Energy Futures

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MIT competes in DOE's Solar Decathlon in Washington, D.C.

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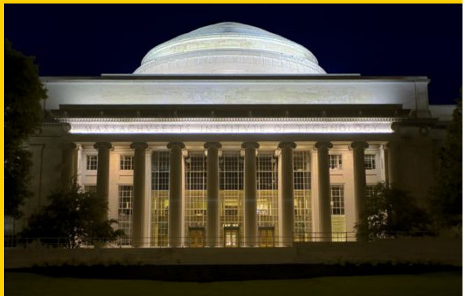

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MITEI supports student innovators to help reduce MIT's energy, environmental footprint

Energy Futures

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Nancy W. Stauffer, editor

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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.

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Update on the MIT Energy Initiative

Dear Friends,

Welcome to the inaugural issue of *Energy Futures,* the newsletter of the MIT Energy Initiative. I'd like to take this opportunity to tell you about some of the exciting developments and activities of the Initiative during its first year of operation.

President Susan Hockfield set MIT's energy initiative in motion during her May 2005 inaugural address when she highlighted MIT's "... institutional responsibility to address the challenges of energy and the environment." Following a yearlong study of how MIT could best contribute, in November 2006 President Hockfield formally launched the MIT Energy Initiative (MITEI) with a broad mandate to address key global and national energy challenges: meeting growing demand for energy while increasing the efficiency with which it is used; enhancing energy security; and mitigating the environmental impacts of energy production, distribution, and consumption, especially the climate risks associated with greenhouse gas emissions.

Building on MIT's long history of first-rate research and industrial and international collaboration, MITEI is designed to accelerate energy innovation by integrating the Institute's cutting-edge capabilities in science, engineering, management, planning, and policy. MITEI also enlists the talent and dedication of MIT's students to address critical energy and environmental challenges. Formal MITEI/industry partnerships enable MIT researchers to work closely with scientists, engineers, and planners in industry, ensuring the rapid movement of ideas into the marketplace. Finally, MITEI seeks to serve as an "honest broker" to the policy discourse, providing leaders in government and industry with unbiased analyses of energy issues, informed energy policy options, and opportunities for critical energy dialogue.

In launching MITEI, President Hockfield named an Energy Council made up of faculty from all five MIT schools to help implement the Initiative's research and education goals. Council members are listed in the box on the facing page. MITEI Deputy Director Robert Armstrong and I work closely with the council to oversee Initiative activities, coordinate with existing energy activities across the Institute, and facilitate the development of relationships with other institutions, industries, and governmental agencies.

To help guide the Initiative, President Hockfield has established an External Advisory Board composed of high-level members from industry, nongovernmental organizations, academia, and think tanks. It will be chaired by former U.S. Secretary of State George Shultz, an MIT alumnus and former faculty member. The first meeting of the board is scheduled for mid January 2008.

MITEI's four major program components—industry research partnerships, education, campus energy management, and outreach—are already yielding important results.

MITEI's industry partnerships support major research programs, early-stage innovative projects, educational initiatives, fellowships, undergraduate research opportunities, other student activities, and outreach. Current industry partners and some of their research interests are BP (coal conversion); Ford (new powertrain technologies); Chevron (ultra-deepwater oil and gas production); b_TEC, Barcelona (renewables); and Schlumberger (subsurface science and technology). This first group of industry partners represents a $70 million commitment over the next five years, including almost 100 new energy graduate fellowships. The partners have also contributed to an Energy Research Seed Fund; the first awards supporting novel energy-related proposals from across the campus will total nearly $1 million and will be announced by January. To date, MITEI has received more than 50 seed fund proposals. This extraordinary response to the first call for proposals shows the breadth and depth of energy-related innovation by MIT faculty.

Two task forces are helping MITEI implement its mandate from President Hockfield. The Energy Education Task Force, co-chaired by Professors Angela Belcher and Jefferson Tester, is assessing the existing curriculum, evaluating and coordinating undergraduate and graduate energy-related subjects, and considering the development of an Institute-wide energy minor. The Campus Energy Task Force is co-chaired by Professor Leon Glicksman and Theresa Stone, MIT executive vice president and treasurer. Activities

MITEI Energy Council

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Fred Fort Flowers '41 and
Daniel Fort Flowers '41 Professor
of Mechanical Engineering

include improving and planning campus energy use, providing input to new campus construction, and supporting student activities that use the campus as a laboratory for energy research and education.

Notable advances in MITEI's education program this year include a very generous grant from the Kabcenell Foundation supporting a variety of curricular initiatives. MIT has also been awarded a Clare Boothe Luce Postdoctoral Fellowship Program for Women in Energy, to be filled starting in fall 2008. Other opportunities, such as an MITEI Practice School, are under discussion.

The Campus Energy Task Force has already awarded student grants for campus energy projects ranging from a wind turbine design competition to a campaign encouraging the use of revolving doors. A second round of funded projects will be announced soon. An exciting parallel development is the generation of numerous student-led projects such as a dorm efficiency competition (won by McCormick Hall) and an award-winning plan to produce biodiesel from campus waste.

The Laboratory for Energy and the Environment has been brought under the MITEI umbrella, providing essential administrative and programmatic support for MITEI. Similarly, MITEI is leveraging the strong Corporate Relations/Industrial Liaison Program network to attract corporate financial support and Foundation Relations and Individual Giving to attract foundations and individual donors. This collaboration avoids duplicating efforts and minimizes the buildup of support infrastructures.

On the outreach front, MITEI held three colloquia during 2007. Professor George Whitesides spoke about exciting breakthrough opportunities in basic energy research. Lee Raymond, the former CEO and chairman of ExxonMobil, discussed the recently released report by the National Petroleum Council on global oil and gas issues. Sir Nicholas Stern spoke about the global climate change imperative. In addition, MITEI, with the support of the MIT Energy Club, recently hosted an Energy Salon for the MITEI Affiliate and Associate members; discussion focused on "Innovation Is an Energy Resource: Growing the Energy Industry in New England," with a panel led by Professor Richard Lester, director of MIT's Industrial Performance Center.

The MITEI website is also up and running at <web.mit.edu/mitei>. We encourage you to take a moment to visit this portal to energy activities at the Institute.

We anticipate adding new MITEI industry partners in the near future. With those partners will come additional energy research opportunities, new energy fellowships for the Institute, and a larger Energy Research Seed Fund to support creative proposals from across the campus. MITEI will also continue to support development of the next generation of energy innovators and entrepreneurs by helping to create education options that combine single-discipline depth with multidiscipline breadth and that use the campus itself as a teaching and learning tool.

Future issues of this newsletter—to be published twice yearly—will highlight energy research outcomes and energy-related activities at the Institute. I appreciate your ongoing interest in energy issues, MITEI, and the key role the Institute is playing to help address global energy challenges.

Sincerely,

Professor Ernest J. Moniz
Director, MIT Energy Initiative

December 2007

Doubling vehicle fuel economy by 2035: Technically feasible, challenging in scope

According to a recent MIT study, it should be possible to double the fuel economy of new cars and trucks sold in 2035 using improved versions of today's technology. Achieving such a doubling is technically feasible, but it will be a major challenge.

In one successful scenario, for example, almost 80% of all vehicles sold in 2035 will be hybrids, diesels, or turbocharged gasoline engines. In addition, technical advances between now and then must focus almost entirely on improving fuel economy rather than making cars faster and larger—the trend over the last few decades.

If those two requirements are not met, then vehicles will have to be substantially lighter for the factor-of-two gain in fuel economy.

Perhaps the biggest hurdle is changing consumers' expectations and buying behavior. "Because of the focus on improving fuel economy rather than, say, increasing acceleration, the 2035 buyer will have to be satisfied with close to today's level of performance," said John B. Heywood, the Sun Jae Professor of Mechanical Engineering and director of MIT's Sloan Automotive Laboratory.

Amid growing concerns about energy security and the impacts of climate change, much attention is focusing on cutting energy use for transportation—a sector that consumes two-thirds of all petroleum in the United States and that generates a third of the nation's carbon dioxide emissions. Congress is now debating legislative proposals to increase the fuel economy of new passenger vehicles over the next two decades. But how realistic are the goals being considered?

For the past nine months, Professor Heywood and graduate students Lynette Cheah, Christopher Evans, and Anup Bandivadekar have been drawing on their accumulated expertise and advanced modeling methods to find out. Their defined goal was to end up with 2035 light-duty vehicles—cars, wagons, SUVs, pickups, and vans—that have on average twice the fuel economy of those being sold today. "This is a surprisingly demanding task," said Professor Heywood. "We don't usually think about doubling the fuel economy—in other words, halving the fuel consumption—of every car in some average sense."

The researchers limited their study to evolved gasoline internal combustion engines and three advanced vehicle technologies: turbocharged gasoline engines, high-speed turbocharged diesel engines, and hybrid-electric systems. "We wanted to focus on readily available technologies that can penetrate the market without a lot of added investment in the technology or fueling infrastructure," said Ms. Cheah. Plug-in hybrids, battery electric vehicles, and alternative fuels were therefore excluded.

They examined three ways of reducing fuel consumption: using more alternative and fuel-efficient propulsion systems (called powertrains in their study), channeling technology improvements toward reducing fuel consumption rather than increasing performance, and reducing vehicle weight and size.

Professor Heywood emphasized that the study does not aim to forecast how vehicles or markets might look in 2035. "We're working backwards to understand the degree of the changes that are necessary to achieve the desired target," he said.

What can we expect by 2035?

