A comprehensive, multidisciplinary study led by MIT researchers has produced a set of recommended actions that could retain nuclear power as a viable carbon-free source of electricity for the future.

The leaders of the study, Professors John Deutch and Ernest Moniz, believe that all options for reducing carbon emissions must be retained as possible responses to potential global warming. The main options, they say, are increased efficiency, renewable resources, carbon sequestration, and nuclear power.

"If we do not take action now, we may lose the nuclear option—one that has the potential to provide lots of carbon-free electricity. The world's population is expected to increase dramatically and so is urbanization. Having large, economical, non-fossil, baseload power plants may be critical."

To determine what steps we should take to retain the nuclear option, Professors Deutch and Moniz assembled a multidisciplinary team of researchers who together examined the technical, economic, environmental, and political issues involved. An external advisory group of experts was convened to help with the decision-making process, and their advice is included in the final report.

"Uncertainty about parameters like future emissions and climate sensitivity is not going to be resolved anytime soon," said Dr. John Reilly of the Joint Program on the Science and Policy of Global Change. "The challenge is to make decisions despite that uncertainty."

Researchers at MIT can now calculate how much a given emissions-reduction policy is likely to reduce the odds of serious impacts from global climate change. Their analytical model takes uncertain inputs such as economic growth, greenhouse gas (GHG) emissions, and climate behavior and calculates the probability of specific outcomes. Thus, it forecasts a set of possible temperature increases by 2100 and the probability that each will occur. Subsequent runs using lower emissions assumptions show how emissions-control policies could change those probabilities.

For decades, the climate-change policy-making process has been stymied by pervasive uncertainty. How much will temperature change and how soon? How sensitive is the climate to GHGs in the atmosphere? And what impact will policies to limit emissions actually have on future temperatures?

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An important but uncertain input parameter in climate change modeling is climate sensitivity, a measure of the change in temperature caused by a doubling of atmospheric carbon dioxide. As shown in this figure, the MIT researchers determined a range of climate sensitivity values and the likelihood that each would occur. Thus, values from 2°C to 3°C are most likely, while values less than 1°C and more than 8°C are less likely but possible.
have developed a method of quantifying and communicating uncertainty. They perform analyses using their Integrated Global System Model (IGSM), a set of linked computer models that simulate economic growth and associated emissions, flows of GHGs into and out of land and oceans, chemical reactions in the atmosphere, climate dynamics, and changes in natural terrestrial ecosystems. The models and the processes they simulate interact, with outputs from one serving as inputs for another.

Before running the IGSM, the researchers must quantify the uncertainties of the many parameters that drive it, from economic growth and energy efficiency improvement to emissions of methane from agriculture and of nitrous oxides from industry. They must also define uncertainties associated with critical processes, including poorly understood processes such as the uptake of carbon dioxide by the oceans and the reflection of heat by particulate pollutants in the atmosphere.

For each parameter and process, the researchers use available data and expert judgment to find not only a possible range of values but also the probability that each will occur. The figure on page 1 shows a sample curve for climate sensitivity, a term that refers to the change in equilibrium temperature caused by a doubling of carbon dioxide in the atmosphere. The researchers based their estimates on 50 years of measurements of atmospheric and oceanic temperatures and calculated interrelationships among climate sensitivity, the effects of aerosols, and the rate at which the deep oceans take up heat.

To permit those uncertainties to propagate through the IGSM, they run the model many times with varying values for each parameter. In every run, the model uses a numerical sampling method to choose a value for each parameter. The sampling method is constructed so that each set of values has an equal probability of occurring. For each set of input parameter values, the IGSM run produces a different result for outcomes such as predicted temperature increase and sea-level rise. By operating 16 computer processors non-stop for about a month, the researchers perform 250 runs—enough to get a good approximation of the distribution of outcomes one would get if the model were run thousands of times. Taking the results from all the runs yields a range of values for a given outcome, with a probability for each value. The uncertainties of the input parameters are thus reflected in the uncertainty of the results.

The figure below shows sample results for calculated temperature increase between 1990 and 2100, presented by latitude. The solid lines show results from "business as usual" assumptions. Ninety-five percent of the calculated values fall between the lines marked "upper 95% bound" and "lower 95% bound." Only 5% of the values were outside those bounds, with 2.5% falling above and 2.5% falling below. At the median, half of the values are above and half are below.

As expected, predicted temperature change varies with latitude. Estimated warming—as well as the associated uncertainty—is significantly greater near the poles than in the tropics. The upper bound is especially worrisome at the poles. Because 2.5% of the answers were above

![Projected Change in Surface Warming Between 1990 and 2100, Presented by Latitude](image-url)
that bound, the data suggest that there is a 1 in 40 chance that warming will exceed 8°C at the South Pole and 12°C at the North Pole.

How might policies to control or reduce emissions change those outcomes? The dashed lines in the figure show results assuming an emissions-control policy that would (for reference climate model conditions) stabilize atmospheric concentrations of carbon dioxide at 550 ppm. Such a policy would require incredibly efficient vehicles and homes and use of non-carbon fuels or carbon sequestration. But the reduction in emissions significantly reduces the temperature increase. Most important, it cuts the unlikely-but-possible high end almost in half.

Reducing the likelihood of the worst-case outcome is a good policy goal, advised Dr. Reilly. “If we restrict emissions, we do not necessarily eliminate the odds of really bad things happening, but we can reduce them. It is like deciding to buckle our seat belts. We do not eliminate the chance that we will die in an accident, but we reduce it,” he said.

The table above presents a quick view of the potential benefits of adopting possible policies versus doing nothing. The left column identifies some specific, serious changes that could occur. The next three columns present the odds that those changes will occur assuming no policy, a relatively lenient emissions-control policy, and finally the stringent policy discussed above. While the lenient policy helps, the more-stringent policy dramatically reduces or potentially eliminates the probability of the selected outcomes.

Teams of researchers in the Joint Program are now working to reconsider the underlying input distributions that go into the analysis. While they might hope to reduce uncertainty, the challenge is to use the available data to constrain parameters of the system when we have a still-incomplete understanding of all the processes that create variability in the climate system.

Dr. Reilly acknowledges that much work remains to be done. In the meantime, he says, “We have taken the best available information and used our best judgment to pull it together. This is what we know today, and we can make our decisions based on it. No doubt we will have to make adjustments in the future because as we learn more, we will know we were not quite right. It is called sequential decision making under uncertainty, and it is the only approach that will allow us to move forward on climate-change policy.”

John Reilly is the associate director for research of the Joint Program on the Science and Policy of Global Change and a senior research scientist in the Laboratory for Energy and the Environment. Mort Webster received his PhD from MIT’s Engineering Systems Division in February 2000 and was subsequently a postdoctoral research associate in the Joint Program until June 2001. He is now an assistant professor in the Department of Public Policy at the University of North Carolina at Chapel Hill. Chris Forest is a research scientist in the Joint Program. This research is supported by the US Department of Energy, the US Environmental Protection Agency, and a group of corporate sponsors from the United States and other countries. Further information can be found in references 1–4.
What energy and environmental issues do you think should be addressed? An important focus will be the scientific, technological, economic, and policy challenges associated with climate change, an area in which MIT has established strong programs. Meeting global energy supply needs for economic and social development while constraining carbon emissions is an extraordinarily difficult challenge that we need to address now. There are relatively few technology pathways available, those being energy efficiency, renewables, nuclear power, and carbon sequestration. It is important to maintain all of them as significant options.

