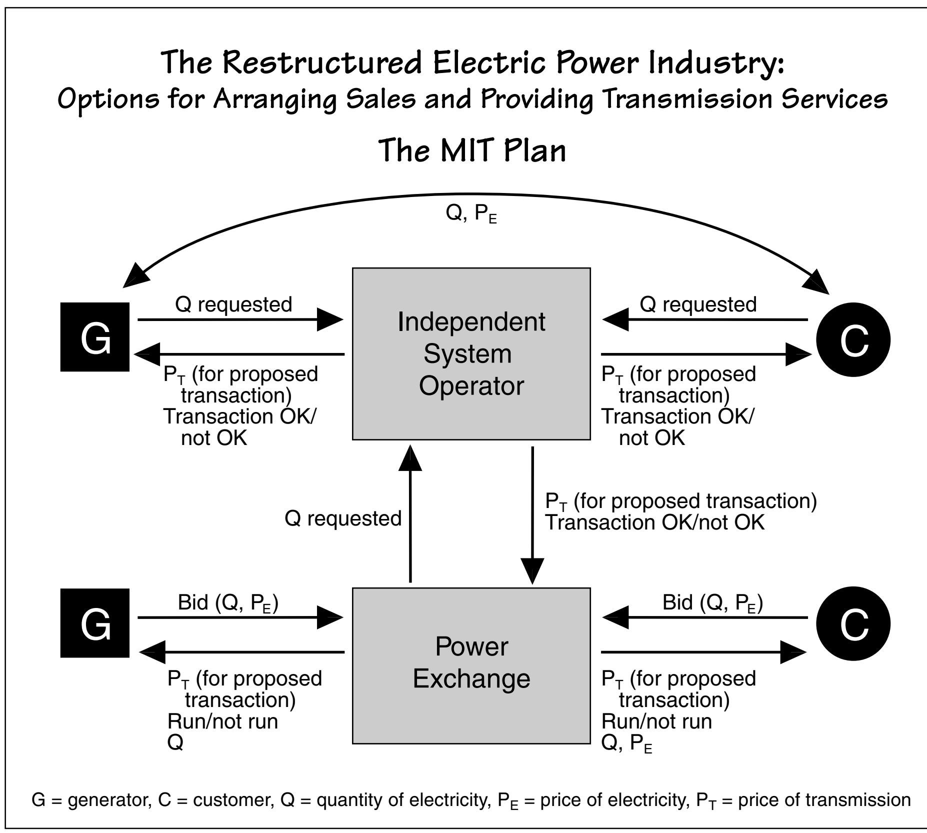
e-lab

Energy Laboratory research and related activities at the Massachusetts Institute of Technology

January–March 1998

Electric Power Transmission: Rationing a Limited Resource

In the redesigned electric power industry, electricity-generating companies compete for customers and then transmit their electricity using the existing transmission system. But at times the transmission system connecting generators and customers may not be capable of handling all sales. Who gets to transmit their electricity and who doesn't during those times is an important technical and legal question. A plan proposed by researchers at MIT and McGill University lets market forces decide. Under their plan, electricity generators and their customers make deals with one another and then submit their transmission needs to a central coordinator that oversees operation of the transmission system. The coordinator responds with a transmission price for each proposed transaction. If a given transaction will move the transmission system toward technical problems, the price is higher. The more serious and more imminent the problem, the higher the price. The market should thus self-adjust: higher prices will cause customers to get off the transmission system, so impending problems should rarely be realized. Money collected by the central coordinator can be used to maintain and upgrade the transmission system. The researchers have already developed software that can produce appropriate transmission price signals, and they are investigating other services provided by the electric power industry that could become competitive and thus more efficient.



This diagram shows the MIT plan for arranging sales between electricity generators and customers and for providing and pricing transmission. (See the text on page 3 for a full description. Note that local distribution services will continue to be provided by regulated companies at regulated prices.) One advantage of this plan is that generators and customers learn ahead the price of transmission for their proposed transaction. Congestion on the transmission system causes the transmission price to go up. When transmission is expensive, some generators and customers will cancel or postpone their transactions, reducing the stress on the transmission system.

IN THIS ISSUE

The look of the electric power industry in the United States is changing rapidly. Traditionally, utilities have owned and operated their own power plants, high-voltage transmission lines, and distribution systems to deliver electricity to customers. In return for providing the public with (generally) uninterrupted service, utilities were entitled to recover their costs plus a profit deemed fair by regulators. Now those large, closely regulated utilities are being replaced by many smaller power-generating companies that can compete for customers—a move expected to increase efficiency and decrease generation costs. Customers will still pay regulated prices for moving electricity over high-voltage regional transmission lines to their local area and over local distribution systems to their homes or businesses. But the price of buying the electricity itself will be deregulated.

However, there is a catch. Under the new system, generators might not be located near their customers. As more electricity must be shipped longer distances, loads on the regional transmission systems are increasing, and sometimes those systems cannot cope. For example, some power lines may already be at capacity; lines may be unavailable due to maintenance activities; a storm or other natural event may bring a line or series of lines down; or proposed transfers of electricity may upset frequency or voltage. Despite such "constraints," the law says that all generators and customers must be given "equal access" to the regional transmission facilities needed to deliver electricity.

Dealing with this problem falls to the "central coordinator"—the entity that makes moment-to-moment adjustments to balance supply and demand, thereby ensuring the delivery of electricity at constant frequency and voltage. When the demand for transmission exceeds the capacity of the transmission system, the central coordinator must decide what action to take. Temporarily cutting off selected generators is one simple and obvious solution. But that approach does not provide equal access and is inherently unfair: any electricity entering the network merges with flows already on the network, so all participants contribute to any problem to some extent. An additional challenge for the coordinator is determining how much to charge for transmission services. A flat fee is inappropriate because the cost of transmitting a kilowatt is not always the same. For example, when flow on a line is high relative to its capacity, the line can heat up, pushing up maintenance costs and increasing the amount of electricity lost as it travels through the lines. Since some electricity is always lost in transit, sending a given amount of electricity to a distant customer is more expensive than sending it to a customer nearby.