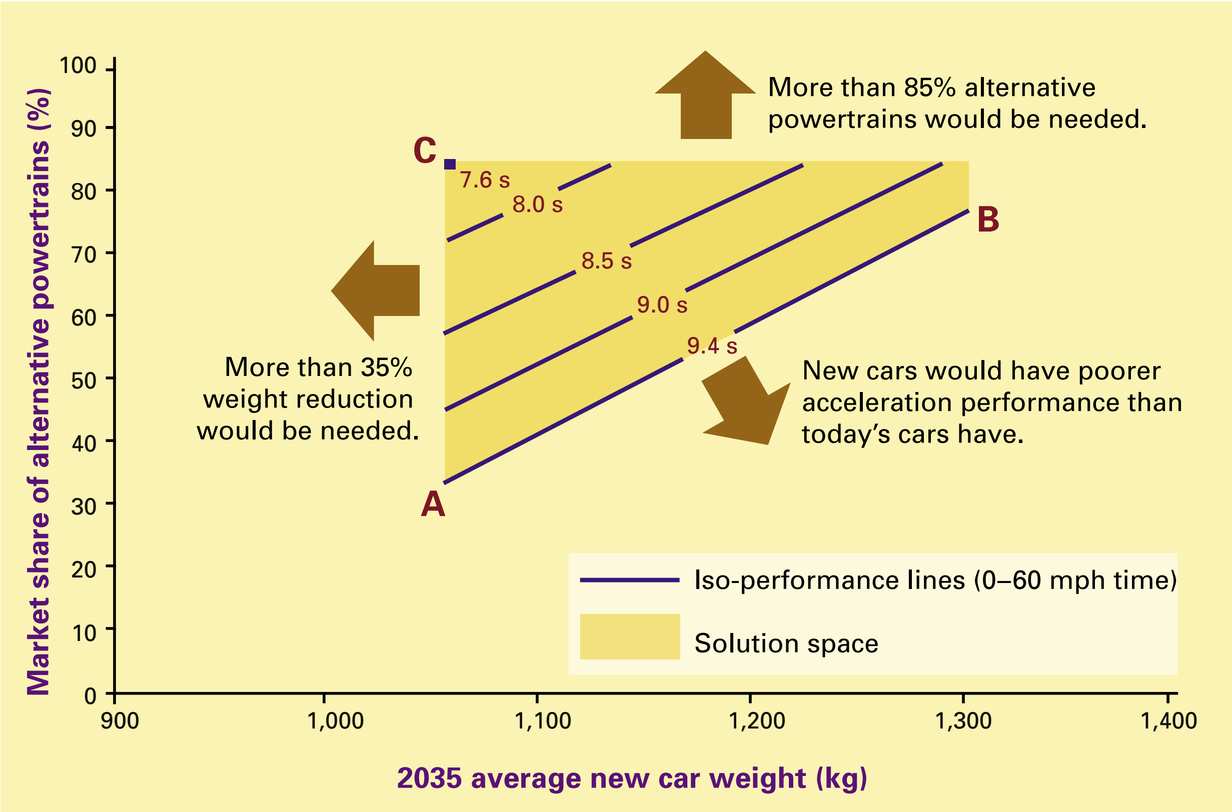
The researchers first determined how much each option, taken to its maximum, could cut fuel consumption by 2035. As a baseline, the analysis assumes that engines and transmissions will continue to improve as they have in the past.

Use alternative, more efficient powertrains. Today, less than 5% of the U.S. market is made up of turbocharged gasoline, diesel, and hybrid vehicles. Based on the rates at which previous new technologies have penetrated the existing vehicle fleet—and assuming aggressive promotion of the new technologies—the researchers assumed that the maximum market-share growth rate of alternative powertrains is 10% per year. At that rate, alternative powertrains could at most make up 85% of new vehicle sales in 2035, yielding a 23% reduction in the fuel consumption of the average 2035 model year vehicle.

Emphasize reducing fuel consumption. As vehicle technologies improve, there is a trade-off between reducing fuel consumption and increasing performance, size, and weight. Over the past two decades, for example, gains have been used to push up horsepower and acceleration rather than to increase fuel economy. A key variable in the study was therefore "emphasis on reducing fuel consumption" (ERFC). Assuming 100% ERFC, vehicle performance would remain unchanged from today, but fuel consumption would be 35% lower in the average 2035 vehicle.

Reduce vehicle weight and size. The third option is to reduce vehicle weight and size (beyond what is assumed at different levels of ERFC). Heavier materials can be replaced by lighter-weight ones such as aluminum and

Sample Scenarios for Doubling Fuel Economy in New 2035 Cars



This figure shows a set of scenarios that would lead to a doubling of fuel economy in new cars in 2035. Points within the shaded area would yield the desired result by combining changes in three factors: market penetration of alternative powertrains, reduction in vehicle weight, and channeling technology improvements more toward increasing fuel economy rather than performance (here indicated by how much acceleration changes from today's average of 0 to 60 mph in 9.4 s). Maximum changes are indicated for each factor.

high-strength steel. As vehicle weight decreases, the engine, suspension, and other components can be downsized. And the overall vehicle can be made smaller—a change that would focus first on larger vehicles, producing a fleet with a more consistent size. Integrating all of those approaches could cut vehicle weight by 35% by 2035, yielding a 19% reduction in fuel consumption in the average 2035 vehicle.

Putting it all together

No single option cuts fuel consumption enough to reach the study's defined target, but various combinations of the three options would do the job. Using their analytical tools, the researchers generated the figure above, which demonstrates how the three options can be combined and traded off to achieve the factor-of-two gain. Any point within the shaded triangle—the "solution space"—will yield the desired outcome.

For example, assume that technology improvements go almost entirely toward fuel economy. In this case, vehicle acceleration in the future will remain essentially unchanged from the current level of 0 to 60 mph in 9.4 seconds (the diagonal line at the lower right). At one extreme (point A), the target can be reached when the market share of alternative vehicles is just 34%, but vehicle weight must then drop to 1,055 kg—more than a third less than vehicles weigh today. At the other extreme (point B), vehicle weight is just over 1,300 kg, a decline of 20% from today, but then the market share of alternative vehicles must rise to almost 80%. Along the diagonal line between those extremes are many combinations of market share and weight reduction that will work.

Now assume an ERFC of only 60%. Given that level of emphasis on increasing performance, the average new car in 2035 would accelerate from 0 to 60 mph in 7.6 s (point C

Plausible Scenario for Doubling Fuel Economy in New 2035 Cars

Model year	Emphasis on reducing fuel consumption	Average acceleration time (0–60 mph)	Average car curb weight	Market share by powertrain			
				Conventional gasoline	Turbo gasoline	Diesel	Hybrid gasoline
2006	—	9.4 s	1,620 kg	95%	1%	2%	2%
2035	75%	8.1 s	1,300 kg (20% reduction)	15%	15%	15%	55%

This table shows one scenario that would yield a fleet of new cars in 2035 with double the fuel economy of new cars today. One key factor is how much emphasis is put on using technology gains between now and then to reduce fuel consumption rather than to increase performance factors such as acceleration. MIT analyses show that accomplishing these changes by 2035 is technically feasible but will require major shifts in the expectations and behavior of consumers, manufacturers, and the government.

in the solution space). But then achieving the factor-of-two target requires taking the other two options to their limits: alternative-vehicle market share must be 85% and 2035 vehicle weight only about 1,055 kg.

Throughout those analyses, hybrids never make up more than 35% of the new vehicle fleet. "But in previous work we've shown that hybrids get significantly better fuel economy than standard-engine vehicles, whether gasoline or diesel," said Professor Heywood. "So an important question is: How much difference can using more hybrids make?"

To find out, another analysis assumed that 55% of all new vehicles are hybrids, with the balance spread about evenly among conventional gasoline, turbo gasoline, and diesel engines (see the table above). The preponderance of fuel-efficient hybrids brings down fuel consumption enough that the target is met even when new car acceleration performance (0 to 60 mph) increases to 8.1 s and vehicle weight drops to 1,300 kg—a reduction that can be achieved by using more lightweight materials.

The researchers estimate that reaching the factor-of-two target will cost manufacturers an extra \$50–\$65 billion in the 2035 model year alone, or roughly 20% more than a baseline assuming fuel economy remains unchanged from today. Considering the fuel savings, however, society as a whole would recoup those costs within four to five years.

They conclude that halving fuel consumption by 2035 is possible but will require aggressive action beginning today. "There will have to be a fundamental shift in the mindset and motivation of a broad base of consumer, industry, and governmental stakeholders," said Professor Heywood. "We'll need new policies that push industry to utilize new technologies while at the same time creating a market demand that pulls technology gains toward reducing fuel consumption."

• • •

This research was supported by Environmental Defense. Further information can be found in:

L. Cheah, C. Evans, A. Bandivadekar, and J. Heywood. *Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035*. MIT Laboratory for Energy and the Environment Publication No. LFEE 2007-04 RP, October 2007. Available at <lfee.mit.edu>.

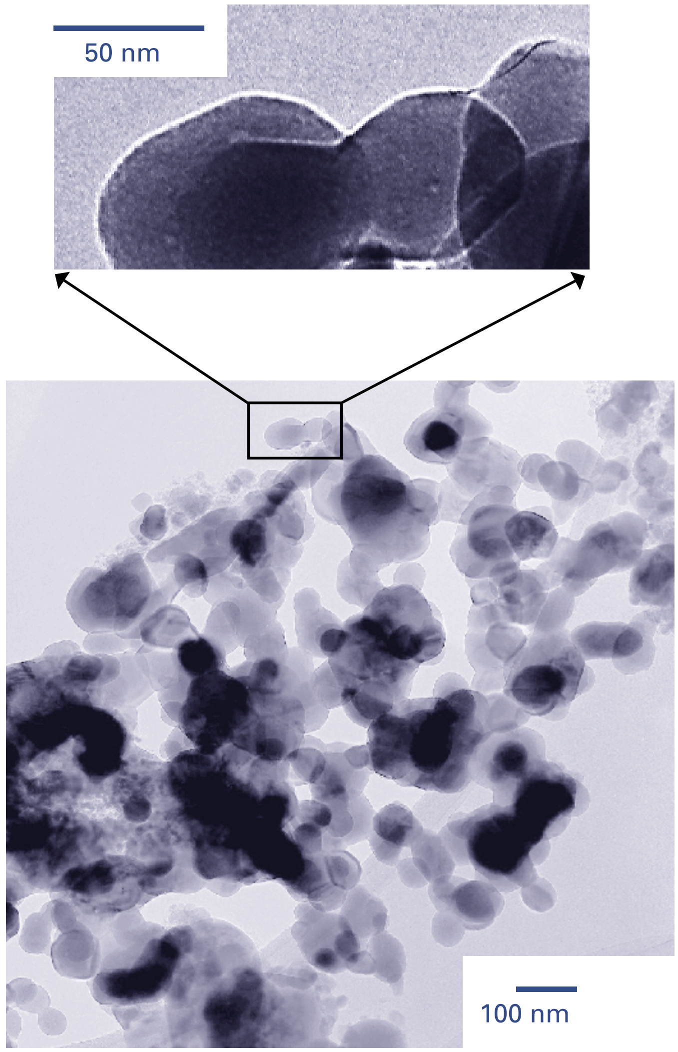
Rechargeable batteries: Nanoscale clues to higher power

Imagine charging up the battery in your electric vehicle in five minutes, then accelerating rapidly to join traffic on the highway. That is the vision of MIT scientists who are looking to speed up the flow of electricity into and out of rechargeable batteries. Their recent research findings provide atomic-level insights into what limits that flow—and why fabricating electrodes from nanoscale particles eases the problem.