You have already completed one such study: the two-year assessment of the nuclear option, which you chaired with Institute Professor John Deutch, also a former Undersecretary of Energy. Yes, I view the nuclear study as a model, or “template,” for future studies. In that study, researchers from four of MIT’s schools performed an integrated, comprehensive analysis of what it would take for nuclear power to be deployed by mid-century at a level that would significantly help in constraining carbon dioxide emissions (see “Preserving the Nuclear Power Option” on page 1). In our final report, we identified unresolved problems concerning cost, waste management, nonproliferation, and safety. We made specific recommendations for tackling those problems, including policy actions and new programs of R&D that would enable the nuclear option to be retained in the portfolio of responses to climate change.

Sounds like a difficult undertaking. We have no illusions about the ease with which our recommendations can be implemented. But we also have no illusions about the difficulty of addressing the carbon problem. If during the next five or six years we at MIT can develop technology-grounded recommendations across the set of options for dealing with the carbon problem, it will be a major contribution.

How will you decide what topics to address? We are forming a committee of interested MIT faculty, and together we will define important energy and environment study areas where faculty and staff across the Institute are interested in coming together to shape and carry through integrative analyses. MIT has a long history of research on energy and the environment, but creating new links among faculty with diverse perspectives should bring added value and new insights.

The R&D programs recommended by the studies should also provide new opportunities for MIT research. Yes. The nuclear study, for example, identified several major research thrusts that would draw on faculty and students across the Institute. My colleagues and I will assess faculty interest and, where possible and helpful, facilitate collaborations to propose and carry out the recommended research programs.

Will MIT students be able to play a role in the broad, integrative studies? Yes, all the activities will provide significant educational benefits. The nuclear study yielded three master’s degrees, a pattern that should be sustained in follow-on research programs. Additional course offerings and a PhD program in energy and the environment could ultimately be made available to students through existing academic departments and the Engineering Systems Division.

What is your definition of success? I will deem our efforts a success if five years from now we have a cohesive community of 30 or 40 MIT economists, engineers, scientists, and others who collaborate on research, regularly assemble for colloquia, guide student theses, develop curricula, and offer new insights that affect energy and environmental policy-making. Our ability to contribute will be greatest if we can weave together people from across the Institute in a coherent fashion.

Ernest Moniz appointed Director of Energy Studies at MIT's Laboratory for Energy and the Environment

In July 2003, Ernest Moniz, MIT professor of physics, became Director of Energy Studies at MIT’s Laboratory for Energy and the Environment (LFEE). An MIT faculty member since 1973, Professor Moniz served as Undersecretary of the US Department of Energy (DOE) from October 1997 to January 2001, with oversight responsibility for DOE’s energy and environmental and science programs. He also served as the Secretary’s lead negotiator for Russian cooperative programs. From 1989 to 1997, he was Associate Director for Science in the Office of Science and Technology Policy in the Executive Office of the President. At MIT, he has served as head of the Department of Physics and as director of the Bates Linear Accelerator Center.

How did your experience at DOE influence your activities at MIT? As Undersecretary of Energy, I focused on advancing the intersection of science and technology research with policy development and implementation. I see enormous opportunity to continue promoting such work at MIT through multidisciplinary research built on the extraordinary strengths of MIT’s faculty in science, engineering, economics, and other disciplines.

How will you pursue that opportunity? From my position at LFEE, I will help initiate integrative studies that involve researchers from across the Institute, are technically grounded, and lead to policy recommendations, including recommendations for public funding of R&D aligned with strategic energy and environmental goals. The studies will be targeted at government, industry, and academic leaders and will involve high-level external advisory committees offering diverse experiences and perspectives.
Preserving the Nuclear Power Option
continued from page 1

high-level experts provided guidance and input based on their wide-ranging experience and knowledge. The target audience was leaders in government, industry, and academia.

Clearly, retaining the nuclear option will not be easy. The researchers selected a scenario with a high payoff. They looked at a worldwide nuclear capacity of 1,000 gigawatt-electric in 2050—about triple today’s capacity and a level at which nuclear generation would contribute significantly to avoiding carbon dioxide emissions. Such growth would keep nuclear’s share of the electricity market about constant as the total electricity market expands.

What are the main challenges to such a global expansion of nuclear power, and what practical steps could we take now to make the 2050 nuclear scenario feasible? The team focused on four unresolved problems: cost, waste management, nonproliferation, and safety.

Cost

To explore the cost issue, they built a model of the actual economic cost (not regulated or subsidized cost) of producing electricity from new nuclear, coal, and natural gas plants—the major existing base-load technologies. The top table shows some of their findings. The baseline cost of electricity is 6.7¢/kilowatt-hour from nuclear plants, 4.2¢ from coal plants, and 3.8¢ from natural gas plants if gas prices are low and 5.6¢ if gas prices are high. Thus, the baseline nuclear cost is well above the others, even assuming high natural gas prices.

Reductions in construction cost and time as well as in operating and maintenance costs could bring nuclear costs down to 4.2¢—more in line with those of coal and gas. But accomplishing those changes may be hard:

<table>
<thead>
<tr>
<th>Case</th>
<th>Real Levelized Cost (cents/kWe-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear (light water reactor)</td>
<td>6.7</td>
</tr>
<tr>
<td>1. Reduce construction cost 25%</td>
<td>5.5</td>
</tr>
<tr>
<td>2. Reduce construction time from 5 to 4 years</td>
<td>5.3</td>
</tr>
<tr>
<td>3. Further reduce O&amp;M to 13 mills/kWe-hr</td>
<td>5.1</td>
</tr>
<tr>
<td>4. Reduce cost of capital to gas/coal</td>
<td>4.2</td>
</tr>
<tr>
<td>Pulverized Coal</td>
<td>4.2</td>
</tr>
<tr>
<td>CCGT* (low gas prices, $3.77/MCF)</td>
<td>3.8</td>
</tr>
<tr>
<td>CCGT (moderate gas prices, $4.42/MCF)</td>
<td>4.1</td>
</tr>
<tr>
<td>CCGT (high gas prices, $6.72/MCF)</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*Combined cycle gas turbine. Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

Carbon Tax Cases (levelized electricity cost, cents/kWe-hr)

<table>
<thead>
<tr>
<th>Carbon Tax Cases</th>
<th>$0/tonne C</th>
<th>$50/tonne C</th>
<th>$100/tonne C</th>
<th>$200/tonne C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>4.2</td>
<td>5.4</td>
<td>6.6</td>
<td>9.0</td>
</tr>
<tr>
<td>Gas (low)</td>
<td>3.8</td>
<td>4.3</td>
<td>4.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Gas (moderate)</td>
<td>4.1</td>
<td>4.7</td>
<td>5.2</td>
<td>6.2</td>
</tr>
<tr>
<td>Gas (high)</td>
<td>5.6</td>
<td>6.1</td>
<td>6.7</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Even so, companies may be reluctant to take on the risk of investing in new nuclear power plants. As an incentive, the researchers recommend that the government provide a “production tax credit” similar to that extended to wind power. A limited number of investors who build nuclear plants that use safety-enhancing reactor designs would get “first-mover” tax credits on construction costs. However, the tax credit would come only after the plants are built and operating competitively. The tax credit could also be extended to other carbon-free electricity technologies.

