energy & environment

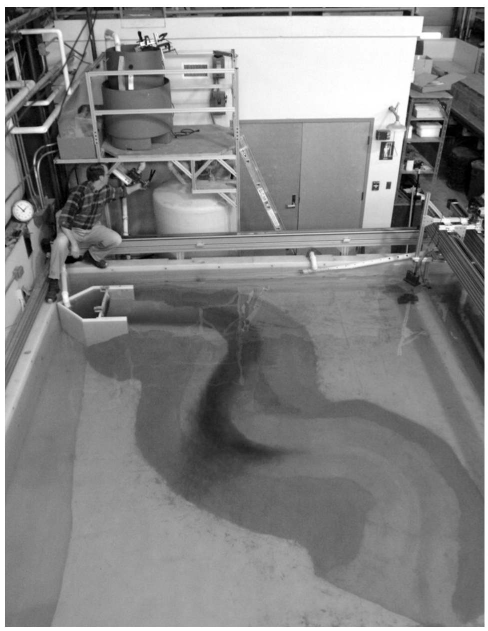
MIT LABORATORY FOR ENERGY AND THE ENVIRONMENT MARCH 2006

Increasing Oil Recovery from Submarine Streambeds

Work in an MIT lab may help energy companies withdraw millions of additional barrels of oil from kilometer-long segments of sediment-filled channels buried under the sea floor. Using a five-meter-square sand table, MIT researchers and their Shell collaborators are creating scale models of those channels, carefully monitoring the processes whereby they fill up with sand and mud. New insights into the likely internal structure of the full-scale channels will soon help industry design drilling programs that can extract more of the oil trapped in the channel fill.

To meet the rapidly rising demand for oil, energy companies are working hard to find new reserves to tap. At the same time, they are looking for ways to get more oil out of their existing fields. Typically, companies recover only 30%–40% of the oil in a given reservoir. The rest remains in the ground. Since a single reservoir may contain a billion barrels total, increasing that “recovery efficiency” by even a single percentage point would mean a lot of additional oil.

Toward that end, Professor David Mohrig of MIT and Dr. Carlos Pirmez of Shell International Exploration and Production Inc. have been examining one geological formation of interest to industry—channels filled with highly permeable and porous sedimentary deposits that extend deep below the sea floor. These structures form when sediment-laden currents flow off the continental shelf and into channels on the deep-ocean floor, dropping sand, silt, and clay as they go. Over many thousands to millions of years, the channels can become filled with porous sandstone covered by impermeable mud—a perfect trap for oil and gas that seep up from below.



At MIT’s Morphodynamics Laboratory, Research Scientist James Buttles adjusts the inflow valve of a sediment-laden, gravity-driven current flowing in an experimental channel. Observing how the sediment is deposited in and around the channel is providing new insights into the structure of oil-rich sediment-filled channels found deep under the sea floor. Photo: Donna Coveney/MIT.

Over the past 20 years, energy companies have withdrawn significant amounts of oil from those buried channels. But they could extract even more if they understood the channels’ internal structure. Studies of outcrops and analyses of seismic data are helpful but do not provide the clear, detailed picture needed to optimize drilling and development programs.

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Introduction: An Interview with Shell’s Jerry Morris

*Shell International Exploration and Production Inc. is now supporting a variety of energy-related research projects at MIT. Some focus on renewable energy sources such as photovoltaics and others on long-term strategies such as the transition to hydrogen transportation. But many projects (including those featured in this issue) focus on the nearer-term challenge of providing hydrocarbon energy to meet rapidly increasing global demand for energy. The emphasis is often on innovative approaches, and Shell is actively looking for more opportunities to collaborate with MIT to pursue new ideas. In a recent interview, we asked **Jerry Morris** of Shell’s Novel Technology/GameChanger Program to tell us more about the MIT/Shell collaboration.*

Q: MIT isn’t your traditional petroleum-engineering school. Why is Shell interested in collaborating here?

A: We see MIT as one of the leading technology universities in the US and in the world as well. A couple of the strengths that we believe MIT brings to the table are its interdisciplinary approach to technology and its position at the technology forefront with a different perspective than most energy universities bring.

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Increasing Oil Recovery from Submarine Streambeds

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Almost three years ago, Professor Mohrig and Dr. Pirmez began to tackle the problem from a different perspective: they started exploring the processes by which the channels form. As an earth scientist, Professor Mohrig had long been interested in how currents from the continental shelf carry and deposit material into channels in the deep ocean. Said Mohrig, "If we could understand how they develop, then we would also understand a great deal about what they're composed of—the distribution of clay, silt, sand, and even gravel that they're built out of." With a better understanding of porosity and permeability within a channel, companies could more accurately determine how much oil is present, where it is located, and how quickly it can be withdrawn.

In Professor Mohrig's Morphodynamics Laboratory, researchers have been recreating the formation of submarine channels—a process that in nature occurs over long times and covers thousands of square kilometers of sea floor. They use a tank that is 5 meters wide, 5 meters long, and 1.5 meters deep. To begin an experiment, they create a well-defined channel through a layer of crushed silica on the bottom of the tank. They then release a sediment-laden mixture that flows along the channel, dropping material as it goes. To monitor the process, they measure velocity and sediment concentration at various locations; they inject dye into the current and videotape the flows from above; and they take careful topographic measurements before and after each run. Guided by data and observations provided by Shell, the researchers have been able to create scale models in their sand table representing sections of channels that in nature would be 4 kilometers long, 400 meters across, and up to 100 meters deep.

The sand-table experiments have yielded results that the academic and industry collaborators call "counterintuitive." On a map, the sinuous submarine channels look strikingly like meandering surface rivers. However, they exhibit behaviors that are markedly different and—to us surface-dwellers—totally unexpected.

The behaviors stem from differences in density. Water in a river is about a thousand times denser than the fluid it flows through—air. As a result, a flow tends to remain confined to its riverbed, escaping over the banks only rarely. In contrast, the current running through a submarine channel may be only 10% denser than the seawater around it. (Its higher density is due to the sediment it carries.) Thus, the current can spill out of its channel more easily and frequently than a river might.

That difference explains several unexpected experimental findings. For example, at times the bottom of the current sloshes almost all the way up the edge of the channel and then back down again. And at bends, the current may go straight, pouring up and over the bank and dropping its sediment outside the channel—an outcome with important implications for energy companies as they plan to drill.

On the other hand, except at sharp bends, the current is surprisingly willing to stay within the channel. In some of the experiments the current continued to be directed by the channel even when it was five times as tall as the channel was. Why? "The densest part of the current is toward the bottom, near the bed," Professor Mohrig explained. "As long as that high-momentum part of the current is moving within the channel, it drags the upper part of the current along with it." And that upper part tends to deposit its sediment onto the channel's banks. In the experiments, the rate of deposition on the crest of the bank nearly matched that in the channel bed. As a result, over time the entire channel structure would move upward in space—another behavior not seen in surface rivers.

