Efficiency and Demand Response

Twins, Siblings, or Cousins?

Analyzing the conservation effects of demand response programs.

By Chris King and Dan Delurey

Does demand response increase or decrease overall electricity usage?

During the 1980s and 1990s, as conservation evolved into the concept of efficiency, load management evolved into a new concept and discipline—demand response. In recent years, demand response programs and activities have grown rapidly in the United States, driven by the desire or need to address peak capacity shortages and reliability issues, or to use demand response as a price-modulating tool in competitive markets.

Energy conservation has not been a design objective of this demand response activity, and some might say that the tradition of efficiency and demand response as the "twin pillars" of demand-side management has been lost. Our study seeks to determine whether or not this is the case.

Given that demand response programs have not been designed to focus on energy consumption, it is not surprising that the evaluations of these activities, where they have been performed, have not focused on determining consumption impacts. Much of the measurement is based on criteria such as load reduced as a percentage of enrolled load, or as a percentage of baseline usage, or the percentage of load reduced versus that which was promised to be reduced.

An extensive review of demand response programs and their conservation effect, which we define as the change in total monthly or annual energy consumption attributable to the program, shows that although the primary intended effect of demand response programs is to reduce electricity use during times of peak load, the vast majority of demand response programs also yields a small conservation effect.[1]

We used a broad definition of demand response, organizing our findings into three main program types: dynamic-pricing programs, reliability programs, and information/feedback programs. Dynamic-pricing programs produce an average conservation effect of 4 percent. Reliability programs, which operate less than 100 hours per year and typically include automated controls (*e.g.*, air conditioner cyclers or energy management systems), reduce total consumption by 0.2 percent. Feedback programs, such as Internet-based or in-home usage displays, have been found to reduce total consumption by an average of 11 percent.

The conservation effect varies significantly among more than 100 programs with available data, from a -5 percent (*i.e.*, increased consumption) effect in one program to more than 20 percent in others. With respect to a single variable, such as the difference between peak and off-peak prices, there is no clear correlation between the variable and the level of conservation effect. In contrast, however, our analysis of the data revealed a very strong correlation among three factors: dynamic pricing, automated controls, and feedback programs or devices. Any combination of these factors produces a greater conservation effect than a single factor alone, with the combination of all three factors producing the greatest effect. While a precise estimate of this synergistic effect is not possible from the literature, the data suggests the effects are often largely additive.[2]

TABLE 1 CONSERVATION EFFECTS OF DYNAMIC PRICING PROGRAMS

Program	Year	Program Type	Conservation Effect
Puget Sound Energy	2003	Residential TOU rates	1.1%
General Public Utilities	2001	Residential CPP program with automated thermostat	4.8%
Central and South West	1996	Residential CPP program 0.8% with automated thermostat	
Southern California Edison	1984	Residential TOU rates	5%
Gulf Power	1994	Residential CPP program with automated thermostat	6.9%
Arkansas	1980	Residential TOU rates	Range from 11 to 26%
Connecticut	1980	Residential TOU rates	13%
North Carolina BREMC	1980	Residential TOU rates	0%
Ohio	1983	Residential TOU rates	0%
Rhode Island	1981	Residential TOU rates	0%
Arizona	1983	Residential TOU rates	0%
Los Angeles DWP	1980	Residential TOU rates	7.3%
North Carolina CP&L	1980	Residential TOU rates	Range from 0 to 13%
Oklahoma	1983	Residential TOU rates	0%
Puerto Rico	1983	Residential TOU rates	0%
Wisconsin	1980	Residential TOU rates	0 to 16%
Britain	1994	Residential TOU rates	3.1%
Finland	1992	Residential TOU rates	3%
California Statewide Pricing Pilot	2004	Residential TOU rates, CPP rates with and without smart thermostats	Range from 5.7 to 8.7% weekdays
Holland - EDON	1997	Residential TOU rates	5.2%
Holland - ENW Amsterdam	1997	Residential TOU rates	Conservation of 6%
Holland - Nuon	1997	Residential TOU rates	Conservation of -5% (usage increase)
Pacific Gas & Electric	1985	Commercial TOU rates	Conservation of 0.6%
AVERAGE			**4.0%**

Conservation Effect of Dynamic Pricing

Dynamic pricing includes pricing that varies by time of day to reflect the higher cost of generating electricity during hours of peak usage. Examples include time-of-use rates, critical peak prices, and real-time pricing.