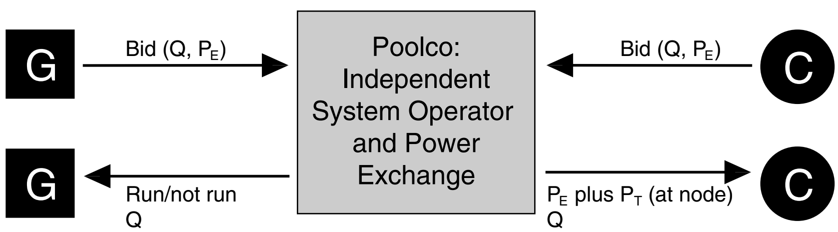
Since the early 1990s, MIT researchers led by Dr. Marija Ilić have been studying problems and opportunities associated with the changing electric power industry. Building on decades of related research at MIT, Dr. Ilić's team has designed software and hardware for controlling operation of the network and has developed methods of establishing prices that would include not just generating costs but also the changing costs incurred in maintaining the network (see *e-lab*, October–December 1994).

Two years ago, Dr. Ilić teamed up with Francisco D. Galiana of McGill University to tackle competition-related transmission issues. To facilitate their research, Dr. Ilić, Professor Galiana, and their coworkers at MIT and McGill established an industrial consortium that not only provides financial support but also holds periodic workshops involving industrial and regulatory representatives. Interaction with those experts is critical: the concepts emerging from the MIT/McGill research differ so radically from other approaches to transmission provision and pricing that feedback from potential users and regulators is a must.

The most widely known approach now being proposed for dealing with transmission is "nodal pricing." This method, based on work done in the 1980s by the late Professor Fred C. Schweppe of MIT, assumes that the electric industry operates as a "poolco"—a structure now emerging in New England and New York, where multi-utility power pools have been strong. As shown in the figure to the right, these poolcos act as the central coordinator, or "independent system operator" (ISO), and also run the "power exchange," a spot market where day-ahead purchases of electricity from generators are arranged by competitive bidding. Generators and customers submit bids to the ISO. The ISO then informs generators whether they should run (the lowest-priced generators are chosen first) and how much electricity they should produce, and it tells customers how much electricity they will receive and the price they must pay. The price for buying the electricity itself is bundled together with a charge for transmission services and billed at the end of each day or of each "transaction" between buyer and seller. The price for transmission differs from one location, or "node," on the transmission system to another. The difference in price reflects the distance of a node from generating units, the capacity of the connecting wires, the level of demand, and other factors that may limit transmission capacity and increase costs at that node at a given time.

The Restructured Electric Power Industry:
Options for Arranging Sales and Providing Transmission Services

Poolco with Nodal Pricing



G = generator, C = customer, Q = quantity of electricity, P_E = price of electricity, P_T = price of transmission

This diagram shows the most widely discussed approach for dealing with transmission. In contrast to the MIT plan shown on page 1, this plan does not inform generators and customers of their transmission price separate from the price of electricity. (See the text on page 2 for a full description. Again, local distribution is provided separately.)

Reviewing the evolving state of the power industry nationwide, Dr. Ilić and her colleagues realized that assuming that the industry is structured as a poolco is too limiting. Indeed, other industrial structures are emerging in other parts of the country. For example, in California the ISO and the power exchange are not linked, as they are in a poolco. Instead, an independent entity runs the spot market and an ISO implements the completed deals with no knowledge of the electricity prices involved. And in the Midwest, the industrial structure is still up in the air. Some companies want to form a poolco, while others want to be free to make “bilateral” agreements—agreements made directly with their customers that would subsequently be implemented by an ISO.

Dr. Ilić and her colleagues therefore reexamined the issues of transmission pricing and provision *without* assuming a specific market structure. As they developed their “MIT plan,” one of their primary goals was to reduce the control given to the ISO. Under nodal pricing, the ISO decides which generating companies will provide the needed electricity—a decision that directly affects the profits of market participants and limits the opportunity for competition. Under the MIT plan, the ISO oversees the real-time operation of the transmission system but not the dealings between the generators and their customers. As the figure on page 1 shows, the ISO and the power exchange are separate entities. Generators and customers can still submit their bids to the power exchange (the bottom box), which runs the spot market. Or they can deal directly with one another to make bilateral agreements (shown at the top of the diagram). The power exchange and the bilateral generators and customers then tell the ISO the amount of electricity (not the prices) they would like to have transmitted.

The ISO must then deal with transmission and its pricing. If the transmission system cannot handle all the requested transfers of electricity, the ISO could accept some generators and reject others, informing those rejected of how to make other arrangements that will not threaten the health of the transmission system. But that setup would give the ISO too much power, so the MIT plan takes a different approach— an approach in which the ISO rejects or cuts off transactions only in emergencies.

On receiving the requests for transmission service, the ISO informs both the power exchange and the bilateral generators and customers of the transmission price associated with their proposed transaction. The quoted price reflects proposed rather than past activity. Thus, participants asking to get on the system—and those already on it—get signals indicating the transmission price they will have to pay. That price is based not on the node involved but rather on the specific transaction’s contribution to any deterioration in overall system conditions. If, for example, a generator plans to feed a large amount of electricity into a line that is approaching its limit, the quoted transmission charge will be high. Knowing that charge, the seller and buyer can choose whether or not to implement the transaction—or they can go back later for a revised quote that will reflect the new conditions on the constantly changing transmission system. The closer the system is to becoming constrained and the more serious the impending problem, the higher the transmission charge.