Yet-Ming Chiang, the Kyocera Professor of Ceramics in the Department of Materials Science and Engineering, is no stranger to powerful rechargeable batteries. In past research, he and his colleagues developed an intrinsically safe, long-lasting lithium-ion battery that was five times more powerful than its competitors. The battery, marketed since 2001 by A123 Systems of Watertown, MA, has been incorporated into high-powered cordless tools and is now being demonstrated in plug-in hybrid electric vehicles.

Despite their success, Professor Chiang and his colleagues—like others in the field—have been uncertain as to why high power is so hard to achieve. While many experts cite limited rates of chemical diffusion, Professor Chiang suggested instead that the impediment is how quickly structural changes can occur at the atomic level—a hypothesis that has been supported by results from recent experimental and theoretical work.

When a lithium-ion battery produces electricity, lithium ions flow from the negative electrode to the positive electrode of the battery. The faster those ions move, the higher the battery's power. The limiting factor has been how quickly the positive electrode can take up the lithium ions. And how quickly that electrode can release lithium ions has limited the rate at which the battery can be recharged.



These images show the nanoscale particles that make up the electrodes of a doped lithium-iron phosphate battery—an intrinsically safe rechargeable battery developed at MIT and remarkable for its high power, long lifetime, and mechanical robustness. Recent MIT research has provided atomic-scale insights into why working at the nanoscale makes those characteristics possible.

Among the electrode materials that work best are olivines, a family of crystalline compounds with a similar atomic-scale structure. For a given olivine, the structure differs slightly depending on whether or not lithium is present. As a result, when lithium ions move into or out of the positive electrode, a new crystalline structure must form in place of the original one. "So the challenge is to engineer, or design, the material to allow that structural or phase change to happen as quickly as possible, because the faster it can go, the higher the power that the battery can deliver and the faster it can be recharged," Professor Chiang said.

But in a conventional electrode, there is a problem: the change from one crystalline structure to the other gets stuck. Consider the flow of lithium into the positive electrode as a charged-up battery is discharged to run a device. "We start off with a positive electrode that contains no lithium," Professor Chiang explained. "As we add lithium, part of that solid modifies its crystalline structure. Now there's a mismatch between that new structure and the original structure in the part of the solid that's still devoid of lithium." The mismatch at the interface between the two crystalline structures slows the uptake of lithium ions, which limits the power of the battery.

The key, then, is to prevent the material from separating into regions with and without lithium. But stable crystalline structures exist for only two compositions: when the material is completely free of lithium and when it is fully saturated with lithium. No stable crystalline structure exists for intermediate concentrations of lithium, such as those present when the battery is discharging or charging. As a result, the material quickly separates into lithium-saturated and lithium-free regions.

The benefits of nanotechnology

In conventional forms of these compounds, the only way to achieve stability at intermediate lithium concentrations is by raising the temperature—not a practical solution for a battery electrode. Another approach is to use nanotechnology. "The fascination with nanomaterials is that unusual things happen when particles get very small," said Professor Chiang. "As the size scale gets smaller and smaller, physical properties such as melting points and optical and electronic properties can change dramatically."

Indeed, when the researchers tested electrode materials made up of particles less than 100 nm in diameter, they observed regions with intermediate lithium concentrations—even at room temperature. In the overall material, the composition was more mixed, reducing or eliminating abrupt interfaces between regions of differing composition. And when that condition prevailed, the battery being tested had much higher power. "Therefore we reasoned that these two are coupled phenomena," Professor Chiang said. "By reducing the particle size to the nanoscale we allow the transition from lithium-devoid to lithium-saturated, and vice versa, to proceed much faster."

Moreover, in tests with different olivines the researchers found that some exhibited the desired behavior far more than others. That finding could explain why certain olivines exhibit exceptional performance as electrode materials while others do not—a discrepancy that has puzzled battery experts. A good criterion for identifying promising new electrode compounds may therefore be their ability to adsorb and release lithium without abrupt and significant structural change. As an added benefit, the use of such compounds should extend battery lifetime. Eliminating abrupt changes in composition will reduce cracking and other damage that can occur with repeated charging and discharging.

Initially, Professor Chiang was reluctant to use the term "nanotechnology" when talking about his ongoing work on battery technology. However, the new fundamental results have convinced him that he and his team are indeed using nanotechnology to engineer and control the physical properties of their electrode materials. "There have previously been observations of [this type of] change in behavior at the nanoscale," he said. "But this is the first time that we're aware of that it's been observed in a battery-storage material and actually used as a mechanism for achieving higher performance."

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This research was supported by the United States Advanced Battery Consortium and a Royal Thai Government Graduate Fellowship. Further information can be found in:

N. Meethong, H-Y. Huang, S. Speakman, W. Carter, and Y-M. Chiang. "Strain accommodation during phase transformations in olivine-based cathodes as a materials selection criterion for high-power rechargeable batteries." *Advanced Functional Materials*, vol. 17, 2007, pp. 1115–1123.

Energy-related environmental changes: Consequences for crop yields, global economy

A new MIT study concludes that changes in the environment caused by increasing fuel use may damage global vegetation, resulting in serious costs to the world's economy.

According to the analysis, changes in climate and increases in carbon dioxide (CO_2) concentrations may, on net, benefit crops, pastures, and forests, especially in northern temperate regions. However, those benefits may be more than offset by the detrimental effects of increases in tropospheric ozone, notably on crops.

The economic cost of the damage will be moderated by changes in land use and by agricultural trade, with some regions more able to adapt than others. But the overall economic consequences will be considerable.

Among the most striking results of the study is the difficulty of controlling ozone levels. "Even assuming that best-practice technology is adopted worldwide, we see rapidly rising ozone concentrations in the coming decades," said John M. Reilly, associate director for research of the MIT Joint Program on the Science and Policy of Global Change. "That result is both surprising and worrisome."

The new findings come from a study that is novel in both design and methodology. While other investigators have looked at how changes in climate and in CO_2 concentrations may affect vegetation, Dr. Reilly and his coworkers at the Joint Program and the Marine Biological Laboratory (Woods Hole, MA) added to that mix changes in tropospheric ozone. Moreover, they looked at all three environmental "stressors" at once, examining their combined impacts on crops, pastures, and forests, all of which compete for land use. (Changes in ecosystems and human health and other impacts of potential concern are outside the scope of this study.)

They performed their analysis using the MIT Integrated Global Systems Model (IGSM), which projects emissions of greenhouse gases (GHGs) and ozone precursors based on human activity and natural systems. Coupled models then track chemical reactions in the atmosphere, flows of GHGs into and out of oceans and land, and impacts on vegetation and soils. Resulting changes in crop yields, grazing land, and forests are fed into a linked economic model, which calculates activity in various economic sectors, accounting for the effects of adaptation to change, international trade, and the imposition of emissions-control policies. Calculations are performed not for selected years but on a continuous, day-by-day basis—an approach that is critical for simulating gradual, long-term changes in soils. Spatial variation is captured by considering 62,000 individual cells covering the Earth's surface.

Expected and unexpected findings

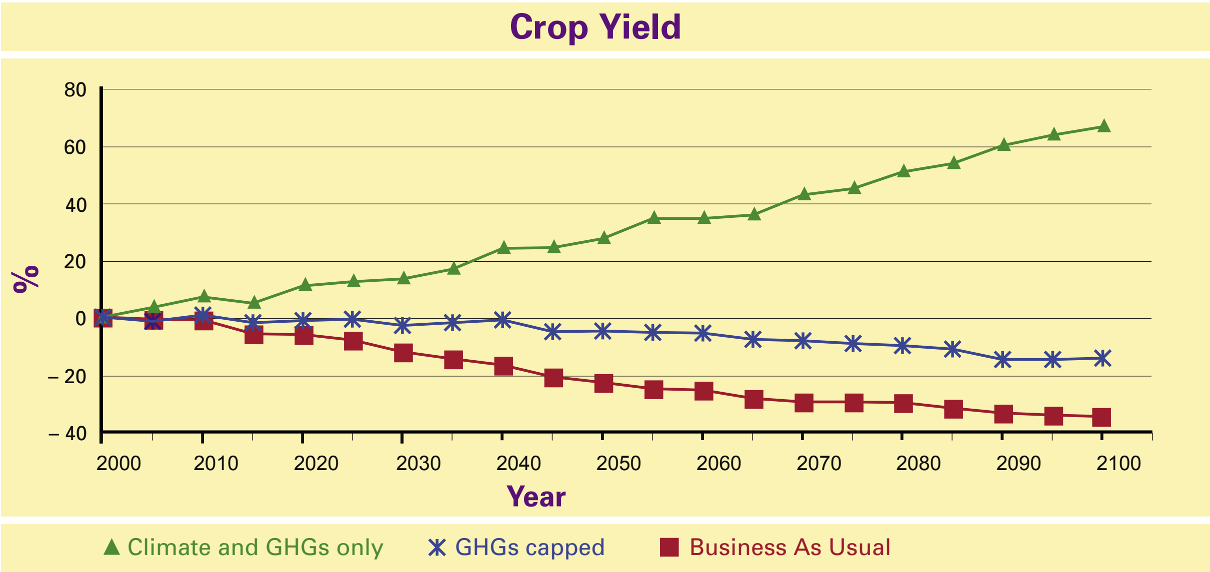
Analytical results for the impacts of climate change and rising CO_2 concentrations (assuming business as usual [BAU], with no GHG emissions restrictions) brought few surprises. The estimated temperature increase—2.75°C by 2100—would benefit vegetation in much of the world, as would the fertilization effect of rising CO_2. However, the impacts on economic markets are not major.