Professor Mohrig is not surprised to find that a shallow channel can guide a thick current. "It's something I've always wondered about, having gone out and looked at the deposits of ancient systems in the rock record and from looking at sea floor images," he said. "But I never understood why that would be. The laboratory experiments help us to understand." To Professor Mohrig, "this is the best kind of science because when you show it to people they say, 'That makes sense!'"

Because of their close and continuing involvement in the scientific investigation, the Shell researchers are well prepared to put the research findings into practical use. "The experiments that [Professor Mohrig] is doing have never really been done before, so we're learning new things about how channels are put together," said Dr. Pirmez. "We're getting new ideas, new concepts that may change the way we think about the subsurface." And quantitative data from the experimental measurements will help Shell test and calibrate the numerical models they use to guide their drilling. The result should be improved predictions, reduced uncertainty, and more efficient recovery from these oil-rich submarine formations. ■

David Mohrig is an assistant professor in the Department of Earth, Atmospheric, and Planetary Sciences and director of MIT's Morphodynamics Laboratory. Carlos Pirmez is a research geologist at Shell International Exploration and Production Inc. *This research was supported by Shell International E&P through the Department of Earth, Atmospheric, and Planetary Sciences. More information can be found in reference 1.*

Introduction: An Interview with Shell's Jerry Morris

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Q: What's the advantage of that different perspective?

A: You can approach a problem from a deep knowledge of the problem set and then try to find the technologies that help. But you can also come at it by looking at emerging technologies that are having an impact elsewhere and see how they might make an impact on the energy industry. I think the strength that MIT brings to us and our industry is that external expertise and perspective.

Q: Is MIT developing tools that your industry will use?

A: Most of the work we've done here is more basic science than the exact problem-solving that our own scientists get involved in. Academic researchers generally want to stay more in the scientific realm, and by working closely with the MIT researchers, we're able to translate their novel scientific approaches into solutions for ourselves and our industry. It's a way we can enthusiastically support and collaborate on projects and still allow the publishing that's necessary for a university.

Q: What are some of the challenges that MIT can help with?

A: To keep up with the growing demand for fossil fuels in the near term, we need to find ways of releasing—or "unlocking"—difficult hydrocarbons. In past decades, we were identifying and producing hydrocarbons that were relatively easy to find and develop. Now it's more difficult to find the hydrocarbons, and the hydrocarbons we find are more difficult to produce.

Q. What are ideas that would help?

A. One approach is to make the reservoir itself into a reactor. Rather than bringing the hydrocarbons to the surface and treating them in a standard chemical-engineering fashion, we could treat or pre-treat them in the reservoir so that they're easier to handle at the surface. Also, the "difficult" hydrocarbons tend to be thicker and less mobile than what we've dealt with in the past. It would be valuable if we could pre-treat them in the subsurface so they're easier to bring up. And if we can leave the contaminants behind in the reservoir, we can do it all in a very sustainable way.

Q: How would you make that happen?

A: You could use either biological or chemical reactions. The industry has investigated "microbial enhanced oil recovery." That's where bugs get in there and form detergents, and the detergents help clean the reservoir so you can move the hydrocarbons out. Or you might chemically inject detergents. But there may be whole new ways to make valuable reactions happen in the subsurface reservoir.

Q: Shell talks a lot about "smart fields." Can you explain what that means and what role MIT can play?

A: There are a lot of advances in modeling capabilities and a lot of advances in information technology. If we can integrate various data sets to model some decision points, we can make operating choices that control our reservoirs and fields in ways that optimize production and minimize impact.

Q: You'll need good data to make that happen.

A: Yes, we'll need robust sensors to collect data and also control systems that can act on the collected data. From that perspective, our industry faces some unusual challenges. Our surface facilities are dispersed over many miles, and the bottom of a well may be as far as 3 miles from the surface—and at a pretty extreme environment in terms of temperature and pressure. Running instruments under such conditions and communicating over such distances is a real feat to accomplish. We also experience a significant delay between our taking an action and seeing a reservoir response. We think that MIT's innovative work in automation and artificial intelligence could bring whole new perspectives to solving problems.

Q: What techniques could be useful as you look for new oil and gas deposits?

A: Advances in visualization and spatial interpretation can help us in the exploration process. Again, the difficulty is that reservoirs can be miles beneath the surface. To get imaging energy down that far, we need to use long-wavelength technologies such as seismic waves. We can focus the energy, get it down there, and receive it back. But because of the long wavelengths, we don't get the fine-scale imaging that we'd like to have. At the same time, there are high-resolution data sets that we get from, say, geologic models, down-hole measurements, and well cores, but they're very local.

Q: Can you use those data sets together?

A: Yes, but the challenge is to "fuse" them in a way that's meaningful. One approach is to draw on fundamental work that MIT has done in brain imaging, which involves using data collected from X-rays and MRIs and "mapping" them together so you know that you're looking at the same area. Another approach comes from photographic and video imaging. It involves looking for statistical patterns between known data sets and then using those patterns to predict a "plausible" high-resolution image from low-resolution data.

Q: Could those techniques also be applied to your operating wells?

A: Yes. Relatively fine features of the reservoir—small discontinuities or changes in direction or breaks in the deposits—can impact our ability to move the hydrocarbons to the production well. Getting a clearer picture of such details could help us in designing and modeling our reservoirs to get the most out of the ground.

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Using MIT Signal-Processing Techniques in the Search for Oil

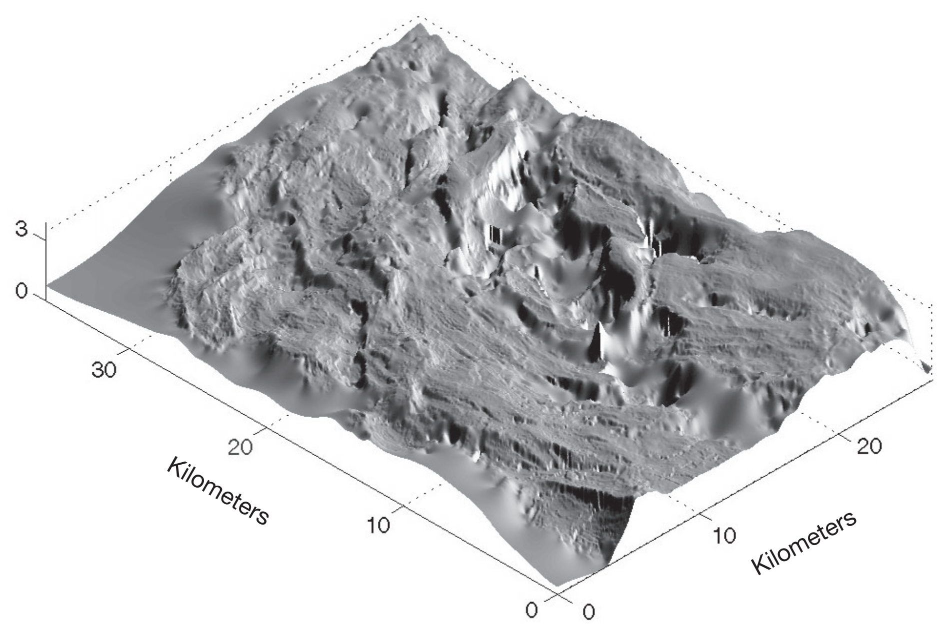
Mathematical procedures developed at MIT will soon help energy companies locate new sources of oil many kilometers under the ground. Working closely with teams at Shell International Exploration and Production Inc., the MIT researchers have demonstrated the power of one of their procedures by mapping out an underground oil-trapping geological formation based on limited seismic data.