This plan has many advantages over the poolco/nodal pricing approach. For one thing, it works in an industry that includes both spot market purchases and bilateral agreements. Supporting both types of deals is important: the spot market enables the ISO to make near-term adjustments in supply and demand, and bilateral agreements enable companies to hedge against swings in demand and price on the spot market. While nodal pricing bills customers for transmission after the fact, the MIT plan lets them know periodically what their transmission charges will be for the next increment of time (say, a day or a week ahead). And they have time to respond to the transmission price signals they receive. If demand gets dangerously high, the transmission price will be high and some users will choose to get off the system. As a result, the impending problem should be averted. The MIT plan thus creates a market that self-adjusts, decreasing the likelihood that constraints will occur on the transmission system. Moreover, simulations performed by the MIT team show that—assuming a competitive market—the prices and quantities in bilateral deals will gradually adjust so as to shift the transmission system toward more efficient operation. Thus, the ISO need not be responsible for efficiency. Market forces will do the job.

From a practical point of view, the MIT plan would be far easier to implement than nodal pricing would be. The price at a given node is supposed to reflect how much the activity at that node has moved the system away from its most efficient operation, that is, the scheduling of generators that would deliver the needed electricity at the lowest cost to the overall transmission system. Defining that "optimized" system is computationally extremely difficult—and for industrial structures other than poolco, conceptually hard. In contrast, the MIT plan calls for determining how close the transmission system is to a constraint and who is contributing how much to the potential problem. The MIT team has already developed software tools that can analyze current and projected flows on a transmission system and calculate appropriate price signals to deliver to potential generators and customers. To implement the software, the ISO can use real-time data from on-line information systems that are now required by the Federal Energy Regulatory Commission.

Finally, the MIT plan permits new ways of looking at the reliability of electricity supply. In the past, utilities tried to provide all customers with uninterrupted service—the highest level of reliability. To do so, they maintained excess capacity and costly backup systems that could be turned on quickly. All customers got high reliability—and paid a high price for it. Under the MIT plan, users are able to choose their level of reliability, cutting themselves off if prices become too high. Thus, the user that places a high value on reliability will pay a high price to get it, and the user that requires less-than-perfect reliability has a new opportunity to save money.

Another interesting question is what to do with the money that the ISO retains as a result of charging for transmission. Professor William Hogan and his colleagues at Harvard University suggest that the money— the "merchandise surplus"—be used to provide insurance policies for system users. Users would buy contracts guaranteeing their right to use the transmission system, regardless of its condition. If conditions on the system precluded a proposed transaction, the ISO would use the merchandise surplus to compensate the contract holder financially. In contrast, the MIT group believes that the merchandise surplus should be used to maintain and upgrade the transmission system. The transmission system now in place is barely larger than it was a decade ago, and much of it is old. Using the merchandise surplus to improve and expand it would mean that more transactions between generators and customers could be fulfilled without constraint.

The MIT and McGill researchers believe that power supply is not the only task that could become competitive in the new electric power industry. For example, utilities have traditionally maintained devices that operate automatically to keep frequency and voltage on the transmission system constant, despite the actions of generators and their customers. But they received no specific compensation for buying or operating those devices. In the restructured industry, other firms are beginning to offer those "ancillary" services. The researchers are examining possible arrangements whereby those emerging firms could also become players in the competitive electricity market. And they are looking for the most efficient means of compensating for transmission line losses. The ISOs could buy the extra electricity needed to make up for those losses and pass their costs on to customers. But more efficient approaches may be possible, perhaps involving special generation-supply firms that act competitively—yet another force to move the market toward lower costs and higher efficiency.

Marija Ilić is a senior research scientist in MIT's Department of Electrical Engineering and Computer Science. Francisco Galiana is a professor in the Department of Electrical and Computer Engineering at McGill University in Montreal, Quebec. *This research is supported through the Energy Laboratory's Electric Utility Program by the consortium "Transmission Provision and Pricing Under Open Access." Sponsors of the consortium are Allegheny Energy, Edison Electric Institute, Electricité de France, and the Electric Power Research Institute.* *Further information can be found in references 1–3.*

Assessing the Effectiveness of Competition in the Electricity Generation Industry

Key to the restructuring of the US electricity industry is allowing generators of electricity to compete for residential, commercial, and industrial customers. But in certain regions or at certain times, might the number of electricity providers be so small that competition is limited, enabling a few providers to exercise "market power," raising their prices above their costs without losing sales? One means of examining that question is to consider the geographic area over which providers can compete. A broad geographic market suggests more competitors and less opportunity for market power. To explore the extent of the geographic market for electricity-generation services, an Energy Laboratory researcher studied trading between providers in the already-operating "wholesale" electricity market, where utilities sell electricity to one another at competitive prices and transmit it using today's transmission system. Using new econometric techniques, the researcher analyzed data on daily wholesale electricity prices to determine the extent to which utilities in the five subregions of the western United States traded with one another during an 18-month period. She found that fully 80% of the time the wholesale market included potential competitors throughout the entire western area. The rest of the time the market was considerably smaller, largely due to congestion on the transmission system. While these findings cannot be directly applied to the emerging retail market, they do suggest conditions under which the number of effective competitors may dwindle and market power may be an issue.