Continued on page 6
Preserving the Nuclear Power Option

continued from page 5

Waste management
Managing and disposing of high-level radioactive waste is another intractable problem for the nuclear industry. Successful operation of the planned disposal facility at Yucca Mountain would ease the waste issue in the United States. But that response is far from sufficient if there is a substantial increase in nuclear power consumption in the United States and other countries.

The research team recommends that the US Department of Energy (DOE) undertake a broader program of research and development, including looking at other possibilities. For example, burying spent fuel in boreholes several kilometers deep in crystalline rock may offer significant benefits compared to mined repositories like Yucca Mountain, but a lot of science and engineering must be addressed first.

Nonproliferation
The risk of proliferation is a potential showstopper for the expansion of nuclear power. The researchers suggest several approaches to deterring proliferation. One is through the careful choice of technology. The researchers advocate using the “open cycle” approach, which sends the nuclear waste to a repository rather than recycling it. They estimate that uranium resources available at reasonable cost will be adequate for at least the next 50 years. The “closed cycle” approach involves reprocessing, that is, separating plutonium from the spent fuel and sending it back to the reactor. That approach is more expensive than the open cycle approach, and the separated plutonium can be used directly in weapons.

The other major deterrent is the nonproliferation treaty framework. The current regime will be inadequate if more countries use substantially larger amounts of nuclear power. A better approach would be to have a small number of “complete fuel-cycle” countries, subject to international treaty and oversight mechanisms and providing cost-competitive fuel-cycle services. Specifically, those countries would provide others with fresh fuel and would remove their spent fuel. Resolving the waste management issues is obviously critical to such arrangements.

According to Professor Moniz, “That is the kind of change in the nonproliferation regime that will be needed for nuclear to be significant worldwide.”

Safety
The research team recommends that the 2050 nuclear scenario be subjected to the same safety standard used today, namely, less than one serious release-of-radioactivity accident in every 50 years from all fuel-cycle activity. Given the nuclear expansion assumed, that standard implies a tenfold reduction in the expected frequency of serious reactor core accidents. Noting the limited safety analysis undertaken to date, the researchers recommend that the government more fully develop the capabilities to analyze life-cycle health and safety impacts of all fuel-cycle facilities.

Other needs and recommendations
Throughout their study, the researchers were struck by the lack of analytical tools for integrated evaluation of fuel cycles. They urge the DOE (perhaps in cooperation with other countries) to establish a Nuclear System Modeling Project. The project would collect the engineering data and perform the analysis necessary to evaluate various reactor concepts and fuel cycles using the criteria of cost, waste management, nonproliferation, and safety.

Expensive demonstration projects should be delayed pending the outcome of this multi-year effort.

Finally, the researchers note that public acceptance of nuclear power is critical to its expanded deployment. Surveys show that most Americans and Europeans oppose building new nuclear power plants. However, the researchers’ survey of more than 1,300 American adults suggested that much of the US public does not view nuclear power as a means of addressing global warming. Public education could help people understand the link between global warming, fossil fuel usage, and the need for carbon-free energy sources such as nuclear power.

The researchers emphasize that nuclear power should be seen as a long-term option and should be pursued along with other options including increased efficiency, renewable energy sources, and carbon sequestration.

Acknowledging the difficulty of implementing the studies’ recommendations, Professor Moniz said, “The time needed to act on carbon emissions may be much longer than the time that was required to reduce sulfur emissions. The carbon problem is international in scope, and it involves infrastructure that turns over very slowly. If we have not begun to make changes in the next ten years, it is going to be difficult or impossible to be where we want to be in 2050.”

John Doucet is a professor of chemistry at MIT and a former director of central intelligence and former undersecretary of energy. Ernest Moniz is a professor of physics at MIT, a former undersecretary of energy, and director of energy studies at the Laboratory for Energy and the Environment. The study was supported by the Alfred P. Sloan Foundation and by MIT’s Office of the Provost and Laboratory for Energy and the Environment. Go to <http://web.mit.edu/nuclearpower/> for a pull of the final report, including a complete list of the members of the study team and of the advisory board.
Research Brief
Estimating emissions reductions from using renewable energy

State regulators must develop formal plans describing the monitoring programs, emissions standards, and other measures they will undertake to ensure that their regions meet federal clean air laws. Recent studies by the Laboratory for Energy and the Environment's Analysis Group for Regional Electricity Alternatives (AGREA) will help them with one challenging part of that task: finding reasonable estimates of the emissions reductions to be gained by including solar- and wind-generated electricity in their plans.

Graduate students Michael Adams and Katherine Martin of MIT's Engineering Systems Division, assisted by Stephen Connors, AGREA's director and LFEE research engineer; integrated numerous US Environmental Protection Agency (EPA) and other databases to look at how emissions reductions from solar photovoltaic (PV) systems vary across the contiguous 48 states. They examined hourly electricity generation from PV systems and matched it with the per-kilowatt-hour emissions from fossil-fuel-fired units in the same power grid, in the same hour. To make their "avoided emissions" estimates more accurate, they used EPA's generation and emissions data (1998–2002) to calculate emissions rates from those fossil units that respond to changes in electricity demand, including changes due to the operation of small sources of generation such as PV systems and small and moderately sized wind farms.

Their results confirm that emissions reductions from "non-dispatchable" resources such as solar and wind generation and electricity conservation are highly dependent on exactly when and where they are used. For example, in Texas, PV systems displace more pollutant emissions in winter than they do in summer, even though the PV systems generate more electricity in summer. The explanation: in summer, Texas brings on cleaner natural-gas-fired generation to meet air-conditioning peaks, so the first units to respond to the solar-generated electricity are the cleaner ones. Another comparison shows that a PV system used in the Southwest will produce 30% more kilowatt-hours than similar systems in the Ohio Valley will. However, the resulting reduction in annual sulfur dioxide emissions will be greater in the Ohio Valley because coal-fired power plants in that region use higher-sulfur coals. Both observations demonstrate the importance of siting future renewable systems such as solar and wind not only where it is sunny or windy but also where electricity production is dirty.

AGREA analyses also suggest that solar-generated electricity and wind-generated electricity are complementary. Solar-generated electricity tends to displace expensive, clean peak-load generation, while wind power is more likely to displace dirtier off-peak generation.

Other AGREA activities include continued assistance to the Mexico City Program in designing integrated emissions-reduction strategies, a new project with universities in Norway and Sweden to identify viable transition paths to a sustainable energy future, and an initiative focusing on offshore wind and robust mini power grids for impoverished areas of developing countries.

News
Professor Beér to receive DOE’s 2003 Lowry Award

Janós M. Beér, professor emeritus of chemical and fuel engineering at MIT, has been named recipient of the US Department of Energy’s 2003 Homer H. Lowry Award, the highest honor given by the Energy Department for outstanding contributions to fossil energy science and technology. The prestigious award, consisting of a citation, a gold medal, and $25,000 in cash, has been presented just seven times since it was established in 1985. In announcing the award, Secretary of Energy Spencer Abraham said, “Dr. Beér has made pioneering research and development contributions for 45 years to combustion science and technology of coal, oil, and gaseous fuels.” Professor Beér was cited in particular for his research leading to commercial burners that control the fuel/air ratio and temperature during combustion to minimize emissions of nitrogen oxides while maintaining high combustion efficiency. Professor Beér was a longtime leader of combustion research in the Energy Laboratory, director of MIT’s Combustion Research Facility from 1976–1993, and a collaborator on Alliance for Global Sustainability research to develop energy-efficient and low-pollution technologies for China. Secretary Abraham presented the award to Professor Beér at a ceremony in Washington, DC, on January 30, 2004.