To keep up with the world's growing demand for oil, energy companies must drill deeper and look harder in increasingly complex geological structures. But locating such structures many kilometers beneath the earth's surface is difficult, and getting it right is important. Companies can spend as much as $100 million drilling a single well—a costly mistake if it comes up dry.

To find promising underground sites, companies collect seismic data using air guns or explosives to send shock waves deep into the earth. How they are reflected by underground layers provides information that sophisticated signal-processing techniques can turn into 3-dimensional images of the subsurface. But identifying promising geological structures within those images requires analysis by teams of experienced geologists and engineers called "interpreters."

"Typically, the interpreter takes the 'seismic volume' and pulls up a series of cross sections, oriented in various directions," said Ron Masters of Shell. "He'll gradually build up in his mind the shapes of the stratigraphic layers and structures. We have mathematical procedures, or 'algorithms,' that can generate views for the interpreter, but we're always looking for improvements on those algorithms."

MIT-Generated Map of Salt-Dome Tops



This map shows the top of a geological structure that is located many kilometers below the sea floor and may be surrounded by large reservoirs of oil. Based on analyses of seismic data, exploration experts at Shell International E&P identified a limited number of data points that they believed were at the top of this structure. MIT algorithms then generated the rest, producing a continuous map along with an uncertainty range for each generated point.

Designing algorithms that can quickly analyze such spatial data is the specialty of the Stochastic Systems Group (SSG) at MIT's Laboratory for Information and Decision Systems. A year and a half ago, Professor Alan S. Willsky, director of the SSG, and researchers at Shell began investigating potential applications for those algorithms in the oil exploration business.

Obvious candidates were SSG's statistical interpolation and estimation algorithms, procedures for defining a continuous surface from a limited set of data points. As a first target, the research teams selected the task of mapping out "top salt," that is, the surface along the tops of contiguous salt domes. Salt domes form deep underground when heavy layers of sediment deposit on salt beds from ancient oceans. The salt extrudes upward like globules in a lava lamp, in the process tilting and blocking off sedimentary layers and creating traps where oil can accumulate.

To generate a map, interpreters pick points in the on-screen images that they think may be at the top of the salt, and the computer fills in the gaps. By changing their "picks," the interpreters produce multiple maps for consideration, each one covering several kilometers in length, width, and relief. Generating those maps quickly is critical.

The MIT algorithms are well suited to the task. The key is how the different picks relate to one another. "There are statistical relationships between things that happen at different points in space," said Professor Willsky. "You don't expect properties of the rock at one point to be completely independent of the properties a meter away."

Given a set of picks, the MIT algorithm automatically defines statistical relationships from one pick to the next and fills in the missing points based on those relationships. Moreover, it defines the uncertainty associated with each generated point. "It's like having 10,000 measurements of height in the Rocky Mountains, and you draw a map of the entire Rockies," said Professor Willsky. "You do it effectively and quickly, and you tell how sure you are of height at every point."

The figure on page 4 shows an MIT-generated map of top salt beneath the deep ocean in an area where Shell will be drilling in the future. "Underlying the calculation is a lattice model, which in this case has about 1800 vertices by 1300 vertices with a distance of about 20 meters between adjacent vertices," said graduate student Jason K. Johnson, "and at every point in the image there's a node and a model for how that point is related to its immediate neighbors." Shell provided estimates of the distance to the top salt at certain locations along the grid lines, and the computer did the rest.

According to Dr. Masters, the new map covers an extensive region, and the relief on the top-salt surface is huge. "There are deep mini-basins, and the salt protrudes very high up in places…so it's a really complex geometry," he said. "Having Jason's top-salt map to incorporate into our analysis could be very valuable as we look for reservoirs and structures to tap."

But identifying the top salt is only the beginning. The company also needs to see the shapes of geologic formations to guide their drilling. With a salt dome, for example, the company needs to drill into the adjacent sedimentary layers but not into the salt itself because it will contain no oil.

Again, the SSG researchers have algorithms that can help—algorithms that they have been using to help medical researchers interpret data from MRIs and CT scans. The mathematical process, called image segmentation, is designed to pick out the shapes of objects within large 3-dimensional data sets. The SSG algorithms examine the data set for statistically meaningful differences from region to region, for example, in the intensity of data distribution. By combining the available imagery with models based on expert segmentations of other data sets, the algorithms extract the best estimates of the shape of an object—whether it is a specific area of a brain or a sedimentary layer beneath the earth.

In using both the interpolation and segmentation procedures, the aim is to reduce the workload of the specialists so that they can do some analysis and the computer can fill in the rest. But other possibilities abound. For example, the MIT techniques are capable of merging, or "fusing," different types of data sets. Detailed measurements gathered by sensors down a well can constrain the interpretation of the wide-ranging but relatively sparse seismic data.

Key to the success of this collaborative research is constant interaction between the MIT and Shell researchers. "We don't just develop tools and throw them over the transom to Shell," said Professor Willsky. "We're constantly looking over each other's shoulders" to find areas of mutual interest and potential benefit. Teaching each other about their separate areas of expertise is also critical. For Shell, the challenge is to understand MIT's "modern mathematical tools" well enough to build them into the company's existing analytical methods. "We need to [take] these faster, more robust algorithms and actually integrate them into a working solution on the desktop for the interpreter," said Dr. Masters. ■

Alan S. Willsky is the Edwin Sibley Webster Professor of Electrical Engineering, director of the MIT Stochastic Systems Group, and a member of MIT's Laboratory for Information and Decision Systems and MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL). Ron Masters is a senior staff geophysicist at Shell International Exploration and Production Inc. Jason K. Johnson is a PhD candidate in the Department of Electrical Engineering and Computer Science. *This research was funded by Shell International E&P through CSAIL.* *Further information can be found in references 2–5.*

Natural Gas Production Systems: Achieving Efficient, Reliable, and Robust Operation

A mathematical model being developed at MIT will help energy companies better plan the operation of their natural gas production systems, thus ensuring greater efficiency and a more reliable supply of this valuable fuel. Network operators will be able to control their fields, pipelines, and processing facilities to maximize production or achieve other goals while also satisfying complicated contractual obligations. MIT researchers are now collaborating with experts at Shell to apply the model to a natural gas production system encompassing several offshore fields in Malaysia.