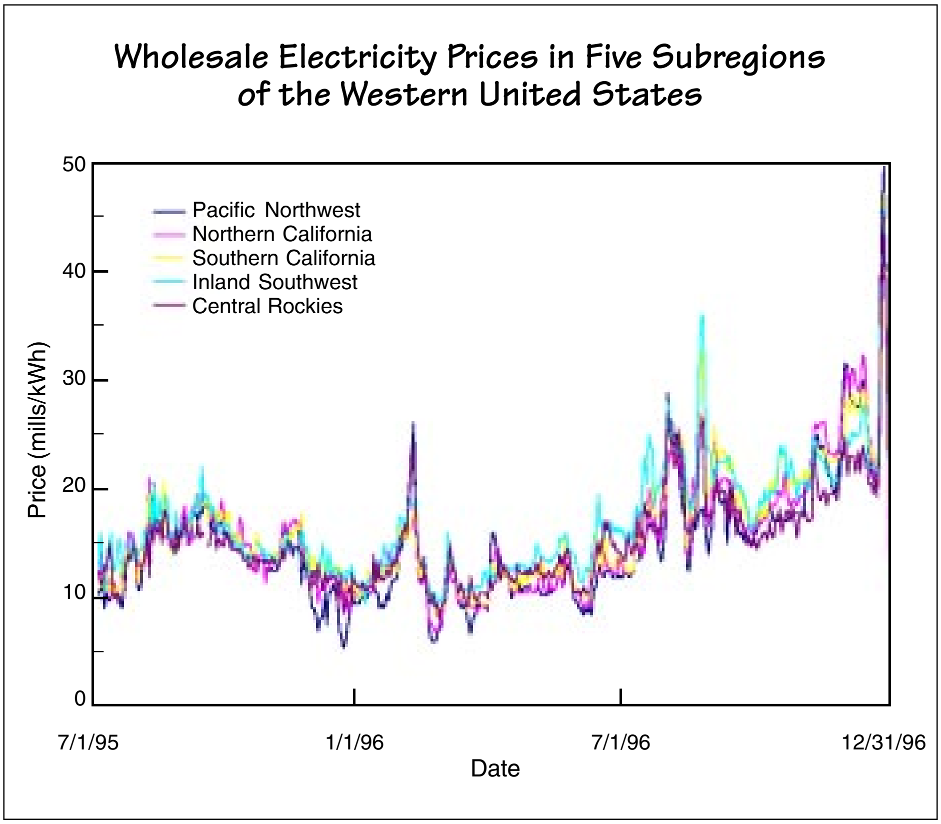
Ideally, when residential, commercial, and industrial consumers of electricity are permitted to shop around for an electricity provider, they should be able to choose among many generating companies that are vying for their business by offering low prices, environmentally conscious operation, or other attractive features. However, some observers worry that customers may not always have many providers from which to choose. When problems arise on the transmission system—when power lines are severed or damaged or simply full—some of a customer's possible providers of electricity may be physically cut off. If too many providers are cut off, those remaining may be able to exercise market power, raising prices above cost in the knowledge that other competitors are out of the picture. Thus, the competitive ideal—many providers for all customers—may not always prevail in a restructured retail electricity market.

Examining whether the emerging retail market for power generation will be geographically broad, thus including many buyers and sellers, and the conditions under which it may narrow has been the focus of a study by graduate student Elizabeth M. Bailey, under the supervision of her faculty advisor, Paul L. Joskow. Because restructured retail markets are just beginning to operate, no historical data are available for analysis. Ms. Bailey looked instead at the long-running wholesale market—the market in which utilities trade electricity with one another. In making wholesale deals, utilities negotiate prices, quantities, and other terms of trade with one another and then transmit the electricity over the transmission lines connecting them. Thus, the existing wholesale market has many features expected to characterize the new retail market. Whether the wholesale market is geographically broad may provide insight into whether the retail market will be sufficiently broad for competition to be effective.

To perform her analysis, Ms. Bailey focused on a wholesale market well suited to this study—the wholesale electric power market in the western United States. The western region has five natural subdivisions: the Pacific northwest, northern California, southern California, the inland southwest, and the central Rockies. Each subregion has distinctive generating and demand characteristics, for example, the primary fuels used and the season in which demand peaks. Many large transmission lines interconnect utilities in the west, so it is possible for the entire region to behave as a single wholesale market. In addition, the market is fairly isolated from activities in the east because only small transmission lines cross the Rocky Mountains. While buying and selling electricity is common among the five subregions, at times transmission problems or other factors can limit trading opportunities between various subregions. Under those circumstances, subregions become isolated markets including fewer utilities, thereby increasing the likelihood that market power can be exercised.

The extent to which subregions were able to trade with one another could be determined from historical data on transfers of electricity from one subregion to another. However, such data are not publicly available. Ms. Bailey therefore used econometric techniques to infer the extent to which subregions could trade from published daily prices for wholesale electricity within each of the western subregions.

To understand how price data can be used to infer the potential for trading, assume that the cost of generating a kilowatt-hour (kWh) of electricity is higher in one subregion than in another. (Cost and price are roughly equivalent under the conditions of this study.) The high-cost subregion will pay less by buying a kWh of electricity from the low-cost subregion than by generating it itself—if the price of transmitting the electricity is less than the difference between the generating costs in the two subregions. As the low-cost subregion starts



These curves show the prices at which utilities sold wholesale electricity to one another during peak periods between July 1995 and December 1996 in five subregions of the western United States. While the prices generally move together, at times they diverge—a sign that trading among the subregions was constrained by congestion on the transmission lines that connect them. By analyzing such wholesale price data, an Energy Laboratory researcher is gaining insight into how often and under what conditions the geographic expanse of the market for generation services may narrow when residential, commercial, and industrial customers begin to buy electricity from competing generating companies.

generating more electricity to sell, it will begin running its more expensive generating units, and its cost per kWh will go up. At some point, that cost plus the price of transmission will exceed the cost of generation in the high-cost subregion. The high-cost subregion will use its own generators to fulfill the balance of its demand. Thus, when the market settles, the costs of generating a kWh of electricity in the two subregions will differ by the price of transmission between them—as long as those subregions are able to trade.