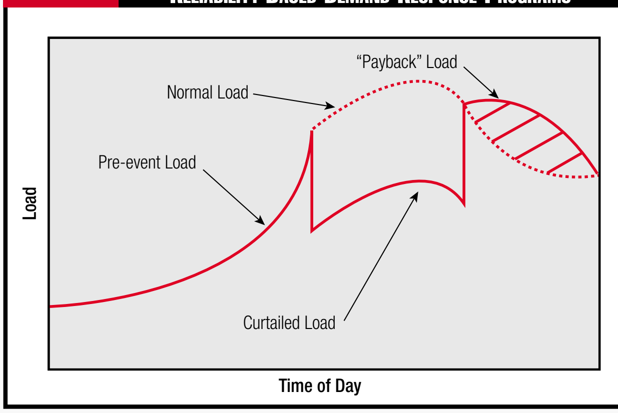
While a main purpose of dynamic pricing is to reduce peak demand, these programs typically result in a small reduction in total electricity consumption as well. There are three reasons a reduction can be expected. First, higher peak or critical peak prices induce load reductions during peak hours, not all of which is shifted to other times. Some reductions are uses that are shifted to other time periods, such as laundry for a residence or a production process for a business. In these cases, the usage is "recovered" at other times. Other reductions, such as lower lighting, are not recovered, as there is no reason for it. Second, dynamic pricing programs cause participants to have a higher awareness of how they use energy, which, in turn, results in lower consumption. Third, these programs usually increase the amount of usage information, or feedback, received by the customer, also lowering consumption. More information on feedback effects is provided below.

The authors reviewed the literature based on hundreds of studies and pilot programs of dynamic pricing in the past 30 years, throughout North America and Europe. While most of these have focused on the effect of such pricing in reducing peak demand, 24 were identified that included analyses of the effect on total consumption. While numerous programs involved commercial customers, including 43 real-time pricing programs now operating in the United States,[3] only one program reported the effect on total consumption. The other 23 results are from residential programs. These results are summarized in Table 1, and include an average reduction in total usage of four percent.

Conservation Effects of Reliability Programs

Reliability programs are designed to be available during the top 100 peak hours of the year. They are dispatched by utilities or grid operators to avoid or meet system emergencies. They typically include interruptible and curtailable programs for commercial customers and direct utility control of residential air conditioners. Demand bidding programs are another pop-

Figure 1 — Illustration of "Payback" Associated with Reliability-Based Demand Response Programs



Source: Chris King

ular form of reliability program. At least 63 such programs for commercial customers were in operation in 2004.[4]

Since these programs are in operation for less than one percent of the hours in a year, and their focus is reduction in demand, not energy, there has been little analysis of the conservation effect of these programs. There is very limited information available. However, the available information suggests a very slight conservation effect, because the amount of usage curtailed during events is less than the amount of usage. A recent analysis of California programs found that only 22 percent of participants in two commercial-customer programs had increased off-peak payback usage to offset or "pay back" their peak reductions (*see Figure 1*):

> *Only 5 percent of CPP and DBP participants surveyed who reported taking DR action for at least one event stated their organization increased their energy usage before the event occurred to make up for the reduction that was to occur, and 17 percent reported they increased their energy use after the event to make up for what was lost.*[5]

The reason is that some uses are curtailed without need or reason for later replacement: the California analysis reported that 29 percent of participants reduced lighting levels and 28 percent reduced air-conditioning levels (in businesses, air conditioning typically shuts down or is greatly reduced by the end of the peak period, as employees depart from the facility). These data suggest an overall conservation effect of approximately 0.16 percent, since the programs operate for 1 percent of the hours, the typical load reduction is 20 percent during those hours, and about 20 percent of the load reduction is offset by increased usage before or after the event.

Studies of residential direct load control of air conditioning and water heating also have found that the payback is less than 100 percent of the amount of reduction during the peak period.[6] A recent example reported for Public Service Electric & Gas of New Jersey estimated payback at approximately 40 percent of the amount reduced during the peak.[7]

Conservation Effects of Customer Feedback Programs

The process of giving feedback on consumption motivates consumers to save energy through reduced waste, yet the body of evidence testifying to this is rarely acted upon in any systematic way. As with dynamic pricing, there is ample literature on the effectiveness of two basic types of feedback to electricity users: direct feedback in the home or business via a device or the Internet or indirect feedback via billing and periodic usage reports. Clear, immediate, and user-specific information is most effective in lowering energy usage. The literature shows that feedback has a significant role to play in raising energy awareness and in bringing about reduced consumption on the order of 10 percent.