Natural gas consumption is expected to increase dramatically in the coming decades. However, in the short term, demand for this clean-burning fuel is highly volatile. Because natural gas is difficult to transport and store, energy companies tend to produce it only when they have buyers lined up and transportation capacity available, generally under long-term contracts. As a result, they miss opportunities for short-term sales, and the overall availability of natural gas is reduced.

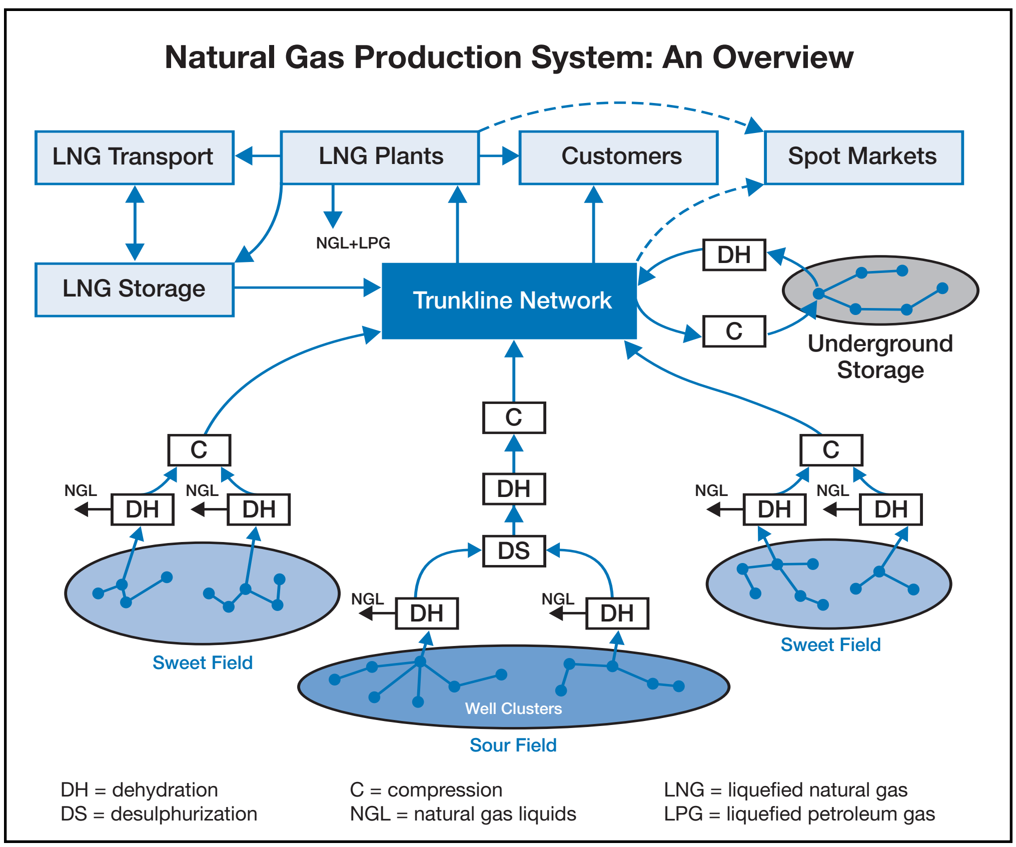
Natural gas companies would like to operate their production networks more efficiently and flexibly. But knowing how best to run those networks—for example, how to set the valves that control flows from the wells and through facilities along the pipelines—is difficult. Operators can be overwhelmed by the sheer number of choices to be made and obligations to be met under supply contracts with customers as well as facility- and production-sharing agreements with other companies.

According to Professor Paul I. Barton, the only way for a company to optimize such a system—that is, to operate it so as to best meet all obligations, objectives, and constraints—is to formulate it as a mathematical problem and solve it. "If there were just one or two decisions to make, an engineer could do it," he said. "But when you've got 20 valves to set and 50 different constraints to satisfy, it's impossible for a person to see. Computer procedures can take all of that into account."

Professor Barton and graduate student Ajay Selot have spent the past two years developing a mathematical model to help guide operators' decisions for the upcoming one to three months. The model focuses on the "upstream supply chain," that is, the system from the natural gas reservoirs to bulk consumers such as power plants, utility companies, and liquefied natural gas plants.

The schematic below shows the generic natural gas production system that the researchers assumed. Gas is typically drawn from several clusters of wells. "Sweet" fields produce gas containing no undesirable components, while "sour" fields yield gas mixed with contaminants. Recovered raw gas passes through a series of facilities that remove water and contaminants, recover valuable light liquids, and compress the gas to keep pressure high. The gas then moves through a "trunkline" network to a variety of recipients or to temporary underground storage.

While other models have focused on optimizing individual subsystems of the upstream



A new MIT model simulates flows of natural gas through production systems such as the one shown above. Mathematical equations calculate changes in the flow rate, pressure, and composition of the gas stream as it is dehydrated, compressed, cleaned, and so on. By using the model to analyze their own situation, energy companies will be able to operate their natural gas production systems more effectively, efficiently, and flexibly.

supply chain, the new MIT model encompasses the whole system. "Ideally, operators would like to make decisions based on information from the entire system," said Mr. Selot. "They can then make full use of their infrastructure and improve production efficiency, increasing the volumes produced and making the supply more reliable."

Based on fundamental physical principles, the researchers formulated mathematical models that describe the flow, pressure, and composition inside every pipeline in the network. Equations describe how the flow properties change as the gas passes through each facility along the way. The equations interact so the model can track flows and how they mix throughout the system.

To be useful in the real world, the model must also incorporate—in mathematical terms—the rules from all contracts and agreements. For example, what fraction of production must be shared with other companies? What access does the company have to other companies' facilities and pipelines? What quantity and composition of output is needed to meet contractual agreements? (The required product composition must be achieved by combining gas from different fields.) Operational constraints must also be included. For example, how rapidly can gas be withdrawn from a given well or be handled by a certain compressor? Finally, the company must define its goals, such as maximizing production, minimizing total costs, or scheduling facilities in a particular way.

The final challenge is to "solve the model" so that it defines the specific operating choices that will yield the integrated system behavior best satisfying the stated obligations, constraints, and goals. Standard optimization techniques cannot handle such a large and complex model. Those techniques will focus on just some of the available operating choices and thus may not find the "best" overall choice or may conclude that there is no way to meet all obligations when one exists. Mr. Selot is therefore refining and extending standard techniques to solve that problem.

He and Professor Barton are now performing a case study of the Sarawak Gas Supply Network, a facility located in east Malaysia and operated by Sarawak Shell Berhad, Malaysia (SSB). The researchers are working closely with field engineers at SSB and Shell International Exploration and Production, The Netherlands, to build a realistic representation of the Sarawak system—a challenge, as the system is the product of decades of evolution rather than coordinated planning. Wells, pipelines, and other facilities were built at different times and are now owned by a variety of companies linked by agreements that govern production- and facility-sharing. All of that complexity must be reflected in the mathematical model if it is to be of practical value to the Sarawak planners.

