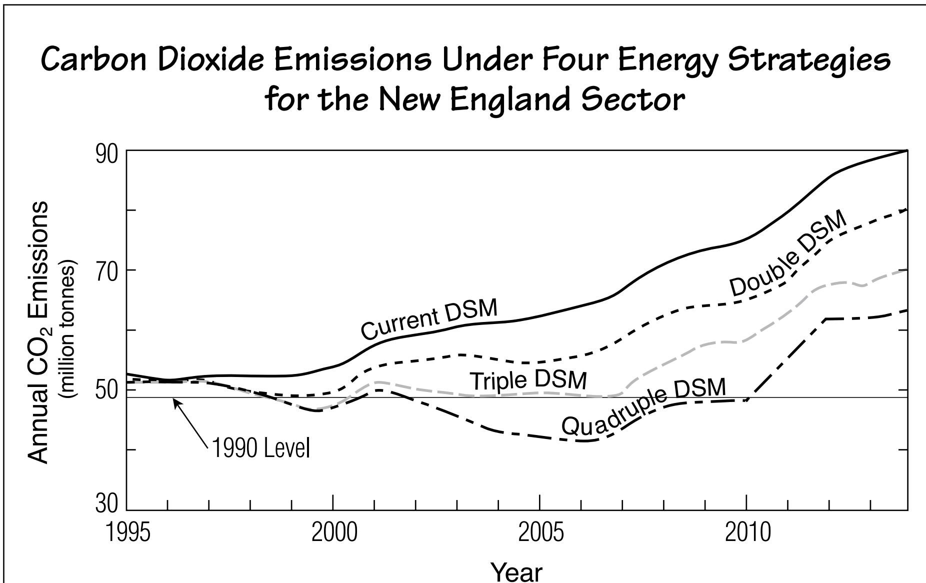
e-lab

Energy Laboratory research and related activities at the Massachusetts Institute of Technology January–March 1999

Reducing Electric Power Emissions: Are Kyoto Targets Reachable?

What mix of policies and technologies will let us produce and use electricity while protecting environmental, economic, and social health for future generations? An international team led by Energy Laboratory researchers has developed a methodology to help decisionmakers address that question. The outcomes of initial case studies are sobering. The methodology combines engineering, cost-accounting, and life-cycle assessment techniques to study potential strategies for specific regions. In each study, an advisory group of governmental representatives, utility executives, business people, and special interest groups provides information on regional needs and constraints and ultimately identifies the strategies that best meet their diverse interests. Studies of New England and Switzerland examined strategies involving expanded use of natural-gas combined-cycle generation and renewable technologies as well as improved end-use efficiency. Even the most aggressive strategies produced carbon dioxide (CO_2) emissions well above the levels prescribed by the Kyoto Protocol. The researchers conclude that achieving substantial and sustained reductions in CO_2 emissions will require changes in the basic electricity supply and demand infrastructure. Target strategies include the use of distributed generation systems including small cogenerators, more efficient transmission systems, novel building designs, and "smart" meters that control electrical devices to maximize operational efficiency. Also critical is the transfer of new technologies to nations whose energy infrastructures are expanding rapidly, especially developing nations. Finally, control of CO_2 emissions must be coordinated with the reduction of other emissions that are more important at local and regional levels.

Most people agree that energy supply and demand systems should be "sustainable." Energy policies and technologies should preserve the environment while supporting economic development and social welfare in both industrialized and developing countries. According to Stephen R. Connors and his colleagues, such broad definitions of sustainability are unlikely to bring about real change because they fail to connect with the more immediate interests of those who can actually implement strategies for electric development. Real change usually occurs in response to near-term or occasionally longer-term regional or local considerations. If climate changes, will



These projections show carbon dioxide (CO_2) emissions from the New England electric sector assuming four strategies involving varying levels of demand-side management (DSM) and new natural-gas combined-cycle power generation. The Kyoto Protocol calls for a reduction in CO_2 emissions by 2012 to 7% below 1990 levels (shown by the horizontal line). Even the most aggressive strategy considered here does not come close to that goal. (See text on page 3.)

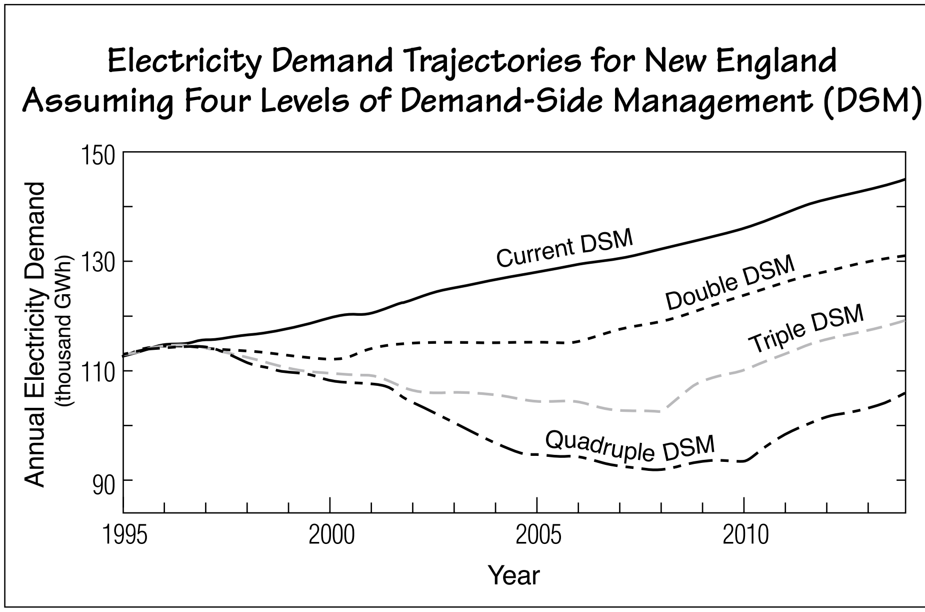
IN THIS ISSUE

- Reducing Electric Power Emissions: Are Kyoto Targets Reachable?
- Nuclear Power Safety Regulation: Reducing Risk and Expense
- News Items, Publications and References, New and Renewed Projects

our farms experience more frequent floods, droughts, or hurricanes? How many of our neighbors will become unemployed? The first step in developing robust sustainable energy practices is to identify region-specific impacts, needs, and constraints. The next steps are to define cost-effective, responsive, and realistic energy strategies and to communicate them to the relevant policymakers.