Janós M. Beér, recipient of DOE’s 2003 Lowry Award
Photo: Marta Beér.
Researchers at MIT and Tsinghua University in Beijing will be collaborating on the development of a pebble-bed nuclear reactor, thanks to a recent international agreement between the US Department of Energy and the China Atomic Energy Authority. With its novel, small-size, modular design, the pebble-bed reactor could become a cost-competitive, meltdown-resistant technology base for future innovations.

For the past six years, MIT and Tsinghua research teams have been working independently on studies of the modular high-temperature pebble-bed reactor. MIT researchers have been performing analytical studies and simulations, while Tsinghua researchers have built and are running experiments in a 10-megawatt (thermal) research reactor, the world’s only operating pebble-bed reactor.

Now the teams will be able to work jointly, coordinating their analytical and experimental studies. Their collaboration is the first case covered by the new international agreement, adopted in mid-September, which establishes mechanisms for the United States and China to exchange technologies and ideas relating to nuclear power.

“The agreement provides an incredible opportunity for bringing the world together on this promising technology,” said Professor Andrew Kadak of the Department of Nuclear Engineering. Professor Kadak leads the MIT research and was instrumental in the three-year effort to get the agreement signed. He is now contacting other pebble-bed researchers in the United States, Europe, South Africa, and elsewhere to develop a list of important topics to address. “I am trying to develop an international effort that will go far beyond the MIT/Tsinghua collaboration since there is worldwide interest in the technology,” he said.

While groups in South Africa and the United States have plans to build pebble-bed reactors, Professor Kadak would like to see the Tsinghua reactor become “the world’s research reactor for this technology to provide the technology base for future innovations.”

Professor Mujid Kazimi, director of MIT’s Center for Advanced Nuclear Energy Systems and a professor of nuclear engineering, stressed the importance of the international agreement itself, which covers the commercial exchange of technologies as well as collaborative research and defines procedures for the government-to-government exchange of nonproliferation assurances. “The agreement thus furthers international cooperation in the area of proliferation-resistant technology,” said Professor Kazimi.

The current MIT research on the pebble-bed reactor dates back to an MIT Independent Activities Period class led by Professor Kadak in 1998. Instructed to find a technology that could address the competitive and political challenges of the nuclear industry, students in the class ultimately selected the pebble-bed reactor—a design originally developed in Germany in the 1960s and studied by the late MIT Professor Lawrence Lidsky in the 1980s. The reactor’s name reflects its fuel: uranium is encased in billiard-ball-size graphite pebbles that cannot get hot enough to melt within the small core and are “prepackaged” for long-term disposal without reprocessing.

Professor Kadak, co-principal investigator Associate Professor Ronald Ballinger of the Departments of Nuclear Engineering and Materials Science and Engineering, and their student design team began taking a fresh look at all aspects of the technology, including the fundamentals of fuel design, safety, and the power-conversion system. Recently, their attention has focused on the modular approach to construction. Block-like structures containing specified components would be manufactured in factories, then shipped and assembled at the site—an approach that could cut construction costs in half.

The “plug-and-play” approach to construction and the small size of the reactor could revolutionize the way nuclear plants are built. “If this works, the economic obstacle to building new nuclear plants will be removed,” said Professor Kadak. If competitive, such small, modular plants will be attractive not only to the US market but also to China and other countries that are developing rapidly and have widely dispersed populations to serve.

Initial exchanges between MIT and Tsinghua were supported by the MIT Laboratory for Energy and the Environment and the MIT International Science and Technology Initiatives. Research funding was subsequently provided by the Idaho National Engineering and Environmental Laboratory and the US Department of Energy. Current funding comes from the US Nuclear Regulatory Commission.
News

Event celebrates MIT’s first on-campus solar-power installation

On October 15, Henrietta Davis, vice mayor of the City of Cambridge, unraveled a ribbon around a sample solar panel to mark MIT’s first solar-power installation—an array of 24 photovoltaic (PV) panels placed on the roof of the Stratton Student Center.

She then presented the leaders of the installation team with a Cambridge proclamation commending their work. Named on the proclamation were Edward Kern of the Laboratory for Energy and the Environment (LFEE), Samuel Nutter and Steven Weisman of the Massachusetts Technology Collaborative (MTC), and Laxmi Rao and Peter Cooper of MIT Utilities.

The Student Center installation will demonstrate the capabilities of the PV technology as part of a broad initiative involving MIT, the City of Cambridge, and the local PV industry. The PV installation provides electricity to the Student Center and is linked to the MIT electric distribution grid.

The ceremony was held on the first floor of the Student Center and was followed by small-group trips to the roof to see the PV panels first-hand. The large gathering of attendees included John Curry, executive vice president of MIT, and students from MIT’s environmental groups.

At the ceremony, Ms. Rao, project manager for the Student Center system, said, “Initial inspiration for the project came from students pressuring MIT to ‘go green.’ The installation will help MIT contribute to the climate action goals set forth by the City of Cambridge, and it will raise awareness of solar power. Architects, consumers, and other designers and potential users will come to MIT to learn from our experience.” She noted plans to install PVs on several other MIT buildings.

MIT has a history of environmental initiatives, including conversion to energy-efficient lighting and installation of an efficient heat-and-power cogeneration system. But the PV project provided “an unusual opportunity for students to get involved in on-campus green activities,” said Philip Michael Sheehy of the MIT Students for Global Sustainability (SFGS).

Experience with the PVs will be integrated into both research and educational activities, including a class offering during Independent Activities Period. Members of the SFGS have produced a video of the installation, and a kiosk on the main floor of the Student Center will monitor the performance of the system in real time.

The Student Center installation is part of the MIT Community Solar Power Initiative, which is supported by a grant from the MTC. The grant provides $455,000 to help fund PV installations of about 75 kilowatts on the MIT campus; on schools, homes, and businesses in Cambridge, Watertown, Arlington, Lexington, and Waltham; and on homes of MIT-affiliated people in other communities. The MTC grant was awarded in October 2002 in response to a proposal submitted by Ms. Rao, Mr. Cooper, and Dr. Kern.

Speakers at the ceremony thanked the MTC not only for its financial support but also for providing the impetus for disparate MIT groups to join in pursuing a green campus. The Student Center installation involved collaborating teams from MIT’s Department of Facilities, Campus Activities Complex, and the SFGS.

Private sector partners were RWE Schott Solar, Inc., and Zapotec Energy. For more information about the MIT Community Solar Power Initiative, go to <http://solarpower.mit.edu/>.
News

MIT expert in building technology participates in Chinese energy planning

On November 16 and 17, MIT Professor Leon Glicksman participated in a high-level forum designed to help the Chinese government formulate an energy strategy for the next two decades. One of only a few dozen non-Chinese invitees, Professor Glicksman contributed by providing evidence of energy-related problems and opportunities in the buildings sector. His presentation was based on results from more than five years’ research into sustainable buildings for China, performed by the MIT Building Technology Program with Chinese and other collaborators and funded by the Kann-Rasmussen Foundation and the Alliance for Global Sustainability (AGS).