In practice, network operators will ultimately combine results from the model with other considerations in their decision-making process. For example, the model may identify several sets of operating conditions that will achieve the same performance. The operator can then make a choice based on other factors, for example, to move production away from a part of the network that is scheduled for maintenance or that is running too close to its capacity limit. Guided by the model, network operators will be able to make informed decisions that should ensure consistent and reliable operation while helping their companies to meet the growing demand for natural gas. ■

Paul I. Barton is a professor in the Department of Chemical Engineering. Ajay Selot is a PhD candidate in the same department. *This research was supported by Shell International Exploration and Production Inc. through the Laboratory for Energy and the Environment. Publications are forthcoming.*

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Q: It seems like all the approaches you've talked about could really make a difference.

A: The "cat's meow" would be to integrate them all. Better visualization techniques could help us find and characterize oil and gas resources. Advanced models and instruments could give us better automation and control of our wells and fields. And in-reservoir processes could enable us to recover more oil with fewer contaminants.

Q: Collaboration sounds critical to the success of the MIT/Shell projects.

A: Yes, it is. It's our belief that if our researchers can bring real-world problems and MIT can bring innovative approaches, it's in the collaborative space in between that real opportunities and solutions arise. And both sides benefit. Working with MIT gives us access to state-of-the art thinking and keeps our scientists up to date and challenged. From an MIT perspective, being involved with real-world problems makes that critical connection between the theory and the practice, which is very important as well.

Q: How do you find opportunities for collaboration?

A: That's a big question for us. Requests for proposals are probably necessary, but some of the best ideas come when folks start to make connections that are outside of what we describe in those requests. Actually, part of the challenge that we face in trying to work with MIT is how well we define our problems. We don't want to so constrain the problem that we get the standard answers. We want the problem definition to be broad enough that the creative solutions are invited into the mix.

I hope that this newsletter will spur people to bring us new ideas. My goal is to present this collaborative research in such an interesting way that it stimulates other MIT researchers to give us a call and say, "I've got an idea you need to think about." ■

News

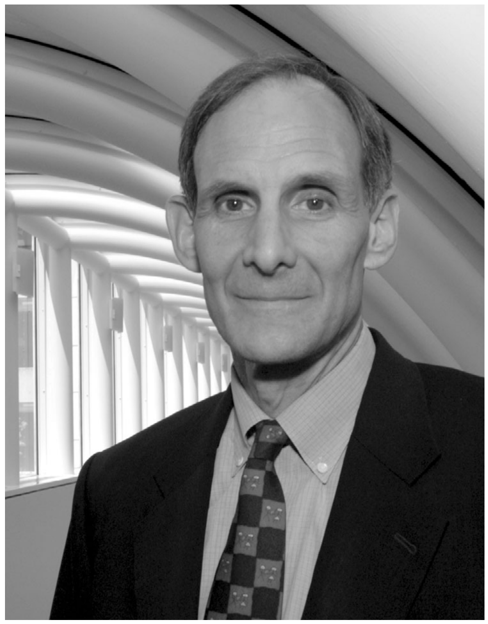
Royal Dutch Shell sends senior scientist to Laboratory for Energy and the Environment

On January 30, MIT and Royal Dutch Shell announced that Richard A. Sears, most recently Shell's vice president for exploration and deepwater technical evaluation, has joined MIT's Laboratory for Energy and the Environment (LFEE) as a visiting scientist. This three-year appointment, a first for the company, will strengthen ties between the MIT and Shell research communities and enhance opportunities for developing innovative solutions to the world's mounting energy problems.

"MIT has a long tradition of working with technology-based industry," said Ernest J. Moniz, the Cecil and Ida Green Professor of Physics and Engineering Systems at MIT, co-director of the LFEE, and former undersecretary for the US Department of Energy (1997–2001).

"The relationship is most effective when there is active dialogue between the parties," he said. "Having Rich Sears here for an extended period will provide practical insight for our faculty and students into the research needs of an international energy company and will provide Shell with opportunities to broaden its research portfolio."

The Sears appointment dovetails with a major Institute-wide energy initiative at MIT, announced by President Susan Hockfield in her May 2005 inaugural address. A 16-member Energy Research Council (ERC) has been working to help determine how MIT scientists, engineers, and social scientists can best address such issues as increased global energy consumption and new routes to renewable and sustainable energy.



Richard A. Sears, LFEE visiting scientist from Shell International Exploration and Production. Photo courtesy/Shell.

"The challenge to sustainably meet growing global demands for energy will require the integration of leading-edge technologies," said John Darley, Shell International Exploration and Production's executive vice president for technology. "Both MIT and Shell have a proud heritage of technical excellence, and this new appointment will further enhance an effective working relationship between the two organizations."

Shell has committed approximately $4 million in research funding to MIT in areas related to exploration and production. The research draws on MIT expertise in fields ranging from geology, geophysics, and seismology to artificial intelligence and biotechnology.

In his role as visiting scientist, Sears will bring his industry perspective to the lab and will serve as a resource to MIT faculty and research staff.

"I'm looking forward to being in the MIT environment," Sears said. "The technical breadth and depth of MIT will offer new perspectives and fresh approaches that will broaden our understanding and impact on the future of energy in the world."

Sears has significant domestic and international experience in oil and gas exploration and production. He is a leading expert in the search for and development of new hydrocarbon resources in the deep ocean (water depths of more than 500 meters). While significant resources remain beneath the ocean floor, Sears warns that identifying and recovering them will require improved imaging and data analysis techniques—an area of ongoing MIT research in which he is particularly interested.

Sears holds degrees in physics and geophysics from Stanford University. Since joining Shell in 1976, he has held technical and management positions in the United States and Europe. He has been an invited and keynote speaker at industry conferences in the United States, United Kingdom, Africa, and Asia and is an author of numerous publications including field studies and case histories, geophysical research reports, and technical training manuals. He is a Licensed Professional Geoscientist in the State of Texas. Since 2004, he has been a member of the Stanford University School of Earth Sciences Advisory Board.

Energy workshop: industry joins MIT in hunt for energy solutions

The automotive, fuel, and other energy-related industries weighed in on how MIT can best contribute to solving the world's energy crisis in a two-day workshop sponsored by MIT's Industrial Liaison Program (ILP) on December 6–7, 2005.

More than 130 participants from industry and academia came together at the workshop, "2005 MIT Energy Challenges Workshop: Igniting New Ideas for Sustainable Energy," to identify priorities and exchange ideas on how to work together to meet fast-rising energy demands while reducing greenhouse gases.

The group heard an overview of the future of coal-based power in increasingly efficient US plants and in a complex and confusing regulatory environment in China. China is expected to account for half the increase in world coal consumption and carbon emissions over the next 25 years. Workshop participants also heard six MIT researchers describe work on topics ranging from photovoltaics to the use of nanotechnology in energy systems.