Feedback Methods

Direct feedback methods include the following:

- In-home/in-building display devices that can show current rate of consumption, current cost of consumption per hour, etc.;
- Internet usage displays that show detailed energy usage information typically on a next-day basis;
- Smart meters operated by smart cards and two-way communications systems that, in conjunction with another device, can show consumption and cost information;
- Prepayment meters that provide direct feedback to use in electricity bill management; and
- Device monitors that are inserted between the plug and wall socket on appliances and show information such as current rate of consumption and current cost of consumption per hour.

Indirect feedback consists of data processed by the utility, then sent to customers. Such feedback includes the following:

- Actual bills based on metered usage rather than estimates, and possibly measured in intervals;
- More frequent bills, *e.g.,* monthly rather than quarterly basis;
- Comparison data on a year-to-year basis or normalized for weather; and
- Usage disaggregation, where use is estimated at the appliance level based on analysis of meter reads in association with customer-provided data such as appliance and housing stock.

Conservation Effect Direct and Indirect Feedback Programs

Sarah Darby of Oxford University conducted a review of 38 feedback studies in 2001, going back to 1975. Of these, 21 studies were from 1987 to 2000. The results show a clear conservation effect of feedback.

Darby discusses these results:

While it is not possible here to go into the detail of each study, it appears that direct feedback, alone or in combination with other factors, is the most promising single type, with almost all of the projects involving direct feedback producing savings of 5 percent or more. The highest savings—in the region of 20 percent—was achieved by using a table-top interactive cost and power display unit; a smartcard meter for prepayment of electricity (coinciding with a change from group to individual metering); and an indicator showing the cumulative cost of operating an electric cooker. In the absence of a special display or a PC display, the feedback was supplied by the reading of standard household meters, sometimes accompanied by the keeping of a chart or diary of energy use. The implication that this meter-reading was a factor in reducing consumption demonstrates how seldom people normally consult their meters (probably hidden away) and/or convert their readings into useful information.

Direct feedback in conjunction with some form of advice or information gave savings in the region of 10 percent in four programs aimed at low-income households (with constant or improved levels of comfort), indicating the potential for feedback to be incorporated into advice programs on a regular basis.

Providing direct financial incentives for consumers to save energy (a method tested during the late 1970s) made little lasting impact: consumption reverted to what it had been once the incentive was removed. Cost signals need to be long-term to have a durable effect.

The implication is that all those studies which demonstrated some effectiveness had enough of a common element (or elements) to succeed; or that they compensated for lack of one element with another. It could be, as a minimal explanation, that any intervention helps if it triggers householders into examining their consumption. It could also be that the personal attention of the experimenters motivated the householders into action. However, the documentation of these feedback projects points strongly to other factors at work, of which immediacy or accessibility of feedback data—allowing the householder to be in control—are highly important, accompanied by clear information that is specific to the household in question. Provision of such data is coming well within reach in terms of the technical possibilities for metering, appliance and heating system design.

TABLE 2 Conservation Effects Shown in Feedback Studies[8]

Savings	Direct Feedback Studies (n=21)	Indirect Feedback Studies (n=13)	Studies 1987-2000 (n=21)	Studies 1975-2000 (n=38)
20%	3		3	3
20% of peak weekdays only			1	1
15-19% Mondays through Saturdays	1	1	1	3
10-14%	7	6	5	13
5-9%	8		6	9
0-4%	2	3	4	6
Unknown		3	1	3

Conservation Effects of Frequent Feedback

Monthly feedback on electric usage is generally insufficient to enable customers to manage usage effectively. In 14 utility and government programs carried out in the United States, residential customers provided with daily feedback on electricity usage reduced total consumption by an average of 11 percent.[9]

TABLE 3 Summary of Literature Results on Frequent Feedback on Electricity Use

3 times/week	13%
Daily on weekdays only	4% to 15%
Daily, Mondays through Saturdays	0%
Daily	15% to 21%
Daily	0%
Daily	0%
Daily	12%
Daily	9% to 16%
4 times/week	11%
Daily	10% to 15%
Daily	7% to 20%
Daily	7% to 11%
Daily	17%
Daily	19%
AVERAGE	**11%**