The special session of the China Development Forum was held in Beijing and focused on energy strategy and reform in China. About 150 scholars, business executives, and government officials attended, including ten Chinese ministerial officials who presented their opinions and exchanged ideas with participants. The forum was sponsored by the Development Research Center of the State Council. (The State Council is the governing body of the People’s Republic of China.)

Participants at the forum agreed that ensuring China’s future supply of energy is important, but first priority must be given to increasing the efficiency with which energy is used. China’s economy is expected to quadruple in the next 20 years. But quadrupling energy consumption to support that growth is not practical. Even now, China is the world’s second largest energy consumer, a major oil importer, and a leading contributor to global pollution. Increasing energy efficiency in all sectors is critical.

In his presentation, Professor Glicksman stressed the importance of the buildings sector. China is currently experiencing an enormous construction boom. In the residential sector alone, some 10 million units are being built per year. Those buildings will last far longer than most other types of energy-consuming equipment. China recently announced new, extremely strict fuel economy standards for cars built in China in the future. However, ensuring the construction of buildings that are energy efficient and environmentally sound is even more important. According to data presented by Professor Glicksman, a less-than-optimal automobile manufactured now will probably be replaced in less than a decade, but a poorly designed building going up now may not be replaced for 30 or 40 years. And many of the buildings now going up in China are indeed poor, as Professor Glicksman demonstrated with a series of photos. Members of the audience, including the Chinese minister of construction, readily agreed with that assessment. Investigation by the MIT research team has shown that, while China’s energy-conservation building codes are reasonably strict, they are not enforced. Designs are submitted for approval, but the finished buildings are rarely inspected for compliance.

Quality of construction is a persistent problem, as many workers are former farmers with little training or experience in construction. Thus, a critical policy challenge is finding a way to enforce the building codes or perhaps to provide incentives or information to builders and consumers that will ensure that the codes are met. Again, the audience agreed.

Professor Glicksman drew on his group’s research to describe some simple approaches to building design that can dramatically reduce energy consumption while maintaining comfort levels. Among the suggestions were planning for the flow of air and natural ventilation within a building; using good insulation, windows, and shades; and simply orienting the building to catch the sun’s heat in winter and the prevailing winds in summer. The use of natural rather than mechanical methods of heating and cooling can mean enormous energy savings. During just the past year, electricity demand in China grew 15%, with peak loads being driven by consumer demands, notably air conditioners.

Finally, Professor Glicksman described a new computer tool being developed at MIT to support energy-efficient building design. Architects, developers, city planners, and non-experts will be able to use the Web-based tool to see how building orientation, window choice, natural ventilation, and other options will affect energy use and comfort levels. The user-friendly tool is designed for use in the initial phases of the design process, well before detailed architectural drawings are begun.

The MIT-led research program is being performed in collaboration with Tongji University in Beijing, Tongji University in Shanghai, local Chinese development companies, and AGS partners Chalmers University of Technology and the Swiss Federal Institute of Technology, Zurich. For more details, see www.chinahousing.mit.edu or go to <http://chinahousing.mit.edu/> on the Web. Findings will be published in a book, Sustainable Urban Housing in China, scheduled for release in June 2004. The book will be the fifth volume in the series “Science and Technology: Tools for Sustainable Development,” published by Kluwer Academic Publications in cooperation with the AGS. The Web-based architectural design tool should be released in spring 2004 and will be described in an upcoming issue of energy & environment.
Forums consider carbon sequestration: progress and potential

“Scenarios for Carbon Sequestration,” the fourth annual MIT Carbon Sequestration Forum, was held on November 6 and 7. Presentations at the forum explored a variety of topics that may affect carbon sequestration’s role in the future.

Sessions focused on details of the generating and capture systems, including modeling their costs and market penetration rates; the government’s role in technological innovation; the future of nuclear power (potentially a major carbon-free generating technology); and what coal plants of the future might look like.

Participants agreed that carbon sequestration has the potential to reduce future greenhouse gas (GHG) emissions significantly, but major obstacles must be overcome. Carbon sequestration may be economically competitive with other methods of reducing energy-related carbon dioxide (CO2) emissions, such as nuclear power. However, like nuclear power, carbon sequestration is not competitive in today’s marketplace, which places no value on lowering CO2 emissions. Indeed, participants suggested that in the absence of tax credits or other economic incentives, technological innovation may be limited.

Discussion of future coal-based technologies for power plants concluded that the integrated gasification combined cycle (IGCC) approach is promising but may not be the panacea that some people believe it is. It is not well suited to all types of coal, and it is still an immature technology. The highly competitive electric power industry will remain wary of adopting it until it is proved sufficiently economical and robust. Thus, the opportunity exists for developing and implementing several technologies for coal plants for the future.

Other sessions of the forum looked at major research efforts aimed at moving carbon sequestration technologies from the laboratory into the field. One panel discussion of research activities involved principals from five of the seven regional carbon sequestration partnerships that were formed last summer by the US Department of Energy (DOE) to help determine the best approaches for capturing and permanently storing GHG emissions. Together, the partnerships involve nearly 150 state agencies, universities, and private companies that span the United States and parts of Canada.

Another session provided updates on major projects. One presentation described progress on the CO2 Capture Project, an international effort to develop new, less-expensive technologies for capturing and storing CO2. The project, funded by eight of the world’s leading energy companies and led by BP, is nearing completion of its first phase and making plans for an aggressive phase two.

Another presentation reported on the proposed FutureGen project. Funded by DOE with industrial cost-sharing, this international billion-dollar initiative to design and build the first emission-free, coal-fired power plant is ten times larger in both size and scope than any existing project on carbon sequestration. The project is scheduled to start officially in early 2004 with about nine million dollars of seed money.

Of particular note was the general level of activity in carbon sequestration research. Both the number and size of projects now under way have increased significantly since the first carbon sequestration forum was held three years ago.

The forum was sponsored by the Laboratory for Energy and the Environment’s Carbon Sequestration Initiative (CSI), an industrial consortium supporting research and information exchange on carbon sequestration technologies. The 95 attendees included representatives from the CSI member companies as well as other leaders in the field of carbon sequestration from industry, academia, and governments, including regulatory agencies.

AGS technical meeting features environmental negotiation simulation

This year’s technical meeting of the Alliance for Global Sustainability (AGS), held at MIT on November 17 and 18, focused on developing skills that will help AGS researchers interact with nonacademic stakeholders more effectively.

The two-day meeting, “Building Research Partnerships for Sustainable Development,” drew 100 participants from the four AGS universities—MIT, the University of Tokyo, the Swiss Federal Institute of Technology, and Chalmers University of Technology—as well as representatives from industry, government, nongovernmental organizations, and other academic institutions worldwide.

The highlight of the meeting was a negotiation exercise designed to give participants skills in interacting in multi-institutional and multidisciplinary collaborative efforts. The “Research Partnership Simulation” was developed especially for the AGS meeting by
Professor Lawrence E. Susskind (Department of Urban Studies and Planning), a leader in the field of negotiation, director of the MIT-Harvard Negotiation Project, and principal of the Cambridge-based Consensus Building Institute (CBI).