In her analyses, Ms. Bailey used daily price data provided by Economic Insights, Inc., a firm that continuously surveys electricity market transactions in the western United States. The data cover June 1995 to December 1996 and include separate price observations for “peak” and “off-peak” periods. (Peak periods include daytime weekday hours, when demand tends to be high. Off-peak periods are nighttime hours and all hours on weekends and national holidays.) The study drew on a total of 948 daily price observations for each subregion as well as information on levels of supply and demand, the status of the transmission system, and other supply and demand conditions that might affect trading.

Ms. Bailey began her analysis by determining whether prices in pairs of subregions differed by a constant amount over time. Again, if two subregions are able to trade without constraint, their prices will differ by the price of transmission. Therefore, if price goes up in one of those subregions, price will also go up in the other. If subregions cannot trade, a change in price in one subregion will not affect price in the other.

As the figure to the left shows, wholesale electricity prices in all subregions generally move together, following the same seasonal trends. But a closer look reveals times when prices go up in some subregions and not in others. To quantify those differences over time, Ms. Bailey determined “price correlations” for each pair of subregions. Price correlations assess the extent to which variations in the value of one price are associated with variations in the value of the other.

The analysis showed high price correlations under normal, uncongested conditions. Lower price correlations occurred during periods when transmission lines were full due to high demand from one subregion and when lines were downed by storms or other incidents or “derated” to carry less than their normal capacity due to damage or maintenance. Those findings confirm that the condition of the transmission system and levels of demand can constrain trading between subregions, narrowing the geographic expanse of the market and thus reducing the number of potential competitors.

But price correlations do not provide insight into how frequently congestion occurs and trading is constrained—critical information because the more often subregions can trade without constraint, the broader the market and the less likely market power can be exercised. Ms. Bailey inferred how frequently trading was constrained or unconstrained by examining how frequently the difference between prices in pairs of subregions was equal to, greater than, and less than the prevailing price of transmission. When the price difference equals the transmission price, the two subregions are able to trade fully with one another. When the prices in the subregions differ by more than the price of transmission, both subregions could benefit economically from trading; therefore, constraints on the transmission system must be preventing the transfer of electricity from the low-priced to the high-priced subregion. And when the prices differ by less than the price of transmission, the high-priced subregion is not interested in trading because it would have to pay more to buy and transmit the needed electricity than to generate the electricity itself.

Because data on transmission prices are not available, Ms. Bailey developed an empirical technique for estimating the implicit prices for transmission services between pairs of subregions. She focused on price pairs for two subregions, southern California and the northwest. She performed separate analyses for peak and off-peak observations and used her new technique to sort the price pairs according to whether the difference between the two prices was equal to, greater than, or less than the price of transmission.

The analysis suggests that trading between southern California and the northwest was, by and large, unconstrained during the 18-month study period, even during times of peak demand. Fully 80% of the price pairs for the peak period differ by roughly the price of transmission, indicating that trading was not restricted by transmission constraints. Thus, on most days during the period studied, the wholesale electricity market extended across both subregions, and utilities could transact with other utilities dispersed over the entire geographic area. In about 19% of the price pairs, the difference between the prices is greater than the price of transmitting the electricity, indicating that trading was constrained. The geographic size of the market narrowed, and the effective number of competing firms fell. In just 1% of the price pairs, the difference between prices in the two subregions was less than the price of transmission, showing that trading was not economically advantageous.

Ms. Bailey cautions against transferring those findings directly to the competitive retail market that is now developing. After all, the structure of the wholesale market does differ from that of the restructured retail electricity market envisioned. In particular, the current wholesale electricity market is overlaid on a closely regulated retail market. Ms. Bailey also warns that the geographic size of a market may imply nothing about the extent to which competition prevails. Even a geographically small market may contain enough generating companies for competition to thrive.

Nevertheless, the study does suggest that markets for buying and selling electricity can be geographically broad. Moreover, the study identifies particular conditions under which the market for generation services may narrow—conditions that may warrant public policy actions to prevent generating companies from raising their prices substantially above their costs. Perhaps most important, as price data become available from the new retail market, investigators can use the analytical techniques developed in this research to assess whether a broad geographic market for retail electricity has emerged.

Elizabeth M. Bailey is a PhD candidate in the Department of Economics. Paul L. Joskow is the Elizabeth and James Killian Professor of Economics and Management and head of the Department of Economics. *This research was sponsored by the National Science Foundation and MIT's Center for Energy and Environmental Policy Research. Further information can be found in reference 4.*

News Items

MIT has established the **Center for Environmental Initiatives** (CEI) to facilitate and coordinate Institute-wide activities on emerging environmental and sustainability issues that affect world-wide development and welfare. Nearly 10% of all MIT on-campus research focuses on environmental topics, and the CEI seeks to develop synergy among those existing programs and to identify fertile areas for new ones. In addition, the CEI supports activities to disseminate the knowledge being built—both within and outside MIT—and to translate that knowledge into progressive MIT educational programs. Director of the CEI is David H. Marks, the James Mason Crafts Professor of Civil and Environmental Engineering. The Energy Laboratory collaborates closely with the CEI, sharing administrative resources as well as participating in several activities and programs that fall under CEI auspices.

Supported partially by CEI funds, the Energy Laboratory organized and hosted a 70-person workshop in November 1997 to launch the new collaborative research initiative, **Program on Energy Choices in a Greenhouse Gas Constrained World** (see the news item in *e-lab*, October–December 1997). In February, representatives of selected petroleum companies participated in a follow-up workshop that focused on research topics that those companies might support. Jefferson W. Tester, director of the Energy Laboratory and professor of chemical engineering, is director of the Program on Energy Choices. Elisabeth M. Drake, associate director of the Energy Laboratory, is program manager. The Energy Choices Advisory Board, chaired by Professor Marks, includes the following Energy Laboratory researchers: Professor Tester; John B. Heywood, Sun Jae Professor of Mechanical Engineering; Henry D. Jacoby, William F. Pounds Professor of Management; and Malcolm A. Weiss, senior research staff member in the Energy Laboratory.

Partial funding for the Program on Energy Choices comes from the CEI's **MIT Venture Fund for Energy Choices**, which was established in fall of 1997 with a grant from the V. Kann Rasmussen Foundation. These funds are used in conjunction with funds from corporate and other sponsors to support long-range, innovative research in strategic areas for which other funding is not readily available. Two Venture Fund initiatives are led by researchers affiliated with the Energy Laboratory. Leon R. Glicksman, professor of building technology and director of MIT's Building Technology Program, is working with his MIT group and researchers at Tsinghua University to assess China's building sector, with a focus on designs and technologies that will improve energy-use efficiency. Mujid S. Kazimi, professor of nuclear engineering, and his MIT colleagues are collaborating with researchers at several Chinese universities to help China develop safety and performance standards for its new but potentially expanding nuclear industry.

The Energy Laboratory is also closely involved in the **Alliance for Global Sustainability** (AGS), another program that falls under the auspices of the CEI. The AGS is a partnership of three universities—MIT, the Swiss Federal Institutes of Technology, and the University of Tokyo—that was created in 1994 as a strategic approach to the problems of global sustainability. Researchers from the three universities work together to develop and promote new policies and processes to deal with international sustainability issues. The annual meeting of the AGS was held in Zurich, Switzerland, on January 21–24. Among the 350 attendees were Professor Tester, Dr. Drake, and Stephen Connors, Energy Laboratory staff member and director of the Laboratory's Electric Utility Program. The meeting was designed to establish a working relationship between the university researchers and governments and residents of developing countries. Discussion focused especially on issues relating to rapidly developing "megacities" including Jakarta, Shanghai, Mexico City, New Delhi, Lagos, and Beijing. The AGS International Advisory Board also heard progress reports on the first set of AGS research projects, launched in 1997, and approved funding for an additional 16 projects, bringing the total number of AGS projects to 37.

With support from the AGS, the MIT Venture Fund for Energy Choices, and select industrial organizations, the Energy Laboratory has initiated numerous **research projects** within the **Program on Energy Choices**. One such project falls in the area of improved buildings, neighborhoods, and urban environments. With funding through the AGS from Kawasaki Heavy Industries, Professor Glicksman and his sustainable-buildings group are collaborating with Japanese researchers in the University of Tokyo's "Tokyo Half Project," which aims to identify urban environments that will reduce greenhouse gas emissions by 50% from today's levels. This work builds on the group's previously described research focusing on China's building sector. Two other AGS-funded projects, led by Mr. Connors, bridge energy needs for buildings and energy supply. "Decision Framework for Energy Choices" seeks to extend the multi-attribute approach developed by Mr. Connors and the Analysis Group for Regional Electricity Alternatives (AGREA) to other energy sectors and sustainability issues, with a focus on developing nations such as China. The SESAMS project (Strategic Electric Sector Assessment Methodology under Sustainability Conditions), which involves collaborators at MIT, the Swiss Federal Institutes of Technology in Zurich and Lausanne, and the Paul Scherrer Institut, has received an additional two years of support. The researchers will add life-cycle analysis to their already robust strategic planning and decision support research capabilities.

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. An order form for the **MIT Joint Program on the Science and Policy of Global Change** is available by request to the MIT Joint Program on the Science and Policy of Global Change, Publications, Room E40-271, Cambridge, MA 02139-4307, tel.: (617) 253-7492; fax: (617) 253-9845; e-mail: tzh@mit.edu. **MIT theses** may be ordered from 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.

Reports and Working Papers

Bailey, E. *The Geographic Expanse of the Market for Wholesale Electricity*. February 1998. MIT Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 98-003WP. 59 pages. $12.00 **(Ref. 4)**

Dixit, A., and R. Pindyck. *Expandability, Reversibility, and Optimal Capacity Choice.* December 1997. MIT Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 97-006WP. 30 pages. $10.00

Judson, R., R. Schmalensee, and T. Stoker. *Economic Development and the Structure of the Demand for Commercial Energy.* January 1998. MIT Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 98-002WP. 48 pages. $10.00

Montero, J. *Voluntary Compliance with Market-Based Environment Policy: Evidence from the US Acid Rain Program.* January 1998. MIT Center for Energy and Environmental Policy Research Working Paper No. MIT-CEEPR 98-001WP. 45 pages. $10.00

Other Publications

Adelman, M. "My education in mineral (especially oil) economics." *Annual Review of Energy and the Environment,* v. 22, pp. 13–46, 1997.

Allen, E., and M. Ilić. "Stochastic unit commitment in a deregulated utility industry." *Proceedings of the North American Power Symposium*. Laramie, Wyoming: University of Wyoming, October 1997.

Auerbach, D., J. Caulfield, E. Adams, and H. Herzog. "Impacts of ocean CO_2 disposal on marine life: 1. A toxicological assessment integrating constant-concentration laboratory assay data with variable-concentration field exposure." *Environmental Modeling and Assessment*, v. 2, pp. 333–343, 1997.

Auerbach, D., J. Caulfield, E. Adams, and H. Herzog. "Impacts of ocean CO_2 disposal on marine life: 2. Probabilistic plume exposure model used with a time-varying dose response model." *Environmental Modeling and Assessment*, v. 2, pp. 345–353, 1997.

Banales, S., and M. Ilić. "On the role and value of voltage support in a deregulated power industry." *Proceedings of the North American Power Symposium*. Laramie, Wyoming: University of Wyoming, October 1997.

Barton, P., R. Allgor, W. Feehery, and S. Galan. "Dynamic optimization in a discontinuous world." *Industrial Engineering Chemical Research*, v. 37, no. 3, pp. 966–981, 1998.

Brodeur, D., V. Angus, and N. Todreas. *Improving Nuclear Utility Generation Capacity, Understanding the Sources of Forced Outage and Learning How to Prevent Them*. Presented at International Atomic Energy Association Technical Committee Meeting, Argonne, Illinois, September 8, 1997. 12 pages. $10.00

Cardell, J. *Integrating Small Scale Distributed Generation into a Deregulated Market: Control Strategies and Price Feedback*. PhD thesis. MIT Department of Electrical Engineering and Computer Science, Cambridge, Massachusetts, August 1997.

Cardell, J., and S. Connors. *Windpower in New England: Modeling and Analysis of Non-Dispatchable Renewable Energy Technologies*. Presented at IEEE Winter Power Meeting, Tampa, Florida, 1997. Paper No. PE-888-PWRS-2-06-1997. Forthcoming in *IEEE Transactions on Power Systems*. 6 pages. $10.00

Connors, S. "Reducing electric sector CO_2 emissions under competition: facilitating technology development and turnover on both sides of the meter." In *Proceedings of The International Conference on Climate Change,* Baltimore, Maryland, June 12–13, 1997. 10 pages. $10.00

Feehery, W. *Dynamic Optimization with Path Constraints*. PhD thesis. MIT Department of Chemical Engineering, Cambridge, Massachusetts, March 1998.

Fink, L., M. Ilić, and F. Galiana. "Transmission access rights and tariffs." *Electric Power Systems Research*, v. 43, pp. 197–206, June 1997.

Galiana, F., and M. Ilić. "A mathematical framework for the analysis and management of power transactions under open access." Presented at IEEE Winter Power Meeting, Tampa, Florida, 1997. Paper No. PE-586-PWRS-2-06-1997. Forthcoming in *IEEE Transactions on Power Systems*. 7 pages. $10.00

Galiana, F., and M. Ilić. *Pool Generation Dispatch with Independent Transmission Projects*. To be presented at 21st Annual International Conference of the International Association of Energy Economists, Chateau Frontenac, Quebec, Canada, May 12–17, 1998. 10 pages. $10.00

Herzog, H., and E. Drake. *Capture, Reuse, and Sequestration Technologies for Mitigating Global Climate Change*. Presented at the 23rd International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, Florida, March 9–13, 1998. 12 pages. $10.00

Hyman, L., and M. Ilić. "Will consumers benefit from new power era?" *Forum on Applied Research and Policy*, v. 12, no. 2, pp. 59–68, Summer 1997.

Ilić, M., F. Galiana, L. Fink, A. Bose, P. Mallet, and H. Othman. "Transmission capacity in power networks." *Electrical Power and Energy Systems*, v. 20, no. 2, pp. 99–110, 1998.

Ilić, M., F. Graves, L. Fink, and A. DiCaprio. "A framework for operations in the competitive open access environment." *The Electricity Journal*, April 1996, pp. 61–69. **(Ref. 1)**

Ilić, M., and L. Hyman. "Electric transmission: scarce resource, real business or threat to profitability?" *Public Utilities Fortnightly,* October 1, 1997. **(Ref. 2)**

Ilić, M., L. Hyman, E. Allen, and Z. Younes. "Transmission scarcity: who pays?" *The Electricity Journal*, July 1997, pp. 38–49. **(Ref. 3)**

Ilić, M., P. Skantze, and C. Yu. "Market-based frequency regulation: can it be done, why and how?" *Proceedings of the American Power Conference*, Chicago, Illinois, April 1997. Chicago, Illinois: Illinois Institute of Technology, 1997.

NEW AND RENEWED PROJECTS, JANUARY–MARCH 1998

Topic	**Donor or Sponsor**	**Investigators (*Department*)**
GIFTS AND CONTRIBUTIONS		
CEEPR membership	Berliner Kraft-und Licht Aktiengesellschaft (BEWAG); Enron Capital & Trade Resources Corp.; Pennsylvania Power & Light Co.; Repsol, SA; Swiss Reinsurance Co.; Vattenfall AB	
Research on Supercritical Fuel-Water Mixtures	Quantum Energy Technology	J. Tester *(Energy Laboratory and Chemical Engineering)*
NEW PROJECTS		
Incentives for Transmission Under Open Access	Southern California Gas Co.	M. Ilić *(Electrical Engineering and Computer Science)*
Consortium on Energy Choices in a Greenhouse Gas Constrained World	Kawasaki Heavy Industries Ltd.; Mobil Oil Gas Corp.	J. Tester *(Energy Laboratory and Chemical Engineering)*
Assessment of Title and Emissions Trading	US Environmental Protection Agency	A. Ellerman *(Sloan School of Management)*
CONTINUING PROJECTS		
Sloan Lab Consortium	Mobil Technology Co.	J. Heywood *(Mechanical Engineering)*
A Collaborative Program of Research in Engineering Sciences (with the Idaho National Engineering and Environmental Laboratory [INEEL])	US Department of Energy	E. Drake *(Energy Laboratory)*
Fundamentals of Elastic-Plastic Fracture: Three Dimensional and Mechanistic Modeling	above	D. Parks *(Mechanical Engineering)*

Ilić, M., Y. Yoon, A. Zobian, and M. Paravalos. "Toward regional transmission provision and its pricing in New England." *Utilities Policy*, v. 6, no. 3, pp. 245–256, 1997.