Technologist, academic, entrepreneur, and long-time MIT supporter Kenan Sahin, founder and CEO of Tiax in Cambridge, Massachusetts, spoke about the critical role of industry in MIT's Energy Research Council (ERC), an Institute-wide initiative to explore how MIT can use its strength in multidisciplinary research to address the nation's and the world's energy issues.

"Energy now has become all-consuming—the key topic in the environment, security, and the economy is energy," Sahin said. "If we can achieve a tight coupling between industry and energy, we have a chance at taming the energy challenge."

ERC co-chair Ernest J. Moniz, Cecil and Ida Green Professor of Physics and co-director of the Laboratory for Energy and the Environment, said that technology will continue to create new ways to use energy more cleanly and efficiently, but that "how technology is deployed for the public good is very much influenced by policy."

Emil Jacobs, vice president of research and development for ExxonMobil Research and Engineering, said that in 2030, oil, gas, and coal will still be the largest sources of energy, with renewable sources such as wind and solar making up only 1% of the world's energy supply. The largest increases in population and economic growth, with corresponding increases in energy needs and production, will happen in developing countries such as China. "We'll need 60% more energy in 2030 than in 2000," Jacobs said.

Bernhard Escherman, senior vice president and head of the Corporate Research Center of ABB Switzerland, questioned how the industrialized world will maintain the reliability of electrical supply in spite of aging power plants, people's reluctance to have transmission lines in their back yards, and the risks of depending on a central infrastructure that might become a terrorist target.

Workshops led by industry representatives came up with the following ways MIT can contribute:

- MIT can help develop advanced turbines, fuel cells, catalytic reactors, and ways to burn coal better and more efficiently. Researchers can design smart energy systems that tell you, for instance, when your driving style is burning more gas or when your tire pressure is low; and home meters that show the dollar amount of energy used.
- MIT can improve existing technologies to up the efficiency of hybrid vehicles, electric motors, friction materials, and engines.
- MIT could provide a "holistic energy plan" that looks not only at supply and demand but also at environment and efficiency through a complex systems approach. MIT can look at the issues in terms of longer time frames than industry can.
- MIT can be an "honest broker" to identify key pathways toward new energy policy and technology across a broad range of stakeholders in industry, politics, and academia.

By Deborah Halber, MIT News Office Correspondent

New book presents insights into cokemaking in China, methods for analyzing industrial change

For almost ten years, an interdisciplinary Alliance for Global Sustainability (AGS) team has been studying one of China's most energy-intensive and highly polluting industries—cokemaking. The focus has been on the rapidly changing relationships among technology, energy, the environment, and health (TEEH) in Shanxi Province, where cokemaking uses more than half of all the coal consumed in the region.

The findings of the research are presented in a new book, *The Technology-Energy-Environment-Health (TEEH) Chain In China: A Case Study of Cokemaking*, edited by Karen R. Polenske, professor of regional political economy and planning in MIT's Department of Urban Studies and Planning and director of the international AGS cokemaking research team.

The authors explain how key economic, environmental, technology, and transportation factors are affecting provincial and industrial energy intensities and environmental pollution in the People's Republic of China (China), the second largest energy user and pollution generator in the world. The result is a new understanding of important industrial changes that are occurring in China and have far-reaching global economic and environmental consequences.

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The authors stress the important role played by the Shanxi Province in encouraging improvements in energy efficiency and pollution by introducing new coke-oven technologies and by encouraging pollution-abatement measures for older ovens.

The analytical tools and methods developed by the AGS team and presented in the book can be used by policy makers, industrial managers, and others to examine TEEH issues in familiar and unfamiliar industries in any country. The results can reveal often-unexpected consequences of industrial management and technology decisions.

The 189-page book begins with an overview of the coke industry and includes chapters written by members of the AGS team on the following topics: alternative cokemaking technologies; economic and efficiency differences between state-owned and township enterprises; modeling the cost and pollution associated with coal and coke transportation; human exposure to ultrafine particulates in the industry; and an analysis of socioeconomic impacts in the region.

This book is the eighth volume in the series "Science and Technology: Tools for Sustainable Development," published by Springer in cooperation with the AGS. Series editor is Dr. Joanne M. Kauffman, senior advisor to the AGS. For information about this and other books in the series, visit the following AGS website: http://globalsustainability.org/content.cfm?uNav=507.

An article describing the research on cokemaking in China was published in the April–June 2003 issue of *e-lab* (http://lfee.mit.edu/metadot/index.pl?id=2329&isa=Category&op=show). See page 5, "Cleaning up China's Cokemaking Sector: Unexpected Research Findings." For a Chinese translation of the article, please go to http://web.mit.edu/dusp/idrp/research/krp2.html.

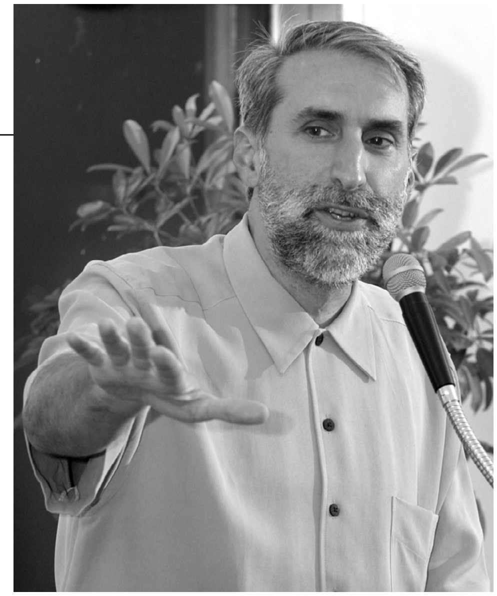
Education Update

New Martin Fellows welcomed, attend environmental fellows' retreat

On September 29, 2005, twenty-four advanced graduate students were welcomed into the Martin Family Society of Fellows for Sustainability (MFSFS) at an induction dinner given in their honor at the MIT Faculty Club. The group comprised Fellows from 10 academic departments as well as the Sloan School of Management and the Engineering Systems Division. The Fellows were selected as a result of their research in and commitment to improving the environment and addressing sustainability issues.

At the dinner, MIT Chancellor Phillip L. Clay, professor of city planning, introduced Mr. Casper Martin, who represented the Martin Foundation. That organization's generous gifts have supported the MFSFS since 1996. Mr. Martin shared with the group an original story featuring his dream of a small, safe, energy-efficient car he called the "Nanogator"—a fantasy car that has few moving parts, lots of computer controls, and is "a blast to drive." The point of the story was not only to amuse the audience but also to inspire the Fellows to feel passion about their research.

As if to underscore that message, Dr. Daniel Nocera, MIT professor of chemistry and the evening's featured speaker, gave a spirited talk focusing on the troubles associated with our oil-based economy and the accompanying carbon dioxide problems. Stressing that conservation will not be enough to save us from disaster, Professor Nocera said, "The only way out of this is science and technology. And you guys, you're going to do that for us...."