From its inception, the AGS’s approach to sustainability has required the integration of disciplinary and regional perspectives. The simulation designed by Professor Susskind and his CBI colleagues addressed another type of cultural difference—between the researchers who produce information and public and private sector actors who must put it into practice.

For the simulation, participants were organized into small groups, and individuals took on the roles of “knowledge producers” and “knowledge consumers.” The task of each small group was to integrate the unique goals and decision-making styles of the participants into a common set of objectives. The simulation was designed to elicit the technical, social, and cultural barriers and constraints to building an effective research partnership. Challenges included varying views of timing, professional perspective, and style. The exercise demonstrated some of the communications issues underlying cooperative research efforts among stakeholders with differing priorities. One question raised was whether the media should play a role in linking the producers and consumers of knowledge.

Following the simulation were concurrent workshops on AGS projects that focused on current and prospective research areas where the skills learned in the negotiation exercise could be put into use. Three of the workshops focused on new research partnerships.

“Bridges to Sustainable Futures: An International Research Partnership to Study Social and Political Aspects of Carbon Capture and Storage Technologies,” headed by Howard Herzog (Laboratory for Energy and the Environment), brings together the resources of AGS investigators and private and public sector stakeholders to identify, study, and address the nontechnical barriers to the introduction of carbon capture and storage from fossil-fueled energy production. The objective is to provide guidance to decision makers.

“New Materials for Sustainable Development,” led by Professors Joel Clark and Randolph Kirchain (Materials Science and Engineering), brings together investigators to develop an integrated assessment of the potential of emerging materials in developing sustainable patterns of resource use. They are applying analytical methods to a series of case studies of new materials.


Two other sessions addressed sustainability issues in the developing world. One workshop focused on the role of information technology (IT) for megacities in developing countries. Participants discussed how IT could be applied to improving the provision of eco-efficient, equitable, and affordable housing in large cities. A panel discussion considered the relationship between power generation and pollution in China and India, two nations experiencing rapid economic growth and increasing demand for energy.

In a special presentation, Professor John Heywood (Mechanical Engineering) outlined current MIT research in transportation. He described a recent comparative assessment of advanced vehicle technologies, including diesel hybrid and fuel cell cars, as well as an ongoing AGS project to develop strategies for increasing vehicle fuel efficiency in the United States.

The annual meeting of the Alliance for Global Sustainability will be held in Göteborg, Sweden, on March 21–24, hosted by Chalmers University of Technology.

The Alliance for Global Sustainability (AGS) is a collaboration among four research universities—MIT, the University of Tokyo, the Swiss Federal Institute of Technology, and Chalmers University of Technology. Researchers leverage the intellectual resources of the four partners to develop new, multidisciplinary approaches to sustainability. They collaborate on major research projects that focus on economic development and societal well-being, such as energy for the 21st century, environmentally conscious design and manufacturing, the growth of megacities, and global demand for mobility. The AGS encourages research partnerships with business, government, and nongovernmental organizations, and the sharing of research results.
Symposium explores future energy options

On December 2 and 3, more than 150 people attended “Meeting Future Energy Challenges,” a two-day symposium hosted by the MIT Industrial Liaison Program (ILP). Professor David H. Marks, director of the Laboratory for Energy and the Environment (LFEE) and meeting chair, opened the conference with a discussion of future energy challenges and the changing nature of energy research at MIT.

A keynote address by Dr. A. Denny Ellerman, executive director of the Center for Energy and Environmental Policy Research, provided an overview of how US energy policy has evolved over the past 40 years.

The symposium then showcased MIT research in a wide range of disciplines bearing on energy sources, uses, and impacts. Speakers included senior faculty members and research staff from seven MIT departments and five research centers and laboratories, many affiliated with the LFEE, as well as representatives from oil and automotive industries. Presentations fell into three broad categories: mobility and transportation technologies; fuels and knowledge management; and electric power systems and technologies, including efficient utilization.

Mobility and transportation technologies

In a talk on mobility, Professor Daniel Roos (Engineering Systems Division) emphasized that moving toward more efficient petroleum consumption is not just a question of improving technology. Efforts must be based on a systems understanding of how and why we use transportation, including freight. Professor Ahmed F. Ghoniem (Mechanical Engineering) focused on the role of technology and of “smart” fuels, matching task requirements to appropriate mixes and sources of fuel, including the use of hydrogen as a gasoline enhancer rather than substitute.

Talks by two automotive experts offered an interesting contrast in perspectives on the future of hydrogen fuel-cell vehicles. Shinichi Hirano of Ford’s Sustainable Mobilities Technology Group was very optimistic about the future of vehicles powered by hydrogen fuel cells. In his view, automotive technology is rapidly advancing to the point that widespread deployment of this nonpolluting source of transportation technology will be feasible.

Professor John Heywood (Mechanical Engineering), director of the LFEE-affiliated Sloan Automotive Laboratory, was not so enthusiastic. He summarized a major study he co-authored with Malcolm A. Weiss, Andreas Schafer, and Vinod K. Natarajan entitled Comparative Assessment of Fuel Cell Cars. Given the continued advances in internal combustion engines and hybrid power trains and the amount of engine technology and infrastructure development necessary to make fuel-cell vehicles an everyday alternative, he concluded that fuel-cell cars will not become the dominant choice for several decades, especially when the required hydrogen infrastructure is considered.

Fuels and knowledge management

Pieter K.A. Kapteijn, Smart Fields Coordinator for Shell International Exploration and Production B.V., described some of the novel technologies of their “smart fields” initiative whereby more oil can be extracted from underground reserves. Professor John R. Williams (Civil and Environmental Engineering), director of the Intelligent Engineering Systems Laboratory, demonstrated state-of-the-art data-encoding approaches (such as XML) that will allow oil and gas companies and others to mine extensive and diverse large datasets much more effectively. Professor Gregory J. McRae (Chemical Engineering) discussed how companies might effectively realize the economic value of sophisticated approaches to smart wells and smart refining.

In October 2003, leading researchers from MIT and Shell met as part of the new “Smart Fields” collaboration. Shell updated the MIT participants about the current state of the art in oil and gas exploration, drilling technology, sensoring, and enhanced recovery so that MIT researchers can apply their methodologies with the best available knowledge.

Electric power systems and technologies, including efficient utilization

Professor James L. Kirtley, Jr. (Electrical Engineering and Computer Science and Laboratory for Electromagnetic and Electronic Systems) provided a review of how changes in the electric power industry and technologies were creating markets for distributed power generation technologies much smaller than in
the past. He compared the leading technologies and highlighted some important factors affecting the industry’s growth, such as grid connection and dispatchability.

In contrast, Dr. Kent Larson (Architecture and Media Lab), director of Changing Places, discussed how current research aimed at understanding how we actively use space and the implications for energy use might dramatically reduce our energy needs. The substitution of information for energy, in an energy-management sense, is one of the long-overlooked components of a robust energy policy.

Howard J. Herzog (LFEE) gave an overview of LFEE’s research program on carbon capture and storage, which he directs. Carbon sequestration is a promising option for removing carbon dioxide emissions from large-scale power plants and industrial sites while alternatives to fossil fuels are developed and implemented.