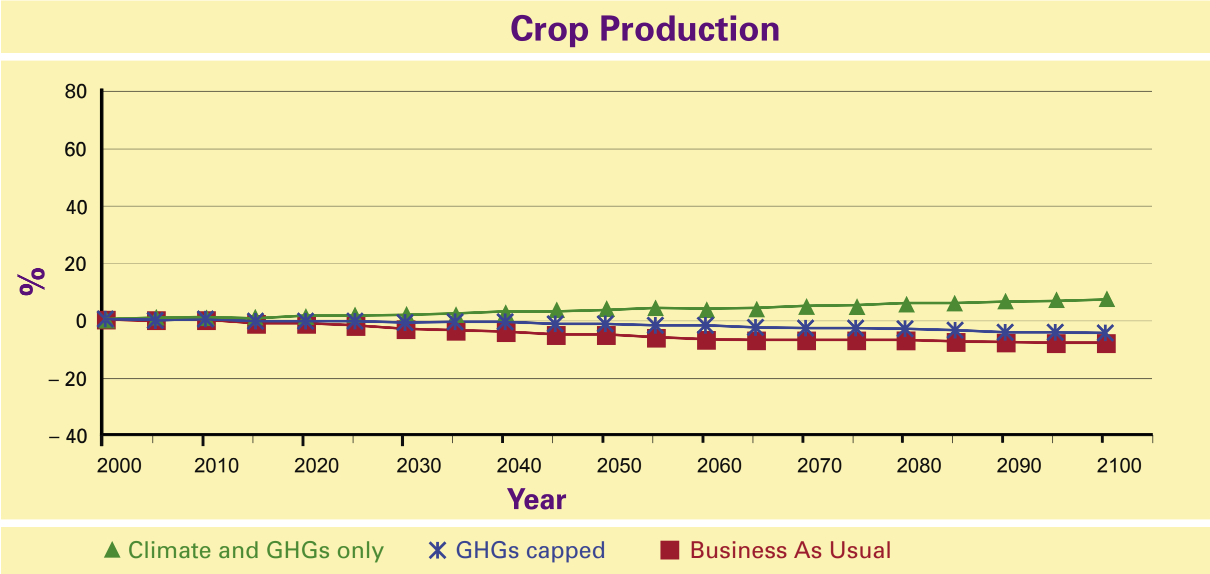
The effects of ozone are decidedly different. The model combined projections of ozone-precursor emissions with data on weather and prevailing winds to generate the first detailed picture of where ozone forms, how it moves around the world, and the concentrations that result. Under the BAU assumptions, those concentrations rise dramatically over time. Increasing wealth leads to more deployment of new technologies with lower precursor emissions per unit of energy; but even so, ozone concentrations increase dramatically due to the scale of the economy and the projected increase in fuel use.

Furthermore, the increased ozone concentrations have a disproportionately large impact on vegetation. In many locations, atmospheric ozone concentrations are currently just below the "accumulated ozone threshold" of 40 parts per billion (AOT-40), the critical level above which adverse effects are observed in plants and ecosystems. "So a relatively modest increase in the average ozone level results in a dramatic increase in the accumulated hours above 40 ppb," Dr. Reilly said. In the BAU case, global average ozone goes up by 50% by 2100, but AOT-40 levels over major vegetation zones increase by five to six times.

While those increases affect all vegetation, crops are hardest hit. Model predictions show that ozone levels tend to be highest in regions where crops are grown. In addition, crops are particularly susceptible to ozone damage because they are fertilized. "When crops are fertilized, their stomata open up, and they suck in more air. And the more air they suck in, the more ozone damage occurs," said Dr. Reilly. "It's a little like going out and exercising really hard on a high-ozone day."

What is the net effect of the three environmental changes? For the BAU case, yields from forests and pastures





These figures show MIT projections of global average percentage change in crop yield (top) and production (bottom) under three scenarios. In the highest curve in each figure, greenhouse gas (GHG) emissions are unregulated, and ozone damage to crops is excluded from the analysis. In the lowest curve, GHGs are unregulated, and crop damage from ozone is included. In the middle curve, GHGs are regulated, which leads to some reduction in ozone concentrations and related crop damage. While crop yields may drop dramatically, crop production never declines by more than 8% because the world adapts by allocating more resources to growing food.

decline slightly or even increase because of the climate and CO_2 effects. But crop yields fall by nearly 40% worldwide (see the top figure on the facing page). Regional projections show a 60% decline in China and a 40–50% decline in the United States and Europe.

However, those yield losses do not translate directly into losses in food production. According to the economic model, the world adapts by allocating more land to crops in order to keep food production up (see the bottom figure on the facing page). Even when crop yields go down by as much as 60%, the production loss is no more than 8%. While such results underscore the world's ability to adapt, that adaptation comes at a cost. The use of additional resources brings a global economic loss of 10–12% of the total value of crop production.

The regional view

Global estimates do not tell the whole story, however, as regional impacts vary significantly. For example, northern temperate regions generally benefit from climate change because higher temperatures extend their growing season. However, the crop losses associated with high ozone concentrations will be significant. In contrast, the tropics, already warm, do not benefit from further warming; but they are not as hard hit by ozone damage because ozone-precursor emissions are lower in the tropics than they are in the northern temperate regions. The net result: regions such as the United States, China, and Europe would need to import food; and supplying those imports would be a benefit to tropical countries.

Such results emphasize the value of the MIT approach. "This is the first time, I think, that people have linked a multistress analysis to an economic model, taking into account adaptation and international trade," Dr. Reilly said. "Climate change is generally seen as worsening the situation in developing countries, but we can't know the true impacts unless we also look at ozone effects and trade among regions."

The ozone projections raise new concerns about how to design effective regulations. According to the model, ozone concentrations are so high that significant intercontinental transport occurs. Once formed, ozone lasts on the order of months. In the Northern Hemisphere, it is transported by prevailing westerly winds from China to North America, from North America to Europe, and so on. Much less transport occurs from north to south, so tropical regions escape the higher levels of the Northern Hemisphere. The research shows that tropospheric ozone is rapidly becoming a transboundary problem that can no longer be controlled within a country or an urban area.

Interestingly, limiting GHG emissions helps. An analysis assuming an aggressive program to cap GHGs leads to lower fuel combustion. As a result, emissions of ozone precursors drop; and global ozone concentrations in 2100 are half as high as they are in the BAU case. In that analysis, crop yields do not benefit nearly as much from climate change and CO_2, but the amount of ozone damage is significantly reduced.

Future plans

Reilly warns that the study's climate projections may be overly optimistic. The analyses to date use a two-dimensional climate simulation, which may not generate sufficiently detailed results. Other studies with large, three-dimensional climate models suggest more spatial and temporal variability, including an increased possibility for drought, particularly in mid-continental regions. The researchers are now incorporating a more realistic climate simulation into their analyses.

They are also adding other environmental stressors generated by fuel combustion. Emissions of nitrogen, for example, will encourage vegetation growth but may also disrupt the natural ecosystem by favoring some plants over others. Emissions of aerosols and particulate matter form haze, which reduces the amount of sunlight reaching the Earth's surface, and also affect cloud formation and precipitation patterns. "It will be interesting to see how inclusion of the impacts of those pollutants in our analyses affects the productivity outcomes, particularly for places like China and India, where there's already a lot of haze," said Dr. Reilly.

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This research was supported by the U.S. Department of Energy, U.S. Environmental Protection Agency, U.S. National Science Foundation, U.S. National Aeronautics and Space Administration, U.S. National Oceanographic and Atmospheric Administration, and the industry and foundation sponsors of the MIT Joint Program on the Science and Policy of Global Change. Further information can be found in:

J. Reilly et al. "Global economic effects of changes in crops, pasture, and forests due to changing climate, carbon dioxide, and ozone." *Energy Policy,* vol. 35, no. 11, pp. 5370–5383, November 2007.

Students develop methodology for assessing options to cut campus energy use, emissions

A new methodology developed as a class project shows that measures such as installing energy-efficient lighting and repairing steam traps on the campus heating system could reduce MIT's energy use and carbon emissions—and save the Institute money at the same time.

The project was part of a new MIT Sloan School of Management class called Laboratory for Sustainable Business, or S-Lab, in which more than 60 students explored the concept of sustainability and the business opportunities and challenges it presents. A key exercise was teaming up to work on real-world projects with clients ranging from multinational corporations and energy startups to nonprofits and healthcare organizations.

For graduate students Nicholas Hofmeister and Brandon Monk of MIT Sloan and Cyd McKenna of the Department of Urban Studies and Planning, the client was MIT itself—more specifically, the Campus Energy Task Force of the MIT Energy Initiative, also known as the "Walk the Talk" (WTT) Task Force. Representing the task force were its co-chair Leon R. Glicksman, professor of building technology and mechanical engineering, and task force member Steven M. Lanou, deputy director for sustainability in MIT's Environmental Programs Office.

The mission of the task force includes identifying and promoting measures that could be taken within the next few years to reduce energy use and carbon dioxide (CO_2) emissions on the MIT campus.

Lanou noted the difficulty of that mission. "Possible projects range from equipment upgrades and energy-efficiency measures to renewable power systems and behavioral change programs," he said. "How do we begin to identify, assess, and prioritize those opportunities based on both financial metrics and greenhouse gas-mitigation metrics?"

Hofmeister and his partners took on the challenge. Assisted by Eric Beaton, senior engineer in the Systems Engineering Group, and others in MIT's Department of Facilities, the students made a list of about a hundred possible projects and—for as many as possible—metrics such as the impact on CO_2 emissions, capital cost, payback period, net present value, and return on investment. Including both environmental and financial impacts allowed the team to assess the net present value per tonne of CO_2-equivalent reduced, which summarizes "how much bang you get for your buck," said Lanou.

To track and store the information, the team turned to Google spreadsheets. "Google spreadsheets allowed us to create a collaborative living document," said Hofmeister. "Rather than having one file that people had to pass around, we had a document that everybody could access and work on simultaneously."

The result of the work—the "Carbon Mitigation Matrix"—includes a range of projects with differing characteristics. For some, the capital investment required is relatively low and would be paid back by operating savings within a few years or less. Examples include replacing conventional light bulbs with compact fluorescents; repairing steam traps; putting "energy misers" on vending machines; and recommissioning buildings, which involves examining all systems to make sure that they are still operating according to the design specifications when they were installed.

The team also assessed behavioral changes, such as using revolving doors, shutting off computers and closing laboratory fume hoods whenever they are not in use, and making energy-efficient purchasing decisions. Those items involve minimal capital cost and would have a significant impact, but they require educational campaigns to help people change their habits.

Other projects involve major capital investment and longer payback periods. Examples include installation of renewable systems such as solar panels and expansion of MIT's energy-efficient cogeneration plant—an option already being scrutinized as part of a utility master-planning effort.

The team identified many opportunities to cut energy use and greenhouse gas emissions while simultaneously saving money. In a number of cases, the estimated rate of return on the projects exceeds that of MIT's endowment.

"The methodology [developed by the students] will be a valuable tool for any institution putting together a portfolio of projects with different capital costs, payback times, and impacts on energy use and emissions," said Lanou. "In some cases, it demonstrates the economic as well as environmental benefits of doing seemingly mundane projects."

The matrix is not a "final polished product," said Peter Cooper, manager of sustainability engineering and utility planning in the Department of Facilities. Indeed, MIT and other universities are engaged in ongoing discussions about exactly how to calculate the reduction in CO_2 emissions associated with buying one fewer kilowatt-hour of electricity. That reduction varies with the mix of fuels used to generate the power supplied over the grid.

Photo: Steven Lanou, MIT

Roger Moore, MIT's superintendent of utilities, explains the workings of the MIT cogeneration plant to visiting MIT students. The cogeneration facility, which combines the production of electricity and steam, reduced greenhouse gas emissions by 30% after it came online in 1995.