Leiendecker, M., N. Todreas, M. Driscoll, and A. Hurtado. *Design and Numerical Simulation of a Two-Phase Thermosyphon Loop as a Passive Containment Cooling System for PWRs. Volume I and Volume II: Program Code Manual*. MIT Advanced Nuclear Program, Report No. MIT-ANP-TR-053, September 1997. Limited copies available from Ms. Paula J. Cornelio, MIT Department of Nuclear Engineering, Room 24-215, Cambridge, MA 02139-4307.

Lerner, P., and M. Ilić. "On the value of transmission systems: incentives for investment under open access." *Proceedings of the 18th Annual North American Conference of the International Association of Energy Economists*, San Francisco, California, September 7–10, 1997, pp. 330–339, 1997.

Noymer, P., and L. Glicksman. "Cluster motion and particle-convective heat transfer at the wall of a circulating fluidized bed." *International Journal of Heat and Mass Transfer,* v. 41, no. 1, pp. 147–158, 1998.

Porat, O., C. Heremans, and H. Tuller. "Phase stability and electrical conductivity in $Gd_2Ti_2O_7$ - $Gd_2Mo_2O_7$ solid solutions." *Journal of the American Ceramics Society,* v. 80, pp. 2278–2284, 1997.

Renick, D., F. Li, and N. Todreas. *Availability Analysis of United States BWR IV Electrical Generation Plants*. Presented at International Atomic Energy Association Technical Committee Meeting, Argonne, Illinois, September 8, 1997. 12 pages. $10.00

NEW AND RENEWED PROJECTS, CONTINUED

Topic	Donor or Sponsor	Investigators (*Department*)
The INEEL University Research Consortium (see *e-lab*, July–September 1995)	INEEL	J. Tester *(Energy Laboratory and Chemical Engineering)* M. Kazimi *(Nuclear Engineering)* E. Drake M. Weiss *(Energy Laboratory)*
Development of Boron Neutron Capture Synovectomy for the Treatment of Rheumatoid Arthritis (new project)	above	J. Yanch *(Nuclear Engineering)*
Improving Nuclear Power Plant Efficiency through the Analysis of Work Process	above	G. Apostolakis *(Nuclear Engineering)*
Integrated Models, Data Bases and Practices Needed for Performance-Based Safety Regulation	above	M. Golay *(Nuclear Engineering)*
Towards Viable Lithium Solid Polymer Electrolyte Batteries: An Integrated Materials Approach	above	A. Mayes *(Materials Science and Engineering)*
Plasma Processing of Functionally Gradient Materials: Diagnostics, Characteristics, and Modeling	above	S. Suresh *(Materials Science and Engineering)*
Optical Fiber Sensors for Concrete Structures	above	C. Leung *(Civil and Environmental Engineering)*

Note: CEEPR = Center for Energy and Environmental Policy Research

Sako, K., M. DiPippo, M. Reagan, and J. Tester. *The Refinement to the Anderko-Pitzer Semi-empirical PVTx$_i$ Equation-of-State for Aqueous Solution at Elevated Temperature and Pressure*. March 1998. Submitted to *Fluid Phase Equilibria*. 13 pages. $10.00

Skantze, P. *Closed-loop Market Dynamics in a Deregulated Electric Power Industry*. MS thesis. MIT Department of Electrical Engineering and Computer Science, Cambridge, Massachusetts, February 1998.

Webster, M. *Uncertainty in Future Carbon Emissions: A Preliminary Exploration.* MIT Joint Program on the Science and Policy of Global Change, Report No. 30, November 1997.

Wong, V., M. Stewart, G. Lundholm, and A. Hoglund. *Increased Power Density via Variable Compression/Displacement and Turbocharging Using the Alvar-Cycle Engine*. Presented at Society of Automotive Engineers International Congress and Exposition, Detroit, Michigan, February 23–26, 1998. SAE Paper No. 981027. Available from SAE, Inc., 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Yanch, J., S. Shortkroff, R. Shefer, S. Johnson, E. Binello, D. Gierga, A. Jones, G. Young, C. Vivieros, A. Davison, and C. Sledge. *Boron Neutron Capture Synovectomy: Treatment of Rheumatoid Arthritis Based on the $^{10}B(n,\alpha)^{7}Li$ Nuclear Reaction*. Internal manuscript. 1998. 37 pages. $10.00

Ying, J. "Nanostructure processing of advanced catalytic materials." In *World Technology Evaluation Center Workshop Report on R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices in the United States, Proceedings of the May 8–9, 1997 Workshop*. Baltimore, Maryland: International Technology Research Institute, January 1998.

Younes, Z. *Deregulation of the Electric Power Industry: The Impact of Transmission on Market Imperfections*. MS thesis. MIT Department of Electrical Engineering and Computer Science, Cambridge, Massachusetts, February 1998.

Younes, Z., and M. Ilić. *Generation Strategies for Gaming Transmission Constraints: Will the Deregulated Electric Power Market Be an Oligopoly?* Presented at the Hawaii International Conference on Systems Sciences, Kona, Hawaii, January 1998. 10 pages. $10.00

Younes, Z., and M. Ilić. "Transmission system constraints in non-perfect electricity markets." *Proceedings of the 18th Annual North American Conference of the International Association of Energy Economists*, San Francisco, California, September 7–10, 1997, pp. 256–265, 1997.

Zhang, L., G. Papaefthymiou, R. Ziolo, and J. Ying. "Magnetic and optical properties of novel γ-Fe_2O_3/SiO_2 nanocomposites via sol-gel matrix-mediated synthesis." In *Proceedings, Second Joint China/USA Chemical Engineering Conference, May 19–22, 1997, Beijing, China*, v. III, pp. 1328–1331, May 1997.

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

Nonprofit Organization
US Postage
PAID
Permit Number 54016
Cambridge, Massachusetts

Recycled Paper