Internet Data Display

Many utilities now offer customers energy usage information via the Internet. The data vary from simple monthly data to estimated usage by appliance for residential customers to detailed quarter-hourly usage data provided on a next-day basis. Customers are slowly but steadily taking advantage of their ability to access such data, typically beginning with a few percent of customers in the first year and growing by a few percent per year. In some cases, such as Ameren-UE, more than 20 percent of customers are actively using the utility Web site to obtain data and carry out customer service inquiries. Initial results from analysis of the effects of these programs on total consumption indicate that access to, and use of, the data cause electricity consumers to become more efficient and use

FIGURE 2 **CUSTOMER HOURLY LOAD DISPLAY ON INTERNET**

Source: eMeter Corp

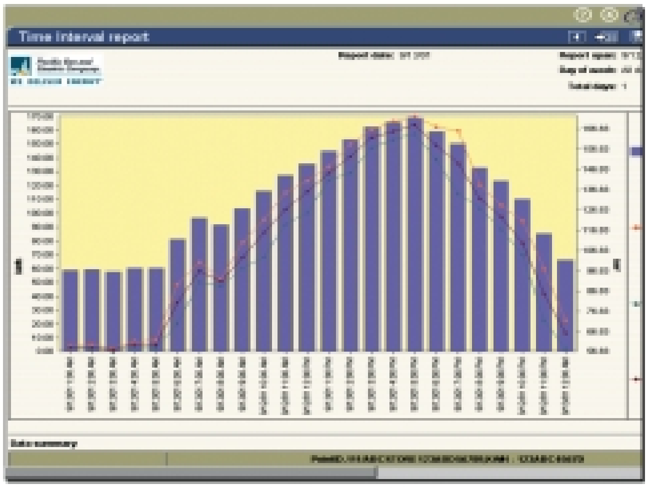


FIGURE 3 **CUSTOMER LOAD COMPARED TO "TYPICAL" BUSINESS OF SAME TYPE**

Source: eMeter Corp

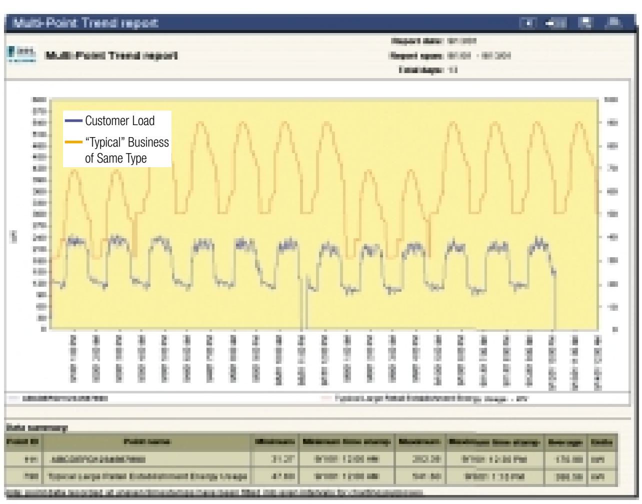
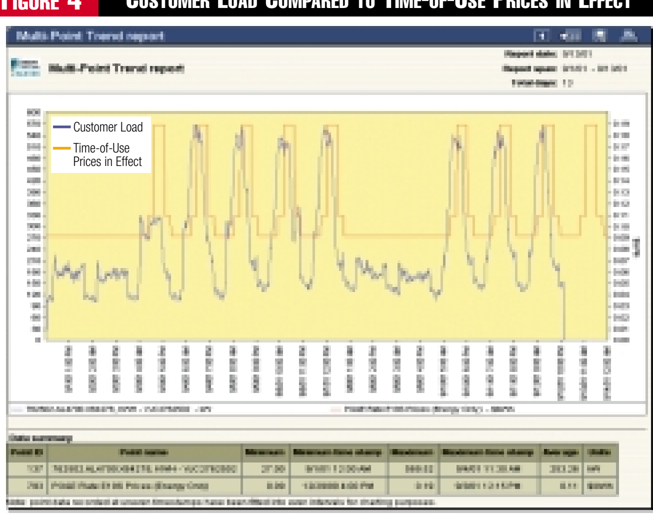


FIGURE 4 **CUSTOMER LOAD COMPARED TO TIME-OF-USE PRICES IN EFFECT**

Source: eMeter Corp



less energy. Many utilities have gone beyond just providing monthly consumption, both current and historical, and provide online energy analyses or even more detailed consumption information. For example, over 120 U.S. utilities offer their residential customers an online bill disaggregation tool that evaluates energy use to show how much each appliance or end use is consuming, and also makes recommendations on where to cut energy use, and by how much.