Nevertheless, Cooper called the matrix a "good tool to get us on our way." Many items on the matrix were known to Facilities, but it also elicited lots of new ideas, especially those relating to changes in behavior. "The matrix served a good purpose in the first year of the Energy Initiative to collect ideas without judging them and to show that there are two different kinds of ideas that could get implemented requiring different skills and different people to get them done," Cooper said.

Accordingly, the WTT Task Force formed two subgroups, one largely populated by Facilities people who can do engineered changes, and the other by campus leaders on recycling and others experienced in promoting behavioral changes.

To John D. Sterman, the Jay W. Forrester Professor of Management and Engineering Systems and one of the S-Lab instructors, developing the matrix was an ideal class project. Students demonstrated for themselves and for others that investing in the environment does not have to come at a fiscal cost; indeed, it can bring a significant fiscal gain. "Often there's no tradeoff," Sterman said. "By making these investments we can help the environment *and* save money."

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Making a difference: Research opportunities for undergrads

How can MIT undergraduates contribute to a new energy future and a sustainable world? Sam Maurer '07 refined a reactor for thermal decomposition of waste biomass. Monica Lewis '06 explored the potential for using innovative green building techniques to reduce the environmental footprint of MIT dorms. Margaret Avener '07 waded through the wet-lands of Augusta, GA, to study water flow and its ability to carry chemical contaminants.

MIT students have responded to the MIT Energy Initiative (MITEI) with a surge of new ideas for meeting global energy challenges and a commitment to investigate and implement solutions. Undergraduates want to integrate energy and sustainability into their academic work at MIT and address those pressing concerns as part of their MIT career. In coordination with MIT's Undergraduate Research Opportunities Program (UROP), the MITEI Education Office provides undergraduates a means of pursuing those interests by participating in energy- and sustainability-related research.

The MITEI Education Office is expanding the special UROP funding opportunities it offers to connect more students to new research in energy, environment, and sustainability. Of special note are positions available through the Campus Sustainability UROP (CS UROP) Program and the Martin Family UROP Program.

In the CS UROP Program, the MITEI Education Office partners with MIT operations—notably the Environmental Programs Office (EPO) and the Department of Facilities—to enable students to study MIT's own energy and environmental challenges and the lessons MIT's campus can provide for local and global applications. Some students study technical innovations that are applicable to MIT's operations and infrastructure. Monica Lewis's study of how to green MIT's dorms is a prime example—one that brought MIT Housing into a new conversation with the Department of Facilities and MITEI. Other students investigate innovative implementation and financing strategies. Annika Larsson '08, for example, benchmarked current university models of revolving loan funds for energy efficiency improvements, a financing strategy that is currently being implemented at universities around the country.

CS UROP projects have also examined the human behavior components of systems, for example, analyzing labor processes and public communications related to recycling on campus. Three CS UROPs focused on the proposed on-campus Biodiesel@MIT processor, which would convert used vegetable oil to biodiesel for transportation fuel. The issues addressed were fuel certification, logistics of transport and production, and opportunities for education and project documentation.

An innovative feature of the CS UROP Program is that each student is supervised by an MIT faculty member in conjunction with a staff member in MIT operations. Both guide student work to assure that student learning goals are served and that operations needs are met. All participating students provide a concluding presentation to which they invite key MIT faculty and staff who may be interested in or affected by the research findings. The presentations both inform MIT projects and give students experience speaking before a professional audience.

Photo: Tim Blackburn

MITEI Education Office staff: from left, Beth Conlin, Karen Luxton, and Amanda Graham.

Steven M. Lanou, deputy director for sustainability in the EPO and a member of MITEI's Campus Energy Task Force, helps identify and develop CS UROP projects and coordinates the participation of MIT operations. "Undergraduate research provides important information that can enhance the effectiveness of campus energy projects," said Lanou. "The CS UROP Program is a valuable mechanism for supporting this type of research, and we in the EPO are thrilled to be able to partner with MITEI."

The Martin Family UROP Program builds on the generous support provided by the Martin family for graduate research in sustainability across the Institute. MIT undergraduates who meet the academic requirements of the program are able to work with a Martin graduate fellow on research contributing to global sustainability. The goals of the program are to connect Martin UROP students to a mentor in research, to show them new pathways to research careers, and to give them a new perspective on the application of research to sustainability projects.

Any MIT faculty member is eligible to nominate one outstanding graduate student working in sustainability-oriented research at MIT for a Martin Fellowship. Martin graduate fellows may then request funding for a Martin Family UROP. Students from all schools and departments at MIT are eligible for Martin UROPs, which may coincide with their major or address a different field of study. The opportunities available vary widely. For example, the research topics addressed by current Martin graduate fellows range from advanced photovoltaic materials to mathematical patterns of infection transmission to negotiation of environmental disputes.

For more information and a list of current UROP openings for spring 2008, go to our UROP site, currently housed on the LFEE website at <lfee.mit.edu/urops>.

Information on the Martin Fellowship programs is available at <lfee.mit.edu/programs/martin>. Nominations for Martin Fellows and Martin Family UROPs for the 2008–2009 academic year are due February 27, 2008.

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By Beth Conlin, MIT Energy Initiative and Laboratory for Energy and the Environment

Stackable cars, alternative energy highlight MIT Energy Night

The air hummed with possibilities in mid October when 1,200 people crowded into the MIT Museum for the third annual MIT Energy Night, which featured more than 40 student and company presenters.

"The event showcases the most exciting research, technology, labs, and startups coming out of MIT," said Matt Albrecht, a second-year MIT Sloan School of Management student and co-director of the event along with electrical engineering master's degree student Fergus Hurly. "The event is a catalyst for networking, collaborating, and generating new business ideas," Albrecht said.

Added Jason Roeder, a second-year MIT Sloan student: "Energy Night truly exhibits the passion and excitement regarding energy at MIT."

Albrecht said this year's Energy Night attracted twice as many attendees as last year's. Next year's Energy Night already is scheduled for October 10, 2008, likely again at the MIT Museum. The MIT Energy Club sponsored the 2007 event along with corporate sponsors Shell, venture capitalist firm General Catalyst, Cambridge Energy Research Associates, EnerNOC, and British Petroleum.

The event featured booths and displays by MIT laboratories, including the Plasma Science and Fusion Center, the Environmentally Benign Manufacturing Research Group, and the Earth Resources Laboratory. Also on hand were the MIT Energy Initiative; Draper Laboratory; companies including A123Systems, C3 BioEnergy, and EnerNOC; and student groups such as the MIT Generator and Biodiesel@MIT.

General Motors' new plug-in hybrid vehicle, the Chevrolet Volt, highlighted the night as attendees received an up-close view of the sportscar before entering the MIT Museum. Surprise guest Craig Cornelius, Solar Programs director at the U.S. Department of Energy, also stopped in to see what the buzz was about.

Students, faculty, staff, business professionals, and others examined posters and displays, sampled hors d'oeuvres, listened to live jazz, and chatted with presenters. Will Lark, a third-year PhD candidate in media arts and sciences at the Media Lab, found himself amid a throng of people asking when and where the City Car stackable vehicle on display would hit city streets. The two-passenger electric car is designed to be shared in dense urban areas as an adjunct to public transportation. For example, a commuter could drive it from a train station to work. The car can be stacked at various points around a city and will use city power to recharge when parked.

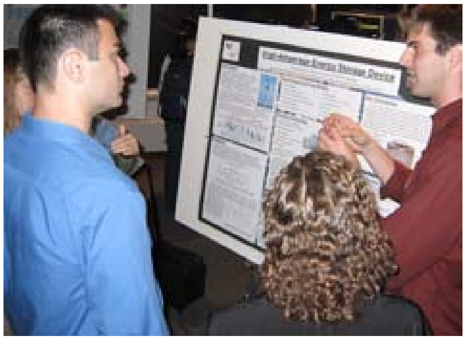
"People weren't questioning if it worked but rather what is next, what city it will be started in, and how we'll implement it," Lark said. "People were excited about the car."

The Media Lab is now in discussions about moving the City Car beyond the concept stage and into manufacturing.

Encounters at Energy Night can lead to interesting opportunities. Andrew Peterson, a PhD candidate in chemical engineering who has exhibited all three years of Energy Night, recalled a chance meeting when Harvard Business School student Tracy Mathews dropped by his poster at last year's event.

"She asked a lot of tough questions about our methane poster and made me feel uncomfortable," Peterson said.

Excitement buzzed at the third annual Energy Night as visitors peered at posters and displays, chatted with the researchers involved, and socialized with one another. Organized by the MIT Energy Club and held at the MIT Museum, this annual event gathers the science, engineering, policy, and business energy communities at MIT and showcases the most exciting energy activities across the Institute.



Energy Night photos: Edmund Carlevale, MIT

Graduate student David Bradwell of the Department of Materials Science and Engineering tells Energy Night visitors about his research on a large-scale, high-amperage energy storage device that could support renewable energy technologies. Used with windpower systems, for example, the device could ensure that electricity is available for customers even when the wind is not blowing.

"I made a mental note that this is someone I want on my side in the future."

That future came sooner rather than later. Over the past year, Peterson and fellow MIT chemical engineering PhD candidate Curt Fischer came up with an idea for renewable propane gas

Visitors to Energy Night took turns sitting in a prototype of the MIT Media Lab's City Car, a two-passenger electric vehicle that can be folded, stacked up with others, and recharged at subway stations and other central sites. A passenger arriving by subway or bus simply takes a fully charged vehicle from the front of the stack and then returns it to a stack near his or her destination so that it is available for others to use.

production. They enlisted Mathews, and together the three students formed C3 BioEnergy, a company designed to commercialize the technology. They won several prizes this past year, including as runner-up in MIT's $100K Entrepreneurship Competition and in Harvard Business School's Business Plan Contest.

Another display focusing on alternative energy was Biovolt, a team of students building a prototype device to more efficiently generate electricity from cellulose-based biomass. Their concept involves using different bacteria to break down the cellulose, eventually producing protons and electrons, which are used to power a fuel cell. The handheld device could be used to power cell phones and household devices, especially in off-grid locations such as developing countries.

The Biovolt team stepped up activity on its project when it entered the inaugural MADMEC, or MIT and Dow Materials Engineering Contest, which the team ultimately won.

"Other people had done microbial fuel cells," explained Joseph Walish, a Biovolt team member and PhD candidate in materials science engineering. "But no one [at the time] had put together a group of symbiotic bacteria in one self-sustaining unit."