Stephen R. Connors (LFEE), director of the LFEE’s Analysis Group for Regional Electricity Alternatives, looked at emerging energy technologies and their associated “niche” markets. He emphasized the need to look at future integrated energy pathways—composed of multiple energy resources, electricity supply, energy carriers, and end uses—to identify the opportunities for these new products and services. Early adopters and early innovators who can “think outside of the box” are critical, as is considering the timing and location of renewable resources, energy supplies, and end users to maximize benefits.

Professor Mujid Kazimi (Nuclear Engineering) described innovative advances in nuclear power generation and some related technologies. Nuclear energy, produced in smaller, safer, more secure plants, could be used not only for electricity generation but also for the direct production of hydrogen using the nuclear reaction’s heat output. Professor Ernest J. Moniz (Physics), LFEE’s director of energy studies, described The Future of Nuclear Power, a major study released in fall of 2003. In the study, senior MIT faculty members and other experts examined critical problems that must be overcome to retain nuclear power as a significant option for reducing greenhouse gas emissions while meeting the growing need for electricity (see “Preserving the Nuclear Power Option” on page 1).

Work described by Professor Marija Ilić (formerly of LFEE, now at Carnegie Mellon University) offered further insight into power-grid reliability and security challenges—one of the problems cited by Professor Moniz. Studies focus on the potential for security threats to energy networks, in particular electric power systems.

In closing the meeting, Professor Marks pointed to the wide range of options outlined by presenters as well as by symposium participants during extensive audience commentary. He observed that many topics barely touched on in the symposium deserve equally detailed treatment. He congratulated the ILP on its continuing efforts to bring MIT’s industrial partners and faculty together to work toward a rational and sustainable energy future.

CEEPR workshop considers dwindling North American supplies of natural gas

The US natural gas market is now undergoing a fundamental change. For some fifty years, natural gas supplies have been both abundant and inexpensive. But now domestic production is slowing, prices are at record highs, and imports will likely be needed to meet growing demand.

Analyzing and evaluating evidence of this change and debating its potential domestic and global consequences were the main focus of discussion at the latest workshop of the Center for Energy and Environmental Policy Research (CEEPR).

Held in Cambridge on December 4 and 5, the workshop included experts on various aspects of natural gas supply and demand. Speakers came from MIT and other academic institutions, oil and electricity supply companies, the Energy Information Administration, and the National Petroleum Council (NPC).

The early signs of change date back to the California electricity shortage of 2000. Soaring natural gas prices spurred a drilling frenzy, but very little new natural gas was found. People were shocked. Conventional wisdom said that if prices got high, new supplies of natural gas would flow into the market, but it did not happen. During the past year or so, prices have been consistently $5.00 to $6.00/mcf—fully twice as high as they have ever been or were expected to be. Yet supplies are still not increasing.

A recent NPC study confirms that the supplies experts thought existed probably do not. The most promising resources have been thoroughly explored, developed, and depleted.
It appears that US gas production has peaked. If domestic supplies stay steady or even decline and demand continues to grow, the United States will have to begin importing natural gas to make up the difference.

Workshop participants noted a parallel to the oil situation in the 1960s. Prior to that time, the United States produced as much oil as it consumed. Eventually, US production of oil peaked and then began to decline slowly, while demand continued to increase. When supply could no longer meet demand, the United States began to import oil in ever-increasing amounts.

The prospect of importing natural gas raises a number of questions.

- Handling liquefied natural gas (LNG, the form in which it is traded) will require major infrastructure investment and development. A number of New England cities and towns are already debating the merits of accepting new LNG delivery terminals and storage plants. Can we site and build the facilities needed to handle LNG imports?
- In the past, the world's abundant natural gas supplies were traded on a well-established global market. The North American market had its own plentiful supplies at relatively low prices, so it operated separately from the global market. Thus, LNG from Trinidad typically sailed up the Atlantic coast and then over to Europe, where prices were high. But we have never seen natural gas prices as high as they are now, so predicting behavior is impossible. Industrial consumers, in contrast, have already begun to respond. Manufacturers of fertilizer, ammonia, and other products who depended on low natural gas prices are moving their operations to LNG-exporting countries where gas is cheaper. Further adjustments are likely but hard to predict.
- High natural gas prices are already affecting the electric power industry. Until recently, gas prices were almost always lower than oil prices. Electric utilities therefore began using natural gas rather than oil, and they expanded capacity by building new natural-gas-based combined cycle gas turbine (CCGT) plants. With natural gas now three times as expensive as coal, those CCGT plants stand idle as coal and nuclear plants run full tilt. What will happen to those “stranded” CCGT plants? If demand for electricity increases enough, might electricity providers use them rather than building new plants—a move that could significantly increase the need for imported natural gas?
MIT's first waste audit suggests campus recycling opportunities

By sorting through three days' trash from several MIT buildings, MIT student and staff volunteers have come up with insights into the community's recycling behavior and how it could be improved.

On three consecutive Tuesdays last fall, MIT students and staff went through three-quarters of a ton of trash taken from the dorm New House, the Stratton Student Center, and an academic office building. Wearing protective coveralls, heavy gloves, and safety goggles, they separated the trash into different categories—paper, plastic, glass, cardboard, food waste, computers, and so on. They then weighed the piles and cataloged their results.

Getting a true picture of MIT's overall waste stream will require a far longer and more comprehensive audit. Nevertheless, results from the three-day pilot audit point to opportunities for increasing recycling and for reducing the overall volume of trash.

For example, evidence from the audit suggests that residents of New House could recycle twice as much of their trash as they do now, bringing their overall recycling rate up to 50%. (Recycling rate is the mass of material recycled as a percentage of total waste.) Much of the non-recyclable waste sorted in the audit was organic material. If New House composted that material, only 20% of its overall solid waste would be considered trash.

At the Student Center, as much as 80% of the material thrown out as trash could have been recycled. The non-recyclable material included a substantial amount of polystyrene food containers and drinking cups, both of which could be replaced by reusable or recyclable materials. Potential gains are significant, as the Student Center is the third largest trash generator (by volume) on campus.

In the office waste, paper actually outweighed the real trash in the sample. Recycling it would have cut the amount of office trash in half.

The three-part waste audit was the core activity of the freshman advising seminar “Achieving MIT’s Environmental Goals,” taught jointly by the Laboratory for Energy and the Environment (LFEE) and the Environmental Programs Office during fall 2003. Seminar students and volunteers from across campus conducted the audit, with support from the Environment, Health, and Safety Office; Facilities; WasteCap of Massachusetts; and the Campus Activities Center.

Based on their findings, the seminar students concluded that a top priority is to increase the community's awareness and understanding of MIT's existing recycling program. They recommended special events, freshman orientation activities, and print and radio advertising to encourage people to take better advantage of current recycling opportunities, to buy environmentally friendly products, and to adopt simple but important habits such as two-sided copying.

According to Norman Magnuson, operations manager in Grounds Services, the pilot waste audit has already inspired MIT to action. MIT’s Department of Facilities recently installed cardboard balers in the Student Center, added more compactors and dumpsters for cardboard and mixed paper, and performed its own initial waste audit of a dumpster containing five tons of trash—half of which could have been recycled. Facilities is now planning four more waste audits beginning in April.

Increasing the recycling rate and reducing the volume of trash at MIT will help both MIT and the City of Cambridge. Cambridge has established a goal of 40% recycling by 2005, and MIT has pledged to share that goal. Recycling 40% of MIT’s trash would reduce the Institute’s $1 million annual waste-management budget by about 10%.