Dr. Daniel Nocera, MIT professor of chemistry, stresses the scale and complexity of the world's energy problems in his address to the new Martin Fellows. Photo: Heratch Photography.

Professor Nocera judges that the currently proposed solutions—for example, biomass, nuclear, and wind energy—will alleviate but not resolve the situation. He suggests that there might, however, be hope in harnessing the sun's energy in a specific way—by discovering the secret of photosynthesis. Specially designed chemicals dissolved in water might be able to replicate what a leaf does: splitting water using just sunshine. Photochemical reactions could split the water into hydrogen and oxygen, which would go through an electricity-generating fuel cell and then recombine as water, ready to start over. This novel system is the crux of Professor Nocera's own research, for which he recently was awarded the prestigious Italgas Prize.

Echoing Mr. Martin, Professor Nocera concluded his talk by challenging the new Martin Fellows to pursue "that magical experience of discovery" in order to solve the pressing problems of our age.

Weekend Retreat for All Environmental Fellows

The Martin Fellows' first major activity was an LFEE-sponsored weekend retreat in Woods Hole, Massachusetts, on October 28–30, 2005, for all members of the MIT Environmental Fellows Group. Also invited were MIT's Earth System Initiative Linden Fellows, the Kabcenell LFEE Future Energy Fellows, the environmental fellows in the Department of Urban Studies and Planning, and the current Wallenberg Fellow. Scheduled activities at the Woods Hole Oceanographic Institution (WHOI) and the Marine Biological Laboratory provided an opportunity for these environmental fellows with different departmental affiliations to get to know each other in an informal setting and to explore a sustainability issue of general interest: wind resource development.

During the retreat, science and policy experts from WHOI discussed the historical and policy context for offshore wind development and described studies of whether offshore turbines have any acoustic effect on marine mammals. Michael Berlinski, an LFEE Future Energy Fellow, presented research findings on the variability of the wind resource and economic and environmental implications.

Participants judged the weekend's activities to be successful in achieving the stated objectives. Said Martin Fellow G. Crystal Ng of the Department of Civil and Environmental Engineering, "[The benefit of such a retreat is] meeting other people interested in environment/sustainability issues and sharing insights. I knew very few people outside my own department, and I think it's especially valuable to discuss issues with those who see things from the perspective of different disciplines." And that was the whole idea.

By Karen Luxton, LFEE Education Program

IAP seminar explores MIT's energy options

Generating electricity from wind turbines that look like rooftop box fans and converting used cooking oil into biodiesel fuel are among the energy innovations that MIT may pilot in the not-too-distant future.

On February 2, for the fourth Independent Activities Period (IAP) in a row, students and instructors took part in a continuing experiment in collaborative education involving the Laboratory for Energy and the Environment (LFEE), the Department of Urban Studies and Planning (DUSP), and the city of Cambridge.

In 2002, the Cambridge City Council adopted a plan to reduce in-city greenhouse gas emissions to 20% below 1990 levels by 2010. This year, five students from MIT and Wellesley College researched biodiesel and wind projects during a monthlong seminar. The projects could be piloted at MIT and applied throughout the city if successful.

"This initiative uses the creativity and energy of the students to investigate a local response to one of the city's most prominent environmental goals: climate protection," said Beth Conlin, co-instructor of "Energy and Climate in Cambridge" and LFEE education program coordinator.

The students' proposals would prototype energy technology on campus for possible use in the wider community. Wind turbines that perch on the edge of a roof would work best on the Green Building, Johnson Athletic Center, the Wood Sailing Pavilion, or the Pierce Boathouse, reported first-year student Jing Han. Han investigated a product called Architectural Wind being developed by AeroVironment of Monrovia, California.

"For the wind project, we are seeking a grant from the Massachusetts Technology Collaborative to do a full feasibility study, including site measurements of the available wind resource, economic analysis, and other technical and nontechnical issues" such as the effect on birds and noise level, said Peter L. Cooper, manager of sustainability engineering and utility planning in the MIT Department of Facilities. If the project seems promising, a construction grant would allow the

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MIT Earth Day Celebration 2006

Thursday, April 27
MIT Stata Center (Building 32)
10:00 AM – 4:00 PM

The celebration will include exhibits by MIT environmental programs and student groups, displays by community groups and businesses, art projects, bike repair, food, drinks, and entertainment.

Related events will take place throughout the week of April 24–28.

Check http://web.mit.edu/earthday for updates.

Sponsored by the Laboratory for Energy and the Environment (LFEE), the MIT Environmental Programs Office, the MIT Staff Working Group Recycling Committee, Share a Vital Earth, and Students for Global Sustainability

Contact: Beth Conlin, LFEE Education Program, bconlin@mit.edu

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wind turbines to be installed a year or more down the road.

A biodiesel conversion facility on campus would take between one and two-and-a-half years to break even, reported Elizabeth Ricker, a junior in brain and cognitive sciences, who worked with Joseph Roy-Mayhew, a sophomore in chemical engineering, and Hailun Wu and Christianne Roach, students at Wellesley College. The team investigated the feasibility of using waste vegetable oil to produce a clean-burning, biodegradable fuel that could help power MIT vehicles and heat MIT buildings.

MIT junior Elizabeth Ricker reports on the feasibility of establishing a biodiesel conversion facility on campus during final presentations held on February 2 for the four-week IAP course "Energy and Climate in Cambridge." Photo: Teresa Hill/LFEE.

The students estimated that 5,000 gallons of waste oil could be collected from campus dining facilities and nearby restaurants, saving the Institute money on fuel costs and saving MIT food vendors money spent for waste oil removal. MIT might even build its own processor for the chemical conversion process instead of purchasing one, Roy-Mayhew said.

"When I was working through the numbers and looking into what other schools and communities were doing, I saw that MIT could and probably should go forward with such a project," Roy-Mayhew said. "I could see MIT setting up a biodiesel conversion unit on campus and in the future expanding throughout Cambridge and Boston."

Steven M. Lanou, deputy director of environmental sustainability, said that the biodiesel facility also will be studied for feasibility.

To review the students' project results, along with information on and results of previous classes, go to the LFEE education page (http://lfee.mit.edu/education/) and click on the link under "IAP Seminar 2006."

By Deborah Halber, MIT News Office Correspondent

Introducing energyClasses, a new Web tool for students

On January 25, the LFEE Education Program launched energyClasses, a new interactive database designed to help students find energy-related classes at MIT. The site—http://energyclasses.mit.edu—was developed under the leadership of the Education Subcommittee of the MIT Energy Research Council, with assistance from members of the students' MIT Energy Club. The site can be browsed by department, by energy topic (e.g., fossil fuels, renewables, buildings, transportation, climate), and by energy systems and processes (e.g., sources, distribution, utilization, economics, regulation).

Martin Family supports undergraduate sustainability research

The Martin Foundation, Inc., established by Lee '42 and Geraldine Martin, founding donors of the Martin Family Society of Fellows for Sustainability, has provided generous new support for undergraduate sustainability research for the next three years (2006–2009). About a dozen students annually will participate in MIT's Undergraduate Research Opportunities Program as "Martin UROPs." Each Martin UROP will collaborate with a Martin graduate fellow and a faculty supervisor on a sustainability-related research project.

LFEE to test project-based energy education for freshmen

In spring 2007, a multidisciplinary faculty team supported by the LFEE Education Program will offer a 9-unit subject engaging freshmen in practical energy projects on the MIT campus and in Cambridge and Boston. The pilot offering of the class is supported by the d'Arbeloff Fund for Excellence in Education in collaboration with the Task Force on the Undergraduate Educational Commons and the Dean for Undergraduate Education.

Contact Dr. Amanda C. Graham at agraham@mit.edu for more information.

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

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

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/

Inquiries can be sent by e-mail to thill@mit.edu for LFEE publications, canes@mit.edu for CANES publications, bubluski@mit.edu for CEEPR publications, and tzh@mit.edu for Joint Program publications. To obtain a copy of an MIT thesis, in paper or electronic format, go to http://libraries.mit.edu/docs/theses.html.

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NEW AND RENEWED PROJECTS, JULY 2005–FEBRUARY 2006

Topic	Donor or Sponsor	Investigators *(Department)*
GIFTS, CONTRIBUTIONS, AND MEMBERSHIPS		
Laboratory for Energy and the Environment	Anne H. Foster Trust	D. Marks *(Laboratory for Energy and the Environment)*
Laboratory for Energy and the Environment	CEA/Centre de Saclay	D. Marks *(Laboratory for Energy and the Environment)*
Energy Research Council Fund	Frederick A. Middleton, Jr. (class of 1971)	E. Moniz *(Laboratory for Energy and the Environment)* R. Armstrong *(Chemical Engineering)*
Center for Energy and Environmental Policy Research membership	Chevron Corp.; EDP-Energias de Portugal, SA; Electrabel; ExxonMobil; Iberdrola; J-Power; Petrobras; Tennessee Valley Authority; Vattenfall	
Joint Program on the Science and Policy of Global Change membership	Chevron Corp; Daimler Chrysler; ExxonMobil; Ford; J-Power; Murphy Oil Corp.; RWE Power AG; Schlumberger-Doll Research; Tennessee Valley Authority; The G. Unger Vetlesen Foundation	
EPA Summer Symposium	ExxonMobil Research and Engineering; National Commission on Energy Policy; PSEG; The Mickey Leland National Urban Air Toxics Research Center; US Department of Transportation Federal Highway Administration; US Environmental Protection Agency (EPA)	D. Marks *(Laboratory for Energy and the Environment)*
NEW PROJECTS		
Before a Transition to Hydrogen Transportation	Shell International Exploration and Production Inc.	J. Heywood Y. Shao-Horn *(Mechanical Engineering)*
Solar Energy Technology Development	Shell International Exploration and Production Inc.	E. Moniz *(Laboratory for Energy and the Environment)*
Integrating the Transport Sector into an Economy-Wide Carbon Mitigation System	Ford Motor Co.	H. Jacoby *(Sloan School of Management)*
Impact of Diesel Vehicles on Climate	Ford Motor Co.	C. Wang *(Earth, Atmospheric, and Planetary Sciences)*
Heat Transfer in Nanofluids	Ford Motor Co.	G. McKinley G. Chen *(Mechanical Engineering)*

NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators *(Department)*
NEW PROJECTS, CONTINUED		
Time Differentiated NO_X Emission Control, Ozone Forecasting, and Value of Information: The Development of an Integrated Analysis Framework	US Department of Commerce—National Oceanic and Atmospheric Administration	P. Joskow *(Economics)*
Factors Affecting the Rate of Penetration of Large-Scale Electricity Technologies	US Department of Energy (DOE)	H. Herzog *(Laboratory for Energy and the Environment)*
Alliance for Global Sustainability (AGS) Flagship Program	AGS International	S. Connors *(Laboratory for Energy and the Environment)*
Competitive Advantage, Regulation, and Environment	AGS International	K. Oye *(Political Science)*
Learning Components—AGS Energy Flagship Website	AGS International	J. Steinfeld *(Chemistry)*
Energy, Environment, and Technology: An Interdisciplinary Project-Based Curriculum for First-Year Students	d'Arbeloff Fund for Excellence in Education	J. Steinfeld *(Chemistry)*
RENEWED PROJECTS		
The Future of Coal—An Interdisciplinary MIT Study	Pew Charitable Trust	E. Moniz *(Laboratory for Energy and the Environment)* J. Deutch *(Institute Professor)*
Integrated Assessment of Multiple Greenhouse Gases and Policy Studies	US EPA	J. Reilly *(Laboratory for Energy and the Environment)*
Environmental Resource Center	Eastern Iowa Community College District	J. Steinfeld *(Chemistry)*
International Collaboration on CO_2 Sequestration	US DOE/Pittsburgh	H. Herzog *(Laboratory for Energy and the Environment)*
Energy Choices: Carbon Sequestration Initiative	Alstom Power Inc.; American Petroleum Institute; Chevron Corp.; Electric Power Research Institute; Electricité de France; ExxonMobil; GM Foundation—North American Operations; Peabody Energy Corp.; Saudi Aramco	H. Herzog *(Laboratory for Energy and the Environment)*

NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators *(Department)*
RENEWED PROJECTS, CONTINUED		
A University Consortium of Homogenous Charge Compression Ignition Engine Research	University of Michigan/US DOE	W. Cheng *(Mechanical Engineering)*
Engine and Fuels Research Consortium	Daimler-Chrysler AG; Delphi Automotive Systems Inc.; Ford Motor Co.; General Motors Research Laboratory; Saudi Aramco	J. Heywood *(Mechanical Engineering)*
Oil and Lubrication Research Consortium	AB Volvo; Dana Corp.; Mahle GMBH; Renault SAS	J. Heywood *(Mechanical Engineering)*
Low-Ash Engine Emissions Consortium—new members	Caterpillar, Inc.; Lutek, LLC; National Renewable Energy Laboratory; Sud-Chemie, Inc.; Valvoline Co.	V. Wong *(Laboratory for Energy and the Environment)*
Low Engine Friction Technology for Advanced Natural Gas Reciprocating Engines	US DOE/Pittsburgh	V. Wong *(Laboratory for Energy and the Environment)*
Water-Based Nanofluids Studies for Nuclear Systems Applications	Battelle Energy Alliance	J. Buongiorno *(Nuclear Science and Engineering)*
Investigation of Fundamental Thermal-Hydraulic Phenomena for Advanced Gas-Cooled Reactor Appliances	Battelle Energy Alliance	P. Hejzlar *(Nuclear Science and Engineering)*

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