To make their device more marketable, the team cut the cost of the recharger device. "We used a non-platinum catalyst for the fuel cells, which decreased cost an order of magnitude," Walish said. "That helped us win the contest."

Those were among the projects highlighting the cutting-edge work on alternative energy being done at MIT. Other projects displayed research on high-current energy storage, nanotube-enhanced ultracapacitors, floating wind turbines, alternative transportation fuels, advanced nuclear energy plants, algal fuel cells, synthetic gas, carbon capture, and photovoltaic nanodefect engineering.

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Martin Fellows welcomed

At a dinner held on September 24, 2007, 21 graduate students from across the Institute were welcomed into the Martin Family Society of Fellows for Sustainability for the academic year 2007–2008. The new Fellows will engage in research on topics ranging from the ecology of marine microbes to hurricane preparedness to the development of simulation tools for sustainable building design.

The Martin Family Society was established at MIT in 1996 by Lee '42 and Geraldine Martin to foster graduate-level research, education, and collaboration on issues relating to sustainability. Since 2006, the Martin Foundation has also been providing support for MIT undergraduates involved in sustainability research through MIT's Undergraduate Research Opportunities Program (UROP). Each "Martin UROP" collaborates with a Martin graduate fellow and a faculty supervisor on a sustainability-related research project.

In her keynote speech, Rebecca Henderson, the Eastman Kodak LFM Professor of Management at the MIT Sloan School of Management and a member of the MITEI Energy Council, both entertained and inspired Martin Fellows and their advisors. Using historical examples, she demonstrated for them the power of small groups of dedicated, visionary people to overcome seemingly insurmountable challenges such as the world energy situation.

An MIT first: Competing in DOE's Solar Decathlon

Martin Fellows photos: Justin Knight

In a presentation at the dinner, Casper Martin, a director of the Martin Foundation, Inc., read through the list of global problems covered in the 1984 State of the World report from the Worldwatch Institute. He relayed his dismay at finding that many of the same problems are featured in the 2007 version of the report. He then exhorted the new Martin Fellows to redouble their enthusiasm and commitment to leading the world toward a sustainable future.

Martin UROP Alexandra Patricia Tcaciuc '09, left, a double major in environmental engineering and chemistry, poses with Charuleka Varadharajan, a Martin Fellow from 2005–2006. They are collaborating on fieldwork and data analysis to better understand methane fluxes in the Upper Mystic Lake in Woburn. Their faculty supervisor is Harold F. Hemond, the William E. Leonhard Professor in the Department of Civil and Environmental Engineering.

Photo: Donna Coveney, MIT

Many hands volunteered in the making of MIT's solar house.

Last spring, a team of MIT students, faculty, and volunteers took on the challenge of designing and building a house that relies entirely on solar energy to meet the electricity needs of a typical American family, from drying towels to cooking dinner.

For the first time, MIT had an entry in the U.S. Department of Energy's annual Solar Decathlon—a village of 20 off-grid solar homes that were built by college students, assembled on the National Mall in Washington, and open to the public October 12–20, 2007.

Once assembled in the Solar Decathlon Village, each 800-square-foot solar home vied for points in 10 categories related to energy efficiency, design, and marketability. Among the tasks set by the DOE: each team had to heat a bucket of water to 110° F, prepare a three-course vegetarian meal for four or five of their neighbors, wash and fluff-dry a load of towels—and on top of all that generate enough electricity to power an electric car.

Although the MIT entry—dubbed Solar7—did not win, it did succeed with the public. "Although we got 13th in the competition, we were very popular with the tourists," said team member Diana Husmann, a senior majoring in physics. "And since the point of the competition was to show that solar can be both powerful and beautiful, we all agreed that, in the end, we were a complete success."

Corey Fucetola, student leader of the Solar7 project and a graduate student in electrical engineering and computer science, said, "The best way to change human behavior is to give people the information they need to change." And the 25,000 visitors who toured the solar homes got countless insights into how to live comfortably off-grid.

Special features of Solar7

Solar7 was designed and built on an asphalt lot at MIT, then broken into modules and sent by flatbed truck to Washington, where it was reassembled by about 20 MIT students and volunteers. The finished product contains a kitchen, full bathroom, living and dining area, and flexible bedroom/office space, defined by opaque pocket

Photo: Eric Damtoft

Left: MIT's Solar7 home, designed and built by students and displayed here at the Solar Decathlon contest in Washington, D.C., was popular with visitors and inspired plans for the 2009 competition.

Photo: Mark Morelli

Peter MacDougal, a volunteer from Independence Energy, and MIT graduate student Kellie Stokes install solar panels on the roof of Solar7.

doors. It has a wide, gracious deck and ramps for accessibility.

While the spaces in the house sound conventional, other aspects of Solar7 are far from conventional. Like all Solar Decathlon entries, Solar7 had to meet specific livability standards. It had to retain warmth but not bake its residents. It had to provide sufficient light to endure rainy days, supply warm water for showers, be handicapped-accessible, and store enough energy to run a dishwasher and an electric car. And it had to be made from commercial building materials and available technologies—no weird science, no fresh-from-the-lab contraptions.

"You [couldn't] yank something out of the lab and throw it up on the roof. You [had] to use production-grade products," said Kurt Keville, advisor to the Solar7 team and a research specialist at the Institute for Soldier Nanotechnologies.

During the half-year of construction, Keville, Fucetola, and construction manager Tom Pittsley had plenty of technology and new materials to keep their interest and to engage the weekend warriors managed by volunteer coordinator Arlis Reynolds.

For any passive solar home, the challenge is keeping the heat. Solar7 has a south-facing light wall made of 1-foot-thick square tiles. Each tile looks like a sandwich: Two opaque plastic squares are the "bread" for a filling of water and a layer of a thermal insulating gel spread on the inside of one of the tile's "slices." The insulating gel transfers the sun's heat from the outside, through the water, to the inside wall. Energy-efficient windows made of three panels of glass with krypton gas as an insulator are used elsewhere in the house.

Photovoltaic cells cover the south-facing roof of Solar7 and do the heavy lifting, energy-wise. They produce about 9 kilowatts of peak generation. Electricity is stored in 24 batteries, which can hold about 70 kilowatt-hours and can power the house for about 48 hours. The batteries also had to power the team's electric car—a key element in the DOE challenge.

Solar7's south face also holds 60 evacuated tubes that carry solar-heated water into the house for showers and washing and for circulation in the warmboards, a radiant heating system based on a molded subfloor that is embedded with plastic tubing.

MIT's long history of solar houses

In typical MIT fashion, the Solar7 team is already beginning to plan for the next Solar Decathlon, to be held in October 2009. After all, MIT is no newcomer to the challenge of designing a solar-powered house. Solar7 is so-named because it had six predecessors.

In 1938, Godfrey Lowell Cabot gave MIT a gift to be used for the development of "the art of converting the energy of the sun to the use of man." The endowment enabled the creation of MIT's Solar Energy Research Project, a 50-year effort involving the design and construction of six experimental or prototypical solar houses. Solar I, completed in 1939, was the first house in America to be heated by the sun's energy.

For more information about Solar7 and the MIT team, go to <solar7.mit.edu>.

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By Sarah Wright, MIT News Office

MITEI supports student innovators to help reduce MIT's energy, environmental footprint

Dan Wesolowski looked out from the second floor of MIT's Building E25, watching in dismay as students and faculty alike ignored signs to use the revolving door below him and save energy. Person after person coming from the nearby Kendall Square subway walked through the swing door to the side of the revolving door.

"A single person walking through a revolving door in February saves enough energy to light a 60-watt light bulb for 23 minutes," said Wesolowski, a fourth-year PhD candidate in materials science and engineering. If everyone used the revolving doors, MIT would save about $7,500 in natural gas a year in E25 alone, which has two of the 29 revolving doors on campus.

The MIT Energy Initiative (MITEI) is now supporting a student plan to encourage that behavior. Wesolowski and three classmates started their Revolving Door Campaign a couple of years ago as part of a project for a class in sustainability and planning. In tests around campus, their 11x17-inch signs saying "Help Conserve Energy, Please Use the Revolving Door" increased revolving door use to 65% from 23%. Based on those results, MITEI is providing funds for printing and installing pedestal-mounted signs at five revolving doors across campus.

The project was one of seven selected earlier this year by MITEI's new Student Campus Energy Project Fund. Twice yearly, the fund makes money available to students to undertake projects in line with the Energy Initiative's Campus Energy Task Force. The fund was seeded by MITEI with $10,000, plus a supplemental donation of $5,000 from Shell Oil Company.

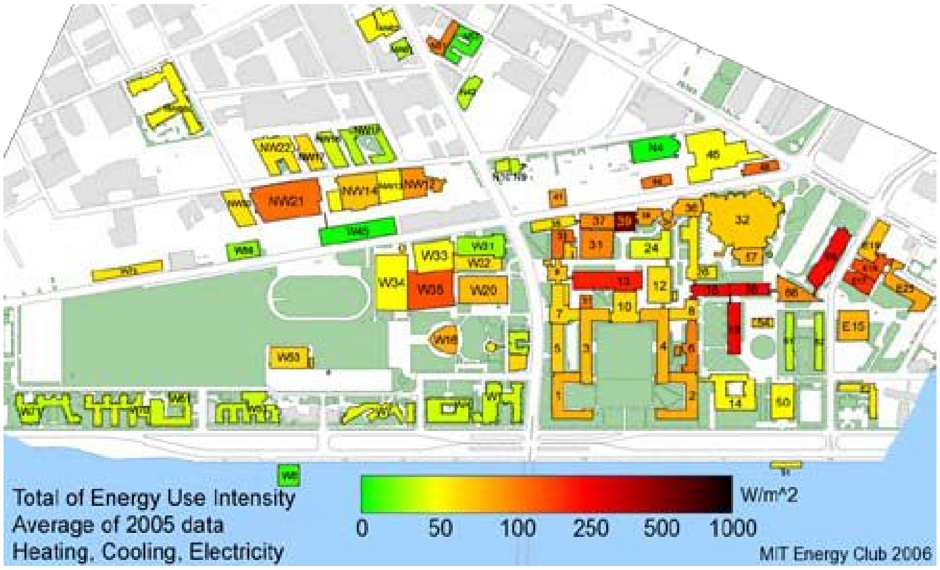
The other projects funded in the first round include:

- **Wind Turbine Design Competition** will be run for the first time during Independent Activities Period 2008. Students will have an opportunity to design and build a wind turbine capable of harvesting electrical energy from the wind.
- **MIT Generator** is a coalition of student groups aiming to catalyze and support student projects with a focus on energy, environment, and sustainability issues on MIT's campus. The goal for 2007–2008 is to expand the community of students involved in campus energy projects through more extensive outreach.
- **Publicity and Recruitment Booklets for the MIT Sustainability Community** is an Undergraduate Association Campus Sustainability Committee project. It published a booklet for freshman orientation to recruit incoming students for sustainability activities on campus.
- **Campus Climate Project (Focus the Nation)** aims to widen awareness and conversation about climate change on campus and to motivate and empower students to take action on this issue. The project will be part of the national link of events on January 31, 2008, known as "Focus the Nation: Global Warming Solutions for America." It will include seminars during the second week of spring semester in February 2008.
- **Plug Load Meters for Appliance Use Case Studies** will measure energy consumption in more detail than at the general building level to include items such as appliances. The goal is to influence user behavior by providing information about how much and for what purpose energy is consumed within each building.

