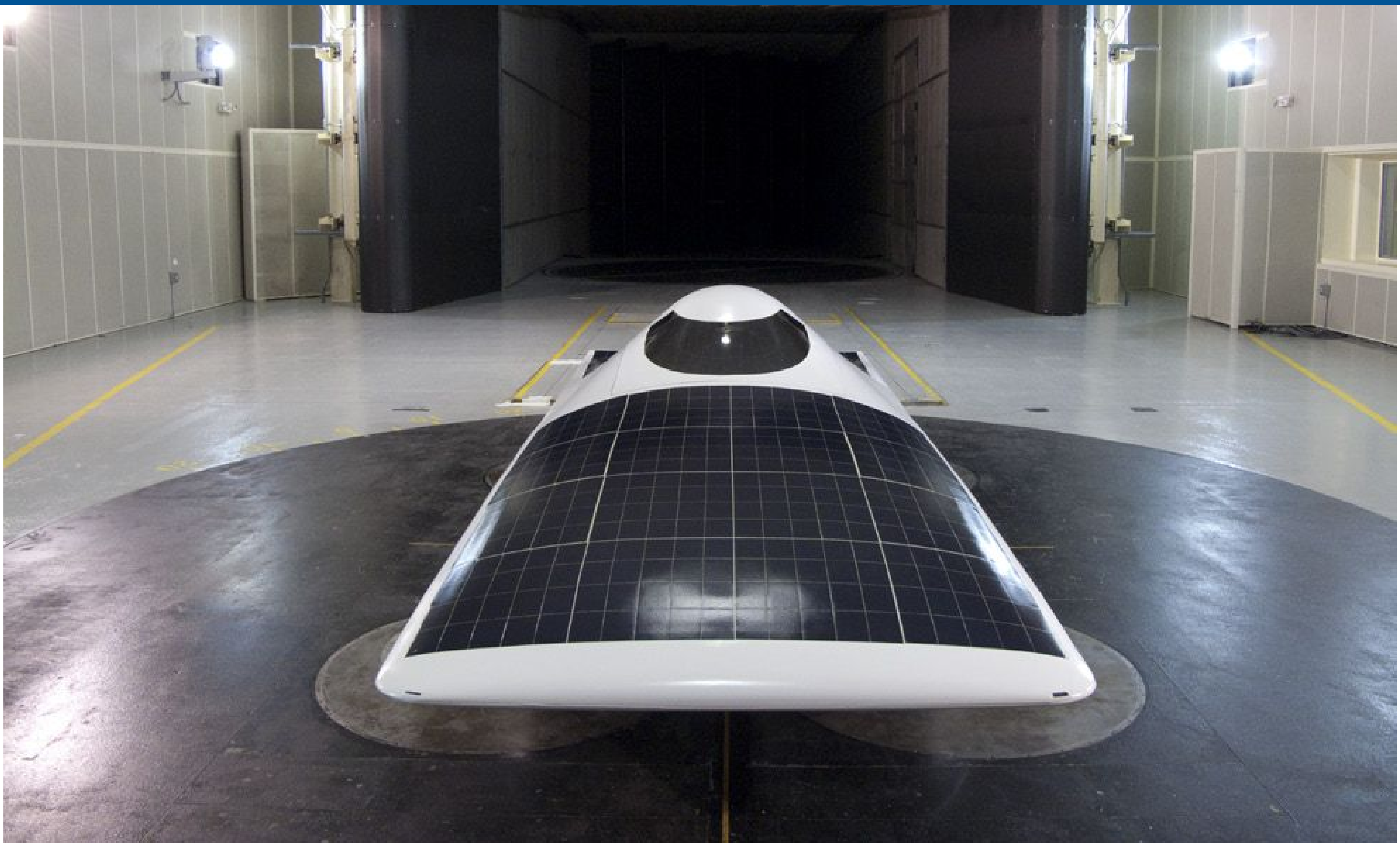


Photo: Chris Pentacoff '06

MIT's Solar Electric Vehicle Team, the oldest such student team in the country, unveiled its latest high-tech car on Friday, February 27, in Lobby 13. The new vehicle, *Eleanor*, is equipped with wireless links so lead and chase vehicles will be able to monitor every aspect of the car's electrical performance in real time. With six square meters of monocrystalline silicon solar cells and improved electronic systems and design, the car can run all day on a sunny day at a steady cruising speed of 55 mph. When fully charged, its batteries have enough energy to get the car from Boston to New York City without need of sunlight. In October, it will be competing in the World Solar Challenge race across Australia.