For commercial customers, the largest and most comprehensive program in place today is in California. During California's 2001 energy crisis, the state legislature approved funding to provide smart meters to all customers with peak demands above 200 kW. Assembly Bill 29X provided $35 million from the state General Fund to the California Energy Commission to install either time-of-use or real-time electric meters for utility end-use customer accounts with peak electric demand levels of 200 kW or more. The energy commission determined that installing real-time, or "interval meters," was the best use of public funds. Real-time meters contain electronic components enabling the utility to read them remotely and then communicate the collected energy-use data to a utility's billing system.

Deployment of real-time electric meters implements one of several technological solutions available to ameliorate California's electricity crisis. To meet the mandate of the legislation, the commission implemented its real-time metering program in May 2001. Through contracts with California's electric utilities, the program provided approximately 23,300 real-time meters and associated electronic communications equipment, enabling customers to view their hourly load profile and energy use either over the Internet or on a real-time basis.[10] The program included all of California's major utilities and was designed to motivate at least 500 MW of peak-demand reduction during its first year of operation.

The utilities provide customer access to usage information via the Internet using an integrated software package, including supporting hardware and software and professional services. Meter data from the previous day is sent to these systems for display to the customer the next morning. Customers have a variety of preformatted reports from which to choose and may also develop custom »

RECOMMENDATIONS

We ascertained several additional steps the industry can and should take in its evaluation of demand response programs.

First, the issue of how demand response and efficiency are, are not, or should be intertwined deserves more discussion and examination.

Second, demand response programs currently in operation should begin to address the conservation impact and include it as a measurement and evaluations criterion.

Third, the extent to which a particular demand response program results in a net conservation effect is dependent on a number of factors that may not yet be completely understood, again due to lack of focus in program design and evaluation.

Fourth, it is not unreasonable to think that demand response programs could be designed to optimize the amount of conservation effect while still achieving the desired peak-management objective.

Finally, the information aspect of demand response programs, whereby customers receive more information (price or otherwise) about their usage, should not be underestimated, particularly as a means of generating reductions in consumption. Providing the user with more information about their consumption so that they can better manage it has long been a cornerstone of energy conservation policy and programs; information provision may be a nexus between energy conservation and demand response that deserves more consideration.—***C.K. and D.D.***

reports. These reports can be generated for specific time frames, such as the last 24 hours, the last month, and the last year. Customers can view charts comparing two different time frames for a single facility (such as July 2002 vs. July 2003) or two different facilities in the same time frame.

Figure 2 shows a retail customer with significant nighttime load, representing perhaps an opportunity for conserving energy. Figure 3 shows a customer whose usage remains high on weekends, in contrast with a typical business of the same type. Figure 4 shows a customer who has reduced usage in the latter part of the peak period.

Southern California Edison (SCE) reported on customer usage of the system in October 2003.[11] At SCE, the system is known to customers as SCE Energy Manager. Following the meter installation and confirmation that the Web site is reliably receiving data, the customer is sent a user ID and password along with sign-on instructions and fact sheets of the various energy rates and load-management programs available from the utility. One of the main objectives of the implementation was to make it easy for the customer to use the system with little or no training. However, for customers to maximize the use of the system, SCE conducted hands-on training sessions throughout its service territory. In addition, SCE staffs a program management office during business hours to assist customers with the Web site.

Surveys determined customer use of Energy Manager. The California Energy Commission reports that 39 percent of Energy Manager users reduced total consumption as a result of using the system.[12] The survey also found that 48 percent of users were able to reduce their energy costs, and 39 percent reduced peak load. With respect to accessing the data, 44 percent reported access at least once a week, with 54 percent reporting monthly or as needed access. SCE asked customers why they used the system, and they received the responses shown in Table 4. SCE reports that customers who use the system are satisfied with it, with three-fourths of users saying the software is easy to understand and use.

Our review shows that demand response programs usually result in a small reduction in total electricity consumption in addition to a much larger reduction in electricity use during peak hours. The average reduction ranges from about 4 percent for dynamic pricing programs, to a fraction of a percent for reliability programs, to around 10 percent for effective information/feedback programs. These averages mask important variations, namely that some dynamic-pricing programs result in no observed reduction in consumption (and in one case apparently led to an increase). With respect to the different types of programs, the conservation effect appears to be largely additive.

We submit that efficiency/conservation and demand response are two similar but different tools in a demand-side

TABLE 4 — CUSTOMER REASONS FOR ACCESSING ENERGY DATA

Reason	Percent of Users
To compare energy usage for different time periods	70%
To develop strategies for reducing monthly bills	60%
To associate daily load patterns with specific equipment or operations	58%
To evaluate the effect of modifying equipment or energy usage patterns	55%
To produce reports for management	48%
To investigate questions about a monthly energy bill	43%

management tool box. Each has its own attributes and each complements the other. Efficiency and conservation can result in load reductions on peak, but likely cannot be dynamically controlled. Demand response offers dynamic control and "dispatch" but, while likely not resulting in increased usage, may not always result in a large conservation effect.

Chris King is chief strategy officer of eMeter and Dan Delurey works for the DRAM Coalition. Contact King at chris@emeter.com and Delurey at dan.delurey@wedgemere.com.

Endnotes

1. Our review included, either directly or indirectly, more than 200 pilot or large-scale programs carried out by government or utility sponsors between 1975 and 2004.
2. See results for Holland ENW Amsterdam in Wolsink, M., "New Experimental Electricity Tariff Systems for Household End Use," Proceedings ECEEE, 1997. Also see, King, C., "Integrating Residential Dynamic Pricing and Load Control: The Literature," *EnergyPulse*, Dec. 14, 2004.
3. Barbose, G. *et. al.*, "A Survey of Utility Experience with Real Time Pricing," *Lawrence Berkeley National Laboratory Report* LBNL-54238, December 2004.
4. Quantum Consulting, "Working Group 2 Demand Response Program Evaluaiton – Program Year 2004 Final Report," December 2004.
5. *Ibid.*
6. Al-Shakarchi, M. and N. Abu-Zeid, "A Study of Load Management by Direct Control for Jordan's Electrical Power System," *Journal of Science & Technology*, 7:2, 2002.
7. Goldberg, M., "Knowing Your Limits: Direct Load Control Capacity Credits Based on Censoring Distribution Analysis," AEIC Load Research Conference, August 2000.
8. Darby, S., "Making It Obvious: Designing Feedback into Energy Consumption," in *Energy Efficiency in Household Appliances and Lighting*, edited by Bertoldi *et. al.*, Springer, 2001.
9. Farhar, B. *et. al.* "Effects of Feedback on Residential Electricity Consumption: A Literature Review," Solar Energy Research Institute, January 1989.
10. California Energy Commission, *Report to the Legislature on Assembly Bill 29X*, June 2002.
11. Wood, K., "SCE's C&I Customers Manage Load in Real Time," *Transmission & Distribution World*, Oct. 1, 2003.
12. Braithwait, Steven. "Peak Demand Impacts of TOU Rates and Customer Access to Usage Data," California Energy Commission Demand Response.

Who Benefits

(Continued from p. 38)

strate the difficulty of determining the value of DER benefits that accrue to anyone other than the owner. Most current market structures are incapable of reflecting the ancillary benefits that DER can supply. The case studies also demonstrate a reluctance on the part of utilities to recognize or acknowledge the benefits to their systems, even when there is clear evidence of a grid deficiency or when a DER operator increases its output in response to a utility's request. In addition, utility input is crucial in determining the value of location-specific transmission and distribution deferrals due to DER installations. In the next stage of this project, a regional model, with a census of available power plants and a comparative technology database, is used to assign market values to both reliability and environmental benefits.

T.K. Stovall, S.W. Hadley, and D.T. Rizy are senior researchers at Oak Ridge National Laboratory, operated by UT-Battelle for the U.S. Department of Energy. Contact Stovall at stovalltk@ornl.gov.

Table 1 — Reasons Cited for Installing DER

Reason	No.	Reason	No.
Cogeneration	53	Environmental sensitivity	6
Cost reduction	34	Fuel flexibility	3
Reliability	38	Reduction in emissions	4
Peak demand	26	Upgrade plant	6
Price protection	15	Market speculation	2
Capacity increase	