Photo: Jason Forte '09

At the Activities Midway during MIT Orientation, senior Austin Oehlerking, chair of the Undergraduate Association Committee on Campus Sustainability, talks with first-year student Jared Trotter about campus sustainability activities and the new *Guide to Sustainability@MIT.* The booklet, prepared with MITEI support, contains information on MIT's student groups, clubs, and initiatives focusing on energy, the environment, and sustainability.

Graphic: Steven Peters and Elsa Olivetti



With MITEI support, a team of MIT students developed software that generated this map showing energy use intensity across campus, building by building. The students are now developing an automated display system that will post real-time energy use data on the web so building occupants can check on their building's usage.

- **Energy Map Project** has developed a prototype map that displays energy use intensity in various MIT buildings with a color scale. A website for displaying and updating the map is now under development (go to <energymap.mit.edu>).

"This first round of projects is just the tip of the iceberg," said Steven Lanou, deputy director for sustainability in MIT's Environmental Programs Office and a member of the grant review committee. "With another round of funding available this semester, I expect to see the ingenuity and creativity of student projects continue to grow and inspire us to do more to reduce our energy footprint and lead with innovative approaches."

While the projects do place a demand on students' time, they can be a welcome diversion from daily studies, according to Tarek Rached. He and fellow graduate student Steven Peters are involved in the Energy Map Project, which is designed to reduce energy use in MIT's buildings. Energy consumption in buildings accounts for the vast majority of campus energy use and produces more than 90% of MIT's greenhouse gas emissions. But most buildings are used without any feedback to the occupants and operators. The project aims to develop tools to measure and analyze MIT's campus energy use, such as the energy map.

The students are now getting monthly data from MIT's Department of Facilities on energy use in MIT buildings dating back five years. "The next phase is to launch an automated display system to get real-time data on the web so people can see what is going on in their building," Rached said. "We want to get people involved to change behavior."

That includes getting incoming freshmen involved in campus energy activities from the get-go. Austin Oehlerking, a senior, became interested in sustainable energy after taking a course during Independent Activities Period last year. He was instrumental in developing the orientation booklet for 2007 to get freshmen interested in sustainability communities throughout MIT. "There are at least 12 different student groups," he said. "So many different projects are going on that it is hard for people to grasp. The booklet is a great opportunity for them to find their niche among sustainability efforts on campus."

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Night and day

Photo: Chris Brown

For the first time in more than thirty years, the iconic Great Dome of MIT's Building 10 is illuminated—a nighttime beacon on the Cambridge skyline. The energy-intensive lighting arrangement of the past has been replaced by a new system incorporating 12 energy-saving light-emitting diode (LED) fixtures and high-efficiency precision metal halide fixtures that light the entire dome using the same amount of electricity needed to run two hairdryers. The new lighting system was made possible by a generous contribution from an anonymous donor.

Photo: Ruth Davis, MIT Facilities

To offset the electricity consumed in lighting the dome, the same donor also provided funds to help pay for the new 40-kilowatt photovoltaic array shown here. Mounted on the roof of the Alumni Pool, this solar installation is connected to MIT's electrical grid and provides three to four times the electrical energy consumed in lighting the dome. The purchase of the solar array was also supported by a grant from the Massachusetts Technology Collaborative.

Dorm Electricity Competition: MIT students save energy where it counts

Residents of New House added their own flair to MIT's first Dorm Electricity Competition by hosting a glow-in-the-dark ping-pong match.

"This was an excellent idea," said Tim Grejtak, a mechanical engineering sophomore and co-organizer of the event with Ariel Esposito, a senior in environmental engineering. The two are planning a second competition for spring 2008 that they hope will generate even more enthusiasm.

The Dorm Electricity Competition awarded $10,000 in energy efficiency retrofits and improvements to the undergraduate dorm that conserved the most electricity over a two-month period from March 9 to May 4, 2007. The dates for the next competition have not yet been set.

McCormick Hall won the 2007 competition, saving an average of 25.95 kilowatt-hours per student per week over the eight weeks. The 11 dorms that participated saved a total of 226 megawatt-hours, enough to power 21 homes for a year and to save MIT around $30,000 in energy costs.

The retrofits at McCormick have not yet begun, but options being examined include installing energy-efficient compact fluorescent lights as well as occupancy sensors that turn off the lights when a room is vacant. Such retrofits could save the dorm about 15% in electricity costs.

Grejtak emphasized that it is not too difficult for students to save energy. Simple steps like turning off lights, washing clothes in cool water, unplugging computer displays to avoid current leakage, and setting laptops to the hibernate mode could save a few kilowatt-hours per student per day. Every bit adds to the overall dorm energy savings.

Photo: Melody Craven, MIT Facilities

The 2007 winner, McCormick Hall. For more information on the competition, please go to <web.mit.edu/mit_energy/programs/campusenergy/dorm_electricity>.

"The simple act of knowing how much energy you are using can change behavior," Grejtak said, adding that one option being looked at is installing wireless meters that monitor electrical use and send real-time data to a website. With these meters, students could get up-to-the-minute information on their energy use.

Grejtak and Esposito agreed that the goal is to get students to make long-term behavioral changes. Other schools, such as Tufts University, have similar programs but do not offer a comprehensive retrofit as a prize. "It's about sustainable behavioral change," said Esposito. "We don't ask people to turn off their fridges during the campaign, only to have them turn them back on afterward."

Esposito said last year's competition yielded some valuable lessons. One main one was to get a longer baseline before the competition starts. Last year, the competition organizers had each dorm's energy use measured for one week; next year, they will measure a baseline for a longer time period, making the weekly measurement comparisons during the competition more accurate.

The organizers currently are raising money for the competition. Last year, the MIT Energy Initiative (MITEI) contributed funds for the contest's operating costs. The MIT Housing Department provided the $10,000 for the award. The organizers are looking for renewed support from the Housing Department and are also pursuing corporate and other funding sources. This year, the competition organizers have already been awarded funds from the MITEI's Student Campus Energy Project Fund.

Esposito also wants more participants in the contest than the 11 undergraduate dorms. She is hoping that outreach efforts will attract some of the 26 undergraduate fraternities, sororities, and independent living groups on campus, as well as some of the graduate dorms.

The competition will start with a kickoff event in the student center with a band and free food. There will also be events during the competition to encourage continued participation. Throughout the competition, the organizers will work with dorm coordinators to suggest specific activities for their unique living environments. For example, Simmons has more common areas where lights can be turned off, while Bexley residents may want to focus more on turning off individual room lights.

It takes some incentive to get students to save energy; but once they do, they continue this behavior. "The competition is a lot of fun," said Esposito. "It raises awareness about how much energy people use and how much they can save."

AGS annual meeting to be held at MIT

The complexity of responding to the challenges of climate change and sustainability has made timely and effective action difficult. A strong current of pessimism runs through the public dialogue, which seems to have evolved from "nothing is wrong so we need to do nothing" to "everything is so wrong that there is nothing we can do."

But it is not too late. Instead, it is time to deploy the knowledge we have—or will soon have—to identify and pursue pathways toward sustainability.

Designing such pathways will be the focus of the upcoming annual meeting of the Alliance for Global Sustainability (AGS), to be hosted at MIT on January 28–31, 2008. The meeting, titled "Designing Pathways for a Sustainable World: at Scale, in Time, and for All," will build on progress made in 2007 to develop AGS's "pathways" concept as a framework for advancing near-term transitions to sustainability.

The meeting will bring together about 200 international scholars, business leaders, and representatives from governments and nongovernmental organizations. Dr. R.K. Pachauri, director-general of the Energy and Resources Institute (formerly the Tata Energy Research Institute) and chairman of the Intergovernmental Panel on Climate Change (a winner of this year's Nobel Peace Prize), will give the keynote speech. Immediately following will be a panel discussion with IPCC lead authors. Both will be open to the MIT community.

The basis of the pathways concept is defining how we transition from our present systems, based on today's technologies, infrastructures, and markets, toward more sustainable systems. In navigating this transition, we must consider the scale, timing, and social equity of proposed bridging technologies and strategies as we respond to the urgent need for substantive action on climate, energy, food, and water challenges.

During the AGS meeting, participants will join panel discussions and parallel breakout sessions focusing on technology and policy options and on the educational challenges to developing the pathways. Topics will include how pathways can be designed and implemented in time to make a difference, how interactions between societal sectors and research universities can be made more effective, perspectives of agents of change and their innovative approaches, and implications of new pathways for the developing world. On the final day, discussions in the various sessions will be synthesized and action steps defined for meeting identified challenges.

For more information about the conference, including the program and online registration, please go to <web.mit.edu/agsam08>.

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By Karen Gibson, MIT Energy Initiative and Laboratory for Energy and the Environment

Designing Pathways for a Sustainable World: at Scale, in Time, and for All

28–31 January 2008 | Cambridge, MA USA

AltWheels festival

For the fifth year in a row, Laboratory for Energy and the Environment staff helped organize and run the AltWheels Alternative Transportation and Energy Festival in September 2007 (www.altwheels.org). Held on Boston City Hall Plaza, the two-day festival showed 35,000 visitors a broad variety of current and future clean energy technologies and practices. The 150 exhibitors included major automobile manufacturers showing hybrid, flex-fuel, and hydrogen vehicles; public transportation agencies; car-sharing organizations; alternative fuel suppliers; and more. Along the Energy Freedom Trail™, interactive exhibits by grassroots organizations and local museums showed how to save energy, "buy green," and reduce, reuse, and recycle.

Photo: Erik Gehring

Boston Mayor Thomas H. Menino (left), AltWheels founder Alison Sander, and Massachusetts Secretary of Energy and Environmental Affairs Ian Bowles at the AltWheels Green Pioneers awards ceremony.

Photo: Stephen Connors, MIT LFEE

AltWheels attendees check out biodiesel- and vegetable-oil-fueled cars and trucks along Biodiesel Boulevard.