MIT’s annual recycling rate for 2003 was 22%—a considerable improvement over the 11% recycling rate in 2000. The increase was due in part to improved handling of food waste and recyclable cardboard and purchasing of “green” products (products that are remanufactured or recyclable, have recycled content, or use energy-saving designs). Major gains were also made in construction and demolition recycling. Indeed, in the recent demolition of a parking garage, fully 99% of the waste was recycled.

First MIT EnviroForum fosters environmental networking, planning

On November 6, more than 70 students, faculty, researchers, and staff gathered at the first MIT EnviroForum, a new series of events designed to bring together MIT’s diverse community interested in environmental and sustainability issues.

Three speakers briefly addressed the theme of the forum: “MIT’s Environmental Commitments, Challenges, and Actions.” The remainder of the two-hour event was devoted to providing attendees with an opportunity to meet like-minded individuals for networking, socializing, and informal conversation.

Forming new connections among such individuals should strengthen existing efforts and spark new projects that benefit from integration across MIT’s environmental education, research, and operations initiatives.

The first speaker was MIT Chancellor Phillip Clay, chair of MIT’s Council on the Environment, who reviewed the history of MIT’s environmental commitment and examined the source of MIT’s “competitive advantage in moving to the next level.” He said, “Our history [has involved] a deliberate effort to blur the lines among action, research, and teaching. And there is no area that is more appropriate for this kind of blurring than the environmental area.”

He noted that MIT’s current focus on the “nano, neuro, info, and bio” is providing new, evolving opportunities for innovative environmental research and teaching. He called for redoubling efforts to attract students with a “passion for the environment” by showing eleventh-graders that MIT is a place where they can pursue that passion on many fronts.

Professor Patrick Jaillet, head of the Department of Civil and Environmental Engineering, focused on the intellectual challenges involved in moving from dialog to action. One challenge is dealing with the interplay between science and engineering. For example, knowing what data to collect depends on the science we know, and making advances in science depends on the data we have. The second challenge is economic. How can we value resources that we consume now when those resources seem unlimited, even in the distant future? Finally, there is the human-behavior challenge. How can we devise strategies that will affect the behavior of the individual when there is no accepted value for today’s natural resources and no easy way of measuring the effects of individual decisions on natural systems?

Professor Jaillet emphasized that MIT is uniquely positioned to work on those challenges, and he instructed audience members to “do what MIT is best at doing: being intellectual leaders.”

The final talk presented an example of environmental action being taken at MIT. Ms. Tiffany Groode, graduate student in the Department of Mechanical Engineering, described her work with Professor John Heywood, director of the Sloan Automotive Laboratory, and the Department of Facilities to generate “benchmarking” data on MIT’s greenhouse gas emissions.

EnviroForum is supported by Chancellor Clay and sponsored by the Laboratory for Energy and the Environment (LFE), the Environmental Programs Office, and the ESI. It is organized by the LFE Education Program, led by Dr. Amanda Graham.

MIT and Cambridge consider new climate protection moves

On Thursday, December 4, members of the MIT and Cambridge communities gathered at the forum “MIT and the City of Cambridge: Collaborating on Climate Protection.” Their mission: to think of new ways for MIT and Cambridge to move forward on their shared environmental goals.

A year ago, the City of Cambridge adopted an aggressive Climate Protection Plan calling for a 20% reduction from the city’s 1990 greenhouse gas (GHG) emissions level by 2010. Since then, MIT and Cambridge have made gains separately and collaboratively on their commitment to climate protection.

The forum, sponsored by the Laboratory for Energy and the Environment (LFE), attracted MIT faculty, staff, and students; Cambridge residents; and a panel of environmental leaders from both communities. Amanda Graham, education program manager for the LFE, served as moderator and introduced “visionary” leaders from Cambridge and MIT.

Henrietta Davis, vice mayor of Cambridge and chair of the City Council’s Health and Environment Committee, noted that her vision centers in part on having MIT as one of the institutional citizens of Cambridge.
The following publications covering Laboratory for Energy and the Environment and related research became available during the past period or are cited as references in this issue. Reports and Working Papers and other indicated publications can be found on-line via the following addresses:

**Laboratory for Energy and the Environment (LFEE):**
<http://lfee.mit.edu>

**Center for Energy and Environmental Policy Research (CEEPR):**
<http://web.mit.edu/ceepr/www/>

**Joint Program on the Science and Policy of Global Change (Joint Program):**
<http://web.mit.edu/globalchange/www/>

**Center for Advanced Nuclear Energy Systems (CANES):**
<http://web.mit.edu/canes/>

Instructions for obtaining copies of Reports and Working Papers are also available by telephoning 617-253-9409 for LFEE publications, 617-253-3551 for CEEPR publications, 617-253-7492 for Joint Program publications, and 617-452-2660 for CANES publications.

**Reports and Working Papers**


**Laboratory for Energy and the Environment.**


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“With the help of MIT, we will be able to find ways to make the reductions in GHGs real...not just to take local action for local action's sake but to have the local action be a demonstration for other cities across the country,” she said. She commended the “bright, innovative, and visionary” MIT students who are working with the city and “constantly demanding more.”

Jamie Lewis Keith, MIT’s senior counsel and managing director of its Environmental Programs Office and Risk Management, focused on the importance of taking an integrated approach, both within MIT and between MIT and Cambridge.

“One of the challenges posed by environmental problems is that they cannot be compartmentalized and solved in isolation. At MIT, research, education, legal compliance, recycling, and other sustainability initiatives are not discrete and unrelated but rather connected and interdependent,” she said.

A discussion among audience and panel members led to several proposals. The observation that fully 95% of MIT’s demolition debris is now recycled elicited a suggestion that MIT’s building-debris removal resources be linked with Cambridge developers in a building-materials exchange. A green vendors fair run jointly by MIT and the city could foster the use of environmentally friendly materials and services.

MIT and Cambridge could also join forces in the bulk purchase of energy-efficient compact fluorescent light bulbs. The MIT Students for Global Sustainability have already surveyed nearly 300 people in Cambridge to measure and increase their awareness of such bulbs.

Both MIT and Cambridge now push the construction of green buildings, but making gains in existing buildings remains a challenge. Peter Cooper, director of Utilities in MIT’s Department of Facilities, said, “Actions that people take in their offices and labs may be more important than many of the steps Facilities can take.” He noted the value of such simple habits as turning off lights and closing ventilation hoods over lab benches.

In closing, Davis invited MIT leaders to share what they learn with the city. “If you come up with a checklist of what you can turn off and turn down in your buildings, share it with us,” she said. City officials implored MIT faculty and students to “use Cambridge as your local research laboratory.”

Ideas suggested at the forum will feed into a month-long seminar during MIT’s Independent Activities Period in January at which MIT students will work with MIT faculty and staff and Cambridge planners to develop innovative emissions-reduction strategies. For information on the seminar, go to <http://student.mit.edu/seminar/fs-17-918.html>.

Welcome to energy & environment, the new newsletter of the MIT Laboratory for Energy and the Environment. We have tried to combine the best features of our previous publications—e-lab and Initiatives in Energy and the Environment—to produce a single newsletter that reflects the wide range of research, education, and outreach activities of the LFEE as well as the interests you expressed in our survey. Thank you for participating.

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