Carrying out those tasks is the goal of a new project called Strategic Electric Sector Assessment Methodology under Sustainability Conditions, or SESAMS. SESAMS has been developed by a multidisciplinary team that is led by Mr. Connors and involves researchers at MIT, ETH-Zürich, the Ecole Polytechnique Federale de Laussane, and the Paul Scherrer Institut. The focus is on electricity because it is cleaner at the point of use than is energy produced directly from fuel combustion and because it is versatile: it can power devices ranging from computers and air conditioners to industrial equipment and vehicles.

SESAMS is designed to determine how different strategies for generating, transporting, and using electricity will affect costs, emissions, and other consequences in a given region. Each strategy consists of a variety of technologies, fuels, conservation programs, policy actions, and so on. The SESAMS approach differs from traditional approaches to utility planning in several ways. It uses engineering models in conjunction with economic models, but the economic and environmental analyses are regional or local—a challenge because statistics for critical factors such as economic growth, electricity production, and pollutant emissions tend to be available for nation- and industry-wide groupings rather than for regional ones. Linked with the engineering and economic models are life-cycle assessment (LCA) models that calculate the emissions, resource consumption, and environmental damages associated with a given strategy. Thus, the LCA models take into account the electricity consumed in extracting and refining fuels, building power plants, constructing factories for making high-efficiency light bulbs, and so on.



These curves show calculated annual electricity demand in New England assuming four levels of demand-side management (DSM) through programs that help increase the efficiency of electricity-using facilities. The top curve assumes that utility-initiated DSM programs continue. The bottom three curves assume more aggressive DSM programs that involve doubling, tripling, and quadrupling the actions taken in the utility-initiated programs. The upturn in demand in each of the three lower curves occurs when those DSM programs end.

Finally, the SESAMS approach does not weigh or prioritize different impacts, for example, by placing dollar values on specific emissions or environmental effects. The priorities of various groups of "stakeholders" involved in policy decisions differ, making such weighting schemes inappropriate for the intended policy dialogue. SESAMS therefore permits the stakeholders themselves to incorporate their interests by involving them in the studies directly—an approach that Energy Laboratory researchers developed a decade ago in electric utility planning studies of New England (see *e-lab*, April–September 1989). Each SESAMS case study involves an advisory group of environmental and economic regulators, business people, and members of environmental and other interest groups. The group's primary goals and constraints—economic, political, environmental, and social—are thereby incorporated into the analysis. With each new set of scenario analyses, the researchers present the advisory group with a graphical representation of the relative costs, emissions, and other implications of the strategies. The stakeholders then work together, discussing the tradeoffs among costs, emissions, and other benefits to identify the strategies that best meet their collective needs.

The researchers have performed several case studies that examine changes in technologies, policies, and practices and their impacts on long-term emissions in well-defined geographical regions. One major study focused on New England. Assisted by an advisory group, the researchers used state-of-the-art engineering models to simulate the operation of the regional power system for thousands of combinations of technology types, environmental regulations, fuel costs, and other factors. Eight of the most interesting strategies, each involving plans for generating the needed electricity and measures to reduce electricity demand, are described here. (Life cycle assessment was not included in the New England project.) The simulations run from 1995 to 2014 and start with the 1995 energy mix used to generate electricity in New England—28% from baseload nuclear power, 16% from coal generation, 40% from oil and natural gas, and the remainder from a mix of hydropower, imported power, and other sources.

The demand-reducing measures used in the strategies involve demand-side management (DSM) programs—utility-implemented programs aimed at increasing the energy efficiency of their customers' facilities. Four levels of DSM are considered. The baseline strategy assumes that current DSM programs continue, cutting electricity consumption by 8% over the 20-year study period. Three other strategies call for increasingly aggressive DSM programs that result in reducing consumption by 15%, 21%, and 26% over the 20-year period. These higher levels of DSM are phased in over time and then stopped so that their longer-term impacts can be assessed.

Two methods of adding new generation are used in the strategies. The first plan uses existing generating capacity to the extent possible and meets any need for additional power using natural-gas combined-cycle generation, a relatively high-efficiency, low-emissions electricity source. The second plan uses the same approach but adds renewable power to the generation mix: 1400 MW of wind generation is phased in during the first ten years of the study period. The result is a total of eight strategies, four DSM levels with and four without windpower. It is important to note that these eight strategies do not represent forecasts of what might happen but rather of what is "technically feasible"—a distinction that must be emphasized, as discussed by Henry D. Jacoby, William F. Pounds Professor of Management (see reference 5). Issues relating to the economic and political feasibility of various strategies as well as policies to promote their adoption must be considered by working with the stakeholder advisory group.

The first step in determining the impacts of the strategies is to calculate the resulting electricity demand under each of the four levels of DSM. The figure on page 2 shows the outcome. The top curve shows the impact of the reference strategy: demand increases steadily at a rate of about 1.3% per year. The three lower curves show the effects of the increasingly aggressive DSM strategies. Electricity demand tends to be relatively flat or declining during the first part of the study period, but each curve takes an upward turn when the DSM programs end.

The next step is to calculate CO_2 emissions resulting from meeting those four levels of demand using the two generation plans (with and without windpower). The figure on page 1 shows the projected levels of CO_2 emissions resulting from implementation of each of the four strategies excluding windpower. In each case, adding windpower lowers the curve shown here by about 2 percentage points. The horizontal line indicates emissions levels in 1990—the historical baseline used in the Kyoto Protocol.

Under the "business-as-usual" reference strategy, CO_2 emissions rise steadily; and by 2014 they are fully 80% higher than the 1990 levels. This increase in CO_2 emissions is caused largely by the long-term growth in electricity demand seen in the figure on page 2. Two events exacerbate the growth in emissions: in 2001, contracts for Canadian hydropower expire; and between 2003 and 2013 aging nuclear units—the source of half the total nuclear power—are retired. Those non-CO_2-producing sources are replaced by new and existing fossil-powered plants, leading to further increases in CO_2 emissions. (These results are somewhat optimistic as the trend in the region has been to retire some of these nuclear units prior to the end of their operating licenses.)

As expected, the more aggressive DSM strategies do better. Those strategies are able to reduce industry-wide CO_2 emissions to or below 1990 emissions—but only temporarily. As soon as the DSM programs are phased out, CO_2 emissions begin to rise. By 2014, the double and triple DSM strategies are 60% and 40% above the 1990 levels. Even the quadruple-DSM strategy (with wind included) is about 25% over 1990 levels—well above the 7% *reduction* called for in the Kyoto Protocol.

The difficulty of designing a CO_2-reduction strategy is illustrated by one observation: as nuclear units are shut down, CO_2 emissions increase more rapidly under the more-aggressive DSM strategies than under the reference case. In the reference case, demand for electricity grows rapidly; and new natural-gas-fired power plants must be built. Generation from nuclear plants is replaced using natural gas plants, pushing up CO_2 emissions. But the outlook is even worse under the more-aggressive DSM strategies. Demand grows more slowly, so less new natural-gas-fired generation is built. And when nuclear generation is retired, old lower-efficiency, higher-carbon-content plants are used to fill the gap. Overall CO_2 emissions therefore increase faster in later years. Emissions such as nitrogen oxides and sulfur dioxide can actually become greater in the more-aggressive DSM strategies than in the reference strategy.

Another case study using SESAMS is examining strategies for the electric power industry in Switzerland. To perform this study, the MIT researchers teamed up with their colleagues at the Paul Sherrer Institut and ETH-Zurich, who contributed both detailed knowledge of the Swiss situation and sophisticated new analytical tools for assessing the life-cycle energy and emissions implications of the strategies studied. Results from the Swiss study are as discouraging as those from the New England study. Switzerland's electricity now comes largely from hydropower and nuclear plants, so CO_2 emissions are already low. But the SESAMS analysis concludes that future increases in CO_2 emissions are inevitable because natural-gas-fired generation is the most likely candidate to replace the retiring nuclear plants. Strategies combining dramatic increases in end-use efficiency and the use of substantial forestry biomass generation could hold emissions down for several decades. But by 2019 demand will be sufficiently high that natural-gas-fired generation is required, and CO_2 emissions will begin to climb.

The researchers are now continuing their SESAMS case studies. They are expanding the Swiss analysis by including nuclear plant retirement, growing reliance on imported power, and increasing competition with Western European electricity markets. They are also undertaking a major study of electric power strategies for the province of Shandong, China, a region with rapidly growing electricity demand and fewer choices for electricity generation.

Based on their work so far, the researchers conclude that achieving significant, sustained reductions in CO_2 emissions will be difficult. No single technology or class of technologies will do the job; and efficiency improvements cannot be assumed to continue indefinitely, on either the supply or the demand side. The only way to achieve the needed reduction is by improving the entire energy supply and demand infrastructure, including the development and deployment of many new cost-effective technologies (see box to right). Such an undertaking requires close coordination among policymakers, technology developers, energy service providers, and the public—a difficult task, especially without the leadership provided in the past by the large utilities.

Stephen R. Connors is a research scientist in the Energy Laboratory and, since 1989, director of the Laboratory's Analysis Group for Regional Electricity Alternatives (AGREA). *The New England case study, which ran from 1988 to 1996, was funded by a consortium of New England utilities and the National Renewable Energy Laboratory. The ongoing Swiss and forthcoming Chinese case studies are supported through the Alliance for Global Sustainability, a partnership of MIT, the Swiss Federal Institutes of Technology, and the University of Tokyo.* *Further information can be found in references 1–5.*

Meeting the Kyoto Emissions-Reduction Targets

Case studies such as those described in the adjacent article suggest that current methods of improving electricity generation and use will not limit emissions of carbon dioxide (CO_2) to the levels defined in the Kyoto Protocol. Based on extensive research on various aspects of electric power, Stephen R. Connors and his colleagues recommend fundamental changes in both the technologies and the policies that affect electricity generation and use.

Replacing high-emitting electric power plants is an obvious priority. Modern natural-gas combined-cycle plants are more efficient and cleaner than many other types of fossil-fueled plants. However, the decision to build new combined-cycle plants must be made with care. Building such plants will reduce emissions only if the new plants replace less-efficient, dirtier plants. New natural-gas-fired plants do emit CO_2, so building them to meet growing demand will increase emissions. Decisions to close still-viable nuclear plants in response to public pressure and short-term economics must also be reviewed carefully, as that carbon-free source may well be replaced by a source that is not carbon free.

The traditional sources of baseload power should be supplemented by other technologies deployed at selected locations in the power grid. For example, windpower, hydropower, and certain solar technologies must be installed where there is the best resource, often in remote areas. However, fuel cells, heat pumps, cogeneration, and photovoltaics are best used near the point of consumption. Such customer-based technologies reduce the need to transport electricity over long distances—a significant advantage, as roughly 7% of all central station generation is lost in today's transmission and distribution systems. Installing high-efficiency transformers, high-voltage DC lines, and superconducting elements on transmission systems could reduce some of those "line losses." Such technological improvements could mean huge fuel, emissions, and cost savings along the electricity supply chain, from fuel extraction to power generation to delivery to the consumer.

Finally, significant opportunities still exist to increase end-use efficiency. There are two basic classes of end-use efficiency. Energy efficiency involves the installation of devices that use less energy to provide the same level of service (light, heat, air conditioning), while operational efficiency uses "smart" devices to better manage the use of energy (for example, sensors that dim lights when there is adequate sunshine and sensors that note that no one is home and postpone the use of air conditioning when electricity is expensive). Operational efficiency may hold real potential because it can be used with both new and existing equipment and because the transition to competition in the power industry is promoting a move toward more time- and price-sensitive use of electricity. A primary example of combined energy and operational efficiency is the use of "total building envelopes." In this concept, the foundation, walls, windows, and other exterior components of a building are designed together with the building control system in order to achieve a substantial reduction in energy use without sacrificing performance.

The researchers' final recommendations concern policymaking for the now-competitive US electricity industry. Conventional utilities are no longer present to take the lead in improving the industry. Therefore, new economic and environmental policies must encourage all participants in the industry to introduce smarter, more efficient, cleaner technologies. Companies should be rewarded for providing not just electricity but electricity management services that focus on maximizing the efficiency with which their customers purchase and use electricity. Finally, policies should support the transfer of low-carbon, energy-efficient technologies to developing nations. Infrastructure turnover and growth rates are relatively low in most industrialized nations, but many developing nations are experiencing rapid growth in their energy provision and consumption infrastructures. Thus, international cooperation and technology transfer can play a major role in controlling worldwide CO_2 emissions in the long term.

Nuclear Power Safety Regulation: Reducing Risk and Expense

In 1997, the Nuclear Regulatory Commission announced that safety regulation for nuclear power plants would be changing. In the past, plant operators had to deal with long checklists of tests and inspections. In the future, they would instead set goals for overall plant performance and undertake procedures focusing on specific components and systems whose failure would most threaten plant safety. However, a period of transition is required; and the ultimate success of the new system is not assured. A new Energy Laboratory study demonstrates the practicality and potential economic and safety benefits of the new "risk-informed, performance-based" regulation and points to several obstacles now preventing its full implementation. A major portion of the study focuses on the example of the emergency diesel generator, a back-up electricity-generating device whose failure could pose a serious risk to the reactor core. Based on surveys of experts and data from an operating nuclear plant, the MIT researchers and their industrial collaborators determined that many of the current requirements do not increase safety and some may actually reduce it. They developed a different inspection and maintenance plan that would—according to probabilistic risk assessments—yield the same or greater level of safety with less effort. However, their work suggests that complete implementation of performance-based regulation requires better data bases and analytical models, the integration of expert opinion into the regulatory process, and improved procedures for testing the reliability of components. They conclude that performance-based regulation, properly implemented, could be critical to the future viability of nuclear power and that it might be the source of important safety and economic gains for other regulatory agencies as well.

Traditionally, the regulation of nuclear power has relied on long, fragmented checklists of requirements that safety-related systems in a plant must satisfy. Most of the requirements were adopted as nuclear safety regulation matured in response to some mishap or newly appreciated concern, with no attention paid to the coordination or coherence of the list or the consistency of its effectiveness at plants of differing design. To identify areas of concern, regulators used an approach called deterministic analysis. They reviewed diagrams of nuclear systems and decided which component failures or combinations of failures would lead to serious problems such as core damage. They then required that the components involved have one or more backups that can switch on if the primary component fails. Athough deterministic analysis is used in the regulation of most hazards in society today, it has shortcomings. In particular, examinations of nuclear plants were not done systematically and comprehensively in a formal, explicit way. As a result, some important potential failures were missed. Nevertheless, the list of regulatory requirements that resulted is so extensive that power plant owners typically have no time or money to pursue innovations and improvements that might further increase safety.

Recognizing such problems, in the late 1990s the Nuclear Regulatory Commission (NRC) announced that it would be moving to a performance-based approach to nuclear power regulation—a change that Professor Michael W. Golay and his colleagues believe could significantly improve both the safety and economics of nuclear power. Under the new regulatory regime, the goal is not to fulfill a checklist of tasks but to define and achieve goals for system performance. Regulatory requirements are motivated not by the possibility but the probability that things will go wrong. That probability is quantified using "probabilistic risk assessment" (PRA), a systematic method for analyzing a complex system to determine the risk that certain events will occur. Developed in the 1970s, PRA calculates the probability that each component in the system will fail or will operate outside its "expected" range of behavior. It then calculates how likely that behavior is to affect other components and their operation. Taking all the pieces together, the PRA analysis finally calculates the probability that the overall system will fail.

According to Professor Golay, such assessments improve the basis for regulation compared to the use of traditional deterministic analyses alone. PRA predictions of the absolute probability that an overall system will fail are substantially uncertain—a shortcoming that has precluded the use of PRAs as a regulatory tool for two decades. Yet PRAs are excellent at examining all identified combinations and sequences of component failures and determining which are most likely to occur and to cause serious damage. Based on those insights, regulators can focus requirements for maintenance, safety testing, and upgrades on components and systems where improvements will most benefit public safety and where additional information will clarify now-uncertain behavior. As new information reduces uncertainty, PRA analysis can redefine where the greatest potential for improvement lies; and regulations can change accordingly.

Risk-informed performance-based regulation may yield the safety and cost improvements needed to keep nuclear power a viable energy source in the future. Yet such regulations have not been implemented widely. To find out why not, Professor Golay and graduate students Sarah Abdelkadar, Jeffrey D. Dulik, Frank A. Felder, and Shantel M. Utton performed a set of case studies on important components. One focused on the emergency diesel generator (EDG), a device that provides a nuclear plant with electricity in an emergency. Also involved were collaborators from Northeast Utilities Services Corporation and the Idaho National Engineering and Environmental Laboratory.

The research team identified the EDG as a primary target for regulatory improvement for two reasons. First, EDGs are critical to safety. If other sources of electricity are cut off, the EDG must quickly switch from standby mode to providing electricity for functions that range from lighting the control room to operating the pumps that provide cooling water to the reactor core to prevent damage. Second, under current regulations, EDGs require frequent and extensive testing and maintenance; yet the requirements were established at a time when there was little relevant operational history for EDGs. A revision of EDG operations reflecting accumulated experience could lead to the replacement of unproductive procedures with more productive ones, yielding a higher level of safety with a lower expenditure of resources.

The case study focused on the EDGs used at Unit 3 of the Millstone Nuclear Power Station, operated by Northeast Utilities. The researchers used several approaches to understand the effectiveness of today's regulations. They surveyed employees who operate, inspect, and evaluate the EDGs at Millstone-3 as well as at other utilities that use the same type of EDGs. They also examined the inspection, maintenance, and overhaul requirements for EDGs used in hospitals, the US Navy, and the Federal Aviation Administration. The message was clear and consistent: the NRC requirements are excessively demanding. In the other settings, EDG inspections and maintenance are less frequent and less intrusive to the diesel, yet the performance and reliability of the EDGs have been satisfactory.

Working with historical data and PRA analyses of the EDGs at the Millstone-3 plant, the researchers recommended specific changes in the NRC requirements. For example, one NRC requirement is to start, load, and operate the EDG for an hour every month (or more frequently if the EDG malfunctions). But when needed, EDGs often must run for dozens of hours; and NRC data show that significant failures can occur throughout the first 17 hours of operation. (Later failures are much less frequent.) The proposed plan therefore replaces the monthly, one-hour test with a 24-hour test performed every 12 months and whenever the reactor is refueled (typically every 18 months).

The current NRC requirements also call for a major inspection every 18 months that requires partially disassembling the EDG. Industry data show that these intrusive procedures rarely reveal failures. Moreover, operators can introduce new defects as they inspect and reassemble the EDG, thereby actually decreasing the reliability of the device. Such intrusive procedures are not part of the inspection in the other EDG-using industries.

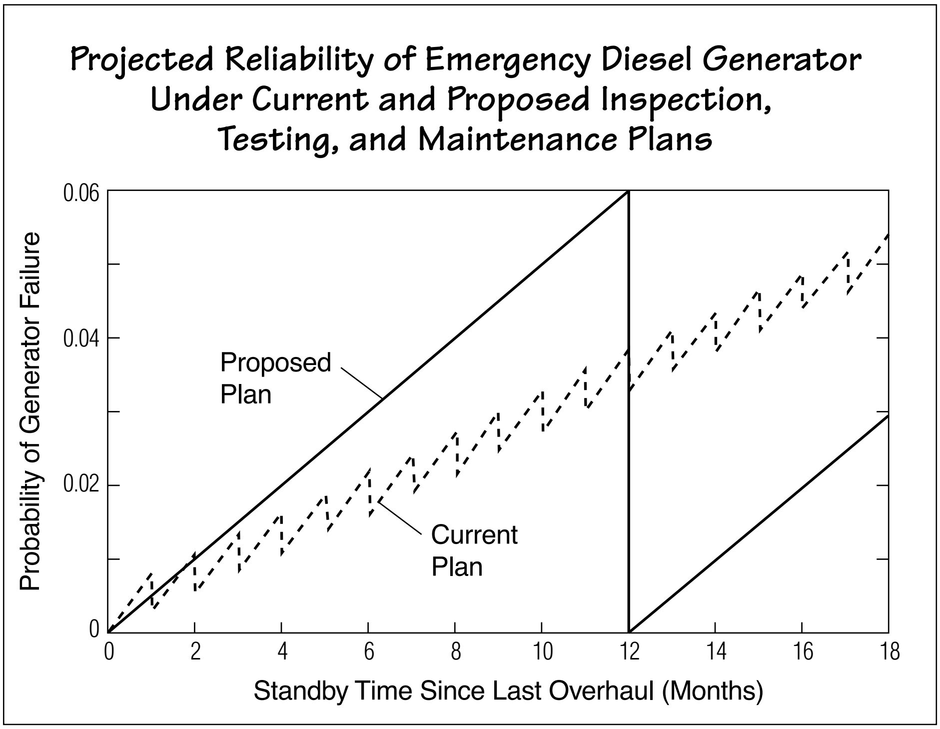
The proposed plan replaces such tasks with more thorough visual inspections and extensive monitoring during the testing procedures. Such monitoring has been made possible by advances in computer technology during the past ten years. The proposed monitoring can replace certain inspection and maintenance tasks. For example, rather than periodically checking the tightness of bolts in the exhaust manifold, operators would continuously monitor exhaust pressure and leakage—an early warning of loose bolts. Operators also now must check the alignment of the crankshaft and the condition of the bearings—tasks that are very intrusive and difficult to perform and have never revealed problems at Millstone-3. Vibration monitoring and oil analysis would achieve the same goal. According to the researchers' analysis, the proposed monitoring system would provide information about the occurrence of about 90% of the events that together contribute about half of the current risk of EDG failure. (Because such monitoring methods are not yet in use, a period of learning would be required to develop the expertise needed for interpreting the data obtained.)

To see how their proposed changes would affect the risk of plant failure, the researchers used PRA techniques to calculate the probability of EDG failure for the upcoming 18 months under the two plans. In the figure on page 7, the dashed line assumes use of current testing procedures, while the solid line assumes use of the researchers' proposed plan, including monitoring during tests. The jagged shape of the dashed line reflects the increase in the probability of failure between one monthly test and the next. The tasks undertaken in the monthly test address only half of the potential risk of failure. Therefore, after each monthly test the probability of failure drops down only half of the past month's increase rather than to zero. The gradual upward climb continues until the 18-month point, when operators will perform the major (intrusive) procedures. Subsequently, the probability of failure drops back to zero.

The solid line reflecting the probability of failure under the proposed plan behaves quite differently. Because there are no monthly tests, it climbs continuously until the annual test, when it drops back to (at least approximately) zero. The major test performed at 18 months (during the refueling outage) also resets the probability of failure back to approximately zero.

For the first 12 months, the probability of failure is generally higher with the one-year test; for the next six months, it is lower. But over the 18-month span, the average probability of failure is about the same with the two approaches. The results for the proposed plan can be varied by changing the duration and frequency of the extensive tests.

These results do not take into account several factors. One is the increased probability of failure due to having only one of two EDGs in service during the testing. At first glance, it may appear that shutting down one EDG for a full 24 hours would be worse on that score. But every test requires time for disconnecting and then reconnecting the EDG. Therefore, the total "out-of-service" time with the annual 24-hour test is probably comparable to that with the one-hour tests



These curves show, for the upcoming 18 months, the probability that the emergency diesel generator, a critical safety device in a nuclear power plant, will fail. The dashed line shows the probability of failure assuming use of the current regulatory requirements, which include monthly inspection, testing, and maintenance. Between monthly tests the risk of failure gradually increases, but after each test it does not drop back to where it started because the test addresses only half the potential sources of risk. The solid line assumes use of a new regulatory plan proposed by Energy Laboratory researchers that requires less frequent but more thorough tests. Both plans call for a major test at 18 months, which the analysis assumes resets both curves to zero. Over the 18-month period, the proposed plan produces the same average risk of failure as the current requirements with less effort expended by plant operators. The effects of taking the EDGs out of service for testing and repair are comparable with the two approaches and are not shown in this figure.

performed every month. The analysis also does not account for the increase in the probability of failure immediately after the major intrusive procedures required every 18 months under the current plan—an increase thought to be far greater than that associated with the non-intrusive tests of the proposed plan.

A final, hard-to-quantify effect involves employee morale. Plant operators now perform their job "by the book," simply to meet written requirements. Knowing that the tasks they undertake provide a valid contribution to plant safety would likely improve employee morale and performance and hence plant safety. Moreover, because the proposed plan would involve fewer required activities—and probably fewer repair operations—labor costs and other expenses would drop.

The researchers conclude that their proposed plan would reduce both risks and expenses—and performing the 24-hour test more frequently would reduce risks still further. While performance-based regulation thus looks promising, the EDG case study points to three issues that must be addressed before it can be implemented confidently. First, researchers need more data and better analytical techniques (both PRA and deterministic). Especially important is an improved understanding of the types of failures that specific components experience, how often each type occurs, and whether failures become more likely as the interval between tests is increased.

Accomplishing those tasks will take some time; and even then conclusive information may not be available for phenomena such as human performance, management quality, and common cause failures. Therefore, objective analytical evidence must be supplemented by the subjective judgment of experts in the field. Researchers need to develop more formal methods for integrating such judgment into the regulatory process; and society must accept the premise that advice from a panel of "wise men" can be a sound basis for regulation, even though the practice—like trial by jury—cannot be defended quantitatively.

Finally, procedures for testing components must be revised. Today, the acceptability of a component is often determined not by testing but by examining its pedigree. (Was it made using high-quality manufacturing processes and machines?) This approach can be improved by following the lead of the manufacturing and electronics industries, where statistical quality-control standards are high and techniques to meet them are well developed. Of particular importance is adopting a clearly defined program of repair and subsequent testing for components that fail in service.

Professor Golay stresses that the results of this study may have implications for other regulatory bodies, including the Environmental Protection Agency, the Occupational Safety and Health Administration, and the Federal Aviation Administration. The NRC is in a good

News Items

position to implement performance-based regulation because the nuclear industry has been the subject of many more systematic analyses of sources of risk than has any other industry. The results of those analyses provide a foundation for the switch to performance-based regulation. Given the projected improvements in safety and cost, other agencies may be advised to follow the NRC example, investigating sources of risk in their fields and subsequently moving toward performance-based regulation.

Michael W. Golay is a professor of nuclear engineering. Shantel M. Utton and Jeffrey D. Dulik received their MS degrees from the Department of Nuclear Engineering in February 1998. Sarah Abdelkadar received her MS degree from MIT's Technology and Policy Program in 1998. Frank A. Felder is a PhD candidate in that program. This research was supported by the University Research Consortium of the Idaho National Engineering and Environmental Laboratory. Further information can be found in references 6–10.

The **Joint Program on the Science and Policy of Global Change** held its **fourteenth Global Change Forum** in Boston, Massachusetts, on January 27–29. The forum, entitled "**Easing the Burdens of Emissions Control**," focused on the implications of the more flexible approach to greenhouse gas abatement adopted at Kyoto. Topics included the biophysical potential of forest and agricultural carbon sinks, the economics and policy of sinks, the inclusion of other gases, compliance options for utilities and transportation, and integrating sinks and other greenhouse gases into an emissions trading framework to consider the effects on cost. Keynote addresses were given by Prof. Dr. Dr. Rudolf Dolzer, director of the Institute for International Law at the University of Bonn, and Dr. Harlan Watson, staff director of the US House of Representatives Subcommittee on Energy and Environment. Meeting participants included about 110 representatives from industry, government, and academia, worldwide. The fifteenth forum will be held in Boston on November 17–19.

John B. Heywood, the Sun Jae Professor of Mechanical Engineering, will receive an **honorary doctorate** from **Chalmers University of Technology** in Göteborg, Sweden, in a ceremony this spring. Professor Heywood is director of the Sloan Automotive Laboratory and works on issues relating to automotive engines and future transportation technology in the Energy Laboratory. His research focuses on the operation, combustion, and emissions characteristics of internal combustion engines and on their fuels requirements.

PUBLICATIONS AND REFERENCES

The following publications of Energy Laboratory and related research were released during the past period or are cited as references in this issue. **MIT theses** may be ordered from the Library Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from Energy Laboratory Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, *only* if a price is assigned and *only* if prepaid by check payable to "MIT Energy Laboratory." Prices are postpaid surface mail. For air delivery, add 15% to US, Canada, and Mexico, and 30% elsewhere. A list of publications is available on request.

Publications marked by an asterisk (*) can be found on-line via the following addresses:
Energy Laboratory:
http://web.mit.edu/energylab/www/
Center for Energy and Environmental Policy Research:
http://web.mit.edu/ceepr/www/
MIT Joint Program on the Science and Policy of Global Change:
http://web.mit.edu/globalchange/www/

Instructions for ordering paper copies of other Center and Joint Program publications are also available at those sites or by telephoning 617-253-3551 for Center publications and 617-253-7492 for Joint Program publications.

Reports and Working Papers

Connors, S. *Ensuring Future Energy Alternatives: The Role of Resource Planning in Forming Long-Range Energy and Environmental Policies.* Energy Laboratory Working Paper No. MIT-EL 96-006WP. December 1996. 17 pages. $10.00 (*International Journal of Global Energy Issues*, forthcoming.) **(Ref. 1)**

Joskow, P., and J. Tirole. *Transmission Rights and Market Power on Electric Power Networks I: Financial Rights*. Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99-003WP. January 1999.*

Joskow, P., and J. Tirole. *Transmission Rights and Market Power on Electric Power Networks II: Physical Rights*. Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99-004WP. January 1999.*

Leotard, J.-P. *Transmission Pricing and Incentives for Investments under Uncertainty in the Deregulated Power Industry*. Energy Laboratory Report No. MIT-EL 99-001. February 1999. $25.00

Pindyck, R. *Irreversibilities and the Timing of Environmental Policy.* Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99-005WP. January 1999.*

Pindyck, R. *The Long-Run Evolution of Energy Prices.* Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99-001WP. January 1999.*

Soderholm, P. *Short-Run Interfuel Substitution in West European Power Generation: A Restricted Cost Function Approach.* Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 99-002WP. January 1999.*

Other Publications

Ahmad, B., and P. Barton. "Solvent recovery targeting." *AiChE Journal*, v. 45, no. 2, pp. 335–349, February 1999.

Allen, E., and M. Ilić. *Reserve Markets for Power Systems Reliability.* IEEE Paper Number 99-WM 343. 8 pages. Available from IEEE Power Engineering Society, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

Bauer, W.-D., J. Wenisch, and J. Heywood. "Averaged and time-resolved heat transfer of steady and pulsating entry flow in intake manifold of a spark-ignition engine." *International Journal of Heat and Fluid Flow*, v. 19, pp. 1–9, 1998.

Calbo, J., W. Pan, M. Webster, R. Prinn, and G. McRae. "Parameterization of urban subgrid scale processes in global atmospheric chemistry models." *Journal of Geophysical Research*, v. 103, no. D3, pp. 3437–3451, February 20, 1998.

Carroll, J. "Organizational learning activities in high-hazard industries: the logics underlying self-analysis." *Journal of Management Studies*, v. 35, pp. 699–717, 1998.

Carroll, J. "Safety culture as an ongoing process: culture surveys as opportunities for enquiry and change." *Work and Stress*, v. 12, pp. 272–284, 1998.

Connors, S. "Competitive electric services and efficiency." In *Power Systems Restructuring: Engineering and Economics*, M. Ilić, F. Galiana, and L. Fink, eds. Boston: Kluwer Academic Publishers, pp. 285–401, 1998. **(Ref. 2)**

Connors, S., and W. Schenler. "Climate change and competition—on a collision course?" *Proceedings of the 60th American Power Conference*, Chicago, Illinois, April 14–16, 1998. Chicago: Illinois Institute of Technology, 1998. Volume 60-1, pp. 17–22. **(Ref. 3)**

Dawson, M., and S. Hochgreb. *Liquid Fuel Visualization Using Laser-Induced Fluorescence During Cold Start*. SAE Paper 982466. Presented at the Society of Automotive Engineers International Fall Fuels and Lubricants Meeting and Exposition, San Francisco, California, October 19–22, 1998. 10 pages. Available from SAE Customer Sales and Satisfaction Department, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Dulik, J., and M. Golay. *Use of Performance Monitoring to Improve Reliability of Emergency Diesel Generators.* MIT Program for Advanced Nuclear Power Studies Report No. MIT-ANP-TR-058, November 1997. Limited copies available from Ms. Paula J. Cornelio, MIT Department of Nuclear Engineering, Room 24-215, Cambridge, MA 02139-4307. **(Ref. 6)**

Dulik, J., S. Utton, and M. Golay. "Improved nuclear power plant operations through performance-based safety regulation." In *Probabilistic Safety Assessment and Management*, A. Mosleh and R. Bari, eds. London: Springer-Verlag, 1998. Volume 1, pp. 384–390. **(Ref. 7)**

Ellerman, A. "The next restructuring: environmental regulation." *The Energy Journal*, v. 20, no. 1, pp. 141–147, 1999.

Golay, M. "Improved nuclear power plant operations and safety through performance-based safety regulation." *Journal of Hazardous Materials, Special Issue on Risk Analysis*, forthcoming, 1999. **(Ref. 8)**

Golay, M., J. Dulik, F. Felder, and S. Utton. *Project on Integrated Models, Data Bases, and Practices Needed for Performance-Based Safety Regulation: Final Report.* MIT Program for Advanced Nuclear Power Studies Report No. MIT-ANP-TR-060, December 1998. Limited copies available from Ms. Paula J. Cornelio, MIT Department of Nuclear Engineering, Room 24-215, Cambridge, MA 02139-4307. **(Ref. 9)**

Harnisch, J., I. Wing, H. Jacoby, and R. Prinn. *Primary Aluminum Production: Climate Policy, Emissions and Costs*. MIT Joint Program on the Science and Policy of Global Change Report No. 44. December 1998. 18 pages.*

Ilić, M., P. Skantze, C.-N. Yu, L. Fink, and J. Cardell. "Power exchange for frequency control (PXFC)." *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 809–819, 1999.

Ilić, M., and C.-N. Yu. "A possible framework for market-based voltage/reactive power control." *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 794–802, 1999.

Jacoby, H. *The Uses and Misuses of Technology Development as a Component of Climate Policy.* MIT Joint Program on the Science and Policy of Global Change Report No. 43. November 1998. 16 pages.* **(Ref. 5)**

Jacoby, H., R. Prinn, and R. Schmalensee. “Kyoto’s unfinished business.” *Foreign Affairs*, v. 77, no. 4, pp. 54–66, 1998.

Kayes, D., and S. Hochgreb. *Investigation of the Dilution Process for Measurement of Particulate Matter from Spark-Ignition Engines*. SAE Paper 982601. Presented at the Society of Automotive Engineers International Fall Fuels and Lubricants Meeting and Exposition, San Francisco, California, October 19–22, 1998. 53 pages. Available from SAE Customer Sales and Satisfaction Department, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Kreucher, W., W. Han, A. Eisenberg, Z. Qiming, Z. Aling, Z. Rui-Lan, S. Bai-Ming, and M. Weiss. “Economic, environmental and energy life-cycle assessment of coal conversion to automotive fuels in China.” SAE Paper No. 982207. *Proceedings of the 1998 Total Life Cycle Conference,* Graz, Austria, November 1998. Book No. P-339. 532 pages. Available from SAE Customer Sales and Satisfaction Department, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Leotard, J.-P., and M. Ilić. “On the objectives of transmission pricing under open access.” *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 476–483, 1999.

Mitton, D., Y. Kim, J. Yoon, S. Take, and R. Latanision. *Corrosion of SCWO Constructional Materials in Cl^- Containing Environments*. Paper No. 257. To be presented at National Association of Corrosion Engineers (NACE) Symposium on Corrosion in Supercritical Processes, Corrosion 99, San Antonio, Texas, April 25–30, 1999. 11 pages. Available from NACE International, Conferences Division, PO Box 218340, Houston, TX 77218–8340.

NEW AND RENEWED PROJECTS, JANUARY–MARCH 1999

Topic	Donor or Sponsor	Investigators (Department)
GIFTS AND CONTRIBUTIONS		
Energy Laboratory Gift	Anne H. Foster Trust	
Center for Energy and Environmental Policy Research membership	Bewag; Enron Corporation; Kansai Electric Power Co., Inc.; Mannheimer VV; Royal Norwegian Ministries of Petroleum and Energy; Pennsylvania Power and Light Co.; Swiss Reinsurance Co.	
MIT Joint Program on the Science and Policy of Global Change membership	Asea Brown Boveri; Royal Norwegian Ministries of Petroleum and Energy	
NEW PROJECTS		
Scenarios for Carbon Sequestration	US Department of Energy (DOE)	H. Herzog *(Energy Laboratory)* E. Drake *(Energy Laboratory)*
CONTINUING PROJECTS		
Strategic MIT/INEEL Nuclear Research Collaboration	Idaho National Engineering and Environmental Laboratory University Research Consortium (INEEL URC)	M. Kazimi *(Nuclear Engineering)*
The Kinetics of Methane Hydrate Formation via First-Principles Simulations	above	B. Trout *(Chemical Engineering)*

Noymer, P., and L. Glicksman. “Near-wall hydrodynamics in a scale-model circulating fluidized bed.” *International Journal of Heat and Mass Transfer*, v. 42, no. 8, pp. 1389–1403, November 1998.

Noymer, P., L. Glicksman, and A. Devendran. “Drag on a permeable cylinder in steady flow at moderate Reynolds numbers.” *Chemical Engineering Science*, v. 53, no. 16, pp. 2859–2896, 1998.

Reilly, J., R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, P. Stone, A. Sokolov, and C. Wang. *Multi-Gas Assessment of the Kyoto Protocol*. MIT Joint Program on the Science and Policy of Global Change Report No. 45. January 1999. 14 pages.*

Schenler, W., and A. Gheorghe. *SESAMS: Strategic Electric Sector Assessment Methodology Under Sustainability Conditions: A Swiss Case Study*. ETH-Zürich. April 1998. 190 pages. $20.00 **(Ref. 4)**

Schmalensee, R., T. Stoker, and R. Judson. “World carbon dioxide emissions: 1950–2050.” *Review of Economics and Statistics*, v. 80, pp. 15–27, 1998.

Skantze, P., and J. Chapman. “Price dynamics in the deregulated California energy market.” *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 287–293, 1999.

Skolnikoff, E. *From Science to Policy: The Science-Related Politics of Climate Change Policy in the US.* MIT Joint Program on the Science and Policy of Global Change Report No. 46. January 1999. 15 pages.*

Sokolov, A., C. Wang, G. Holian, P. Stone, and R. Prinn. “Uncertainty in the oceanic heat and carbon uptake and its impact on climate projections.” *Global Biogeochemical Cycles*, v. 25, no. 19, pp. 3603–3606, 1998.

NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators (Department)
A Collaborative Program of Research in Engineering	US DOE	E. Drake *(Energy Laboratory)*
Predicting Fracture in Welded Structures from Fundamental Tests and Mechanical Modeling	above	D. Parks *(Mechanical Engineering)*
Consortium on Energy Choices for a Greenhouse Gas-Constrained World	Chevron Corp.; Exxon Corp.; Kawasaki Heavy Industries Ltd.; Mobil Oil Corp.	J. Tester *(Energy Laboratory and Chemical Engineering)*
Sloan Lab Consortium	Ford Motor Co.	J. Heywood *(Mechanical Engineering)*
New Concepts and Software for Competitive Power Systems: Operations and Management	Electricité de France	M. Ilíc *(Electrical Engineering and Computer Science)*
Development and Application of Biophysical Mechanism Theory: Ruling Out Electric and Magnetic Field Exposure for Biological Effect Due to Electric Power Use	Southern California Edison Co.	J. Weaver *(Harvard-MIT Division of Health Sciences and Technology)*
Analysis of Post-Kyoto Greenhouse Gas Emissions Trading	Electric Power Research Institute	A. Ellerman H. Jacoby *(Sloan School)*
Toxic Substance for Coal Combustion	Physical Sciences, Inc.	J. Yanch *(Nuclear Engineering)*

Sokolov, A., and P. Stone. "A flexible climate model for use in integrated assessments." *Climate Dynamics*, v. 14, pp. 291–303, 1998.

Soo, P., B. Huang, Y.-I. Jang, Y.-M. Chiang, D. Sadoway, and A. Mayes. "Rubbery block copolymer electrolytes for solid-state rechargeable lithium batteries." *Journal of The Electrochemical Society*, v. 146, no. 1, pp. 32–37, 1999.

Thirouard, B., T. Tian, and D. Hart. *Investigation of Oil Transport Mechanisms in the Piston Ring Pack of a Single Cylinder Diesel Engine, Using Two-Dimensional Laser Induced Fluorescence.* SAE Paper 982658. Presented at the Society of Automotive Engineers International Fall Fuels and Lubricants Meeting and Exposition, San Francisco, California, October 19–22, 1998. 9 pages. Available from SAE Customer Sales and Satisfaction Department, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Utton, S., and M. Golay. *Risk-Informed, Performance-Based Regulatory Implications of Improved Emergency Diesel Generator Reliability.* MIT Program for Advanced Nuclear Power Studies Report No. MIT-ANP-TR-058, January 1998. Limited copies available from Ms. Paula J. Cornelio, MIT Department of Nuclear Engineering, Room 24-215, Cambridge, MA 02139-4307. **(Ref. 10)**

Visudhiphan, P., and M. Ilić. "Dynamic games-based modeling of electricity markets." *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 274–281, 1999.

Xiao, X., D. Kicklighter, J. Melillo, A. McGuire, P. Stone, and A. Sokolov. "Linking a global terrestrial biogeochemical model with a 2-dimensional climate model: implications for the global carbon budget." *Tellus*, v. 49B, pp. 18–37, 1997.

Ying, J., C. Mehnert, and M. Wong. "Synthesis and applications of supramolecular-templated mesoporous materials." Invited review article in *Angewandte Chemie, International Edition in English*, v. 38, no. 1, pp. 56–57, 1999.

Yu, C.-N., and M. Ilić. "Congestion clusters-based markets for transmission management." *Proceedings*, IEEE Power Engineering Society Meeting, New York, January 31–February 4, 1999, pp. 821–832, 1999.

Yu, C.-N., Y. Yoon, M. Ilić, and A. Catelli. *On-Line Voltage Regulation: The Case of New England.* IEEE Publication Number PE-082-PWRS-0-02-1999. 8 pages. Available from IEEE Power Engineering Society, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

Yuan, X., Q. Chen, and L. Glicksman. "A critical review on displacement ventilation." *ASHRAE Transactions*, v. 104, no. 1, 1998.

Zhang, Z., C.-C. Wang, R. Zakaria, and J. Ying. "Role of particle size in nanocrystalline TiO_2-based photocatalysts." *Journal of Physical Chemistry B*, v. 102, no. 52, pp. 10871–10878, 1998.

Massachusetts Institute of Technology
Energy Laboratory
Room E40-479
Cambridge, Massachusetts 02139-4307

e-lab

Nancy W. Stauffer, editor
Karen K. Luxton, associate editor
ISSN 0739-4233

ADDRESS CORRECTION REQUESTED