Workshop celebrates new doctoral program in Portugal

On October 6–8, 2007, the Sustainable Energy Systems Focus Area of the MIT-Portugal Program launched its new doctoral program with a three-day workshop that highlighted the challenges to the design and deployment of sustainable energy systems.

Organized and led by David H. Marks, the Morton and Claire Goulder Family Professor of Civil and Environmental Engineering and Engineering Systems, the workshop gathered 48 students and 23 faculty and staff from MIT and from the five Portuguese institutions that are collaborating in the joint doctoral program in Portugal. Together, the attendees examined research needs in the area of building design, including microgeneration; smart energy systems that coordinate local energy resources and demand management; and integrated energy planning and regulation from local, national, and international dimensions.

The workshop celebrated the first PhD program to be offered jointly by the Portuguese institutions, with assistance from MIT. Participating are the University of Porto's Faculty of Engineering, the Technical University of Lisbon including the Instituto Superior Técnico and the Instituto Superior de Economia e Gestão, the University of Lisbon's Faculty of Science, and the University of Coimbra's Faculty of Science and Technology.

The first doctoral workshop was held in the historic city of Porto. Attendees from MIT included Marks; Leon Glicksman, professor of building technology and mechanical engineering and director of MIT's Building Technology Program; Stephen Connors, director of the Analysis Group for Regional Energy Alternatives at MIT's Laboratory for

David H. Marks, the Morton and Claire Goulder Family Professor of Civil and Environmental Engineering and Engineering Systems.

Energy and the Environment (LFEE); and 13 MIT graduate students.

The Sustainable Energy Systems Focus Area, led by the LFEE, is part of the MIT-Portugal Program, a five-year research and educational collaboration supported by the Portuguese government working with numerous Portuguese research universities, industry, and government. Marks and Connors have been working with MIT-Portugal Program headquarters since summer 2006 to design and implement the Sustainable Energy Systems research and education program.

Through the research program, MIT teams are collaborating with Portuguese colleagues on projects addressing integrated energy systems, economics and regulation, and distributed energy systems. Key to the design of the program is the recognition that while clean-energy technology is a "global business," the deployment and best use of component technologies is "situational." Local energy resources, the age and distribution of existing energy networks, and the energy-consuming "built environment" are all crucial factors when looking at how new energy technologies might benefit a given region.

Collaborative research projects in the focus area and their MIT participants include the following:

- Interactions among building, neighborhood, and city design from energy and materials flow perspectives (Glicksman and Professors Leslie Norford and John Fernandez of architecture)
- Smart electrical/energy networks to improve overall system performance by enabling dynamic load control and diverse mixes of renewable generation (Professor James Kirtley of electrical engineering and computer science, Professor Richard Larson of civil and environmental engineering and engineering systems, and Connors)
- Markets for energy and emissions (Drs. A. Denny Ellerman and John Parsons, Center for Energy and Environmental Policy Research)
- Wave energy systems (Professor Chiang Mei of civil and environmental engineering and Professor Michael Triantafyllou of mechanical engineering)
- Alternative vehicles and fuels, including plug-in hybrids (Professor John Heywood of mechanical engineering)

The MIT-Portugal Program is housed in MIT's Engineering Systems Division and includes tracks in transportation, manufacturing, and bioengineering in addition to sustainable energy and a cross-cutting "engineering systems" set of activities. The program is now entering its second year, with the first year being a startup year. For further details, go to <www.mitportugal.org>.

Inauguration ceremonies held for energy center at the Cyprus Institute

In ceremonies held on December 10, 2007, the Energy, Environment, and Water Research Center (EEWRC) of the Cyprus Institute (CyI) celebrated the commencement of its operations. Attendees included the president of the Republic of Cyprus, Tassos Papadopoulos, and many other dignitaries from Cyprus and abroad.

MIT's Laboratory for Energy and the Environment (LFEE) featured prominently at the inauguration ceremonies. The EEWRC is being developed in close cooperation with the LFEE and its Cyprus Institute Program for Energy, Environment, and Water Resources (CEEW), which is directed by Professor David H. Marks, the Morton and Claire Goulder Family Professor of Civil and Environmental Engineering and Engineering Systems.

At the ceremony, Professor Ernest J. Moniz, the Cecil and Ida Green Professor of Physics and Engineering Systems at MIT and director of the MIT Energy Initiative, was decorated by President Papadopoulos for his contributions to the establishment of the Cyprus Institute and EEWRC and to the development of research and education in the Republic. At the close of the inauguration day, Professor Moniz presented a public lecture on "Energy Supply and Climate Change—Can We Manage Both?"

Ceremonies at the Cyprus Institute on December 10 celebrated not only the commencement of operations of the Energy, Environment, and Water Research Center but also the inauguration of the center's new "Guy Ourisson" Building, shown above.

The December 10 event was a significant milestone in the development of the EEWRC. It marked the inauguration of the Center's first building as well as a number of important scientific initiatives. Of particular interest is the launching of a new climate change "Meta Study." This study, which will be led by a group of scientists of international repute, will address the impacts of climate change on the Eastern Mediterranean and North Africa, a region of great political significance that is expected to be disproportionately affected by climate change. The ambitious project complies with the objective of the Cyprus Institute to work on problems of regional importance and global significance.

The link between the Cyprus Institute and MIT also has other facets, including activities on campus. A joint doctoral and postdoctoral program between the CEEW and the EEWRC is considered a vital element in enhancing the collaboration between MIT and the Cyprus Institute. The first two postdocs have been appointed under this initiative. Dr. Nicholas Polydorides arrived at MIT in October and is now working with Professor Dimitri Bertsekas of electrical engineering and computer science on energy-related computational problems, particularly on issues relevant to underground carbon sequestration techniques. Dr. Jan Adamowski will arrive in January and will be collaborating with Professor Elfatih Eltahir of civil and environmental engineering, Professor Marks, and Professor Lawrence Susskind and Dr. Herman Karl of urban studies and planning on problems of climate change impacts for water management in the Mediterranean Basin. After spending two years at MIT, both postdocs will continue their research at the EEWRC at the developing Cyprus Institute.

Other MIT involvements with the Cyprus Institute include collaborations with the MIT Center for Materials Research in Archaeology and Ethnology and the MIT Sea Grant Program. For more information on the Cyprus Institute, go to <www.cyprusinstitute.ac.cy>.

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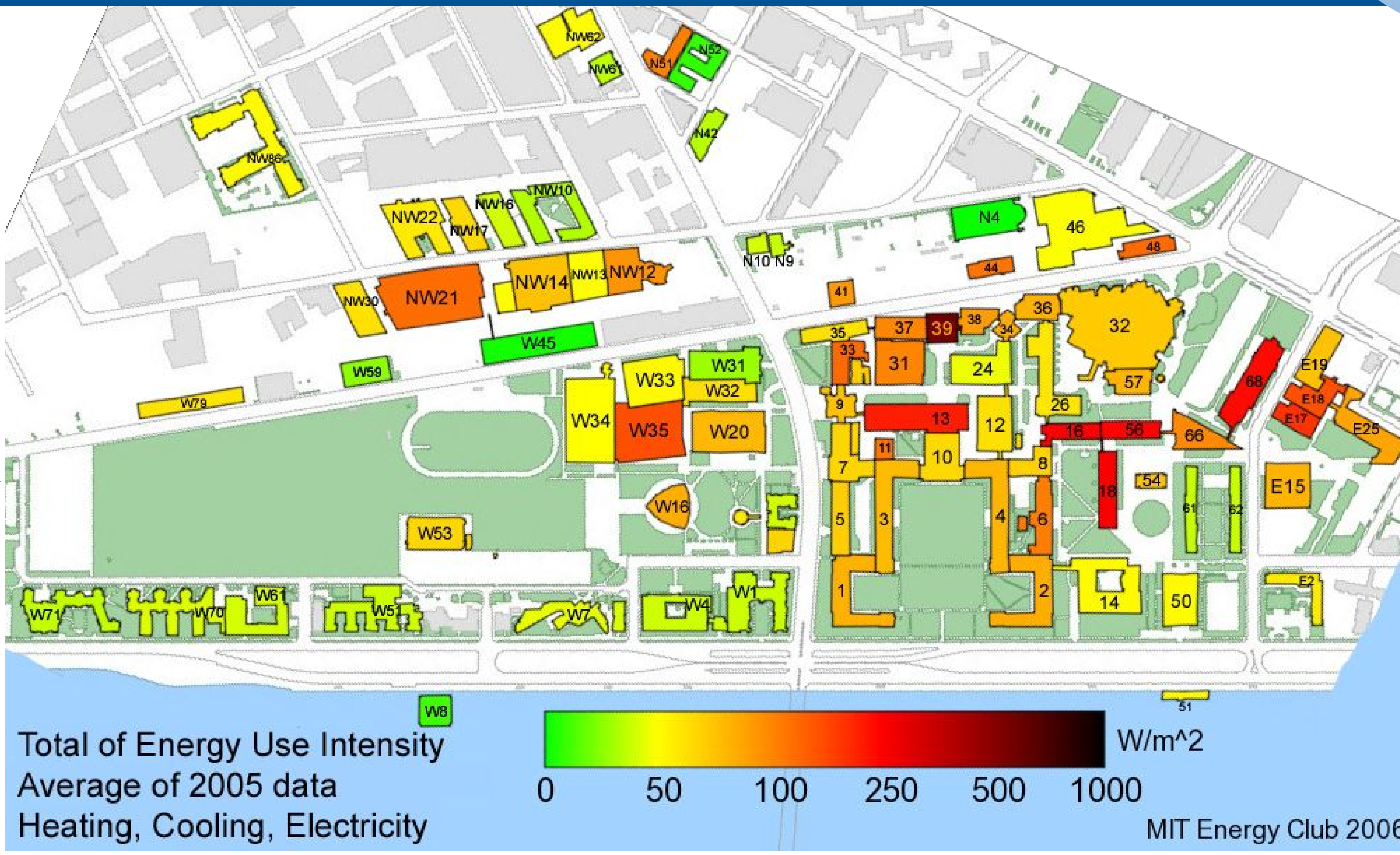

Graphic: Steven Peters and Elsa Olivetti

With support from the MIT Energy Initiative, a team of MIT students developed software that generated this map showing energy use intensity across campus, building by building, based on data provided by the MIT Department of Facilities. The students are now developing an automated display system that will post real-time energy use data on the web so building occupants can check on their building's usage. MITEI's new Student Campus Energy Project Fund is supporting a variety of such innovative student projects aimed at reducing the energy and environmental footprint of the campus **(see page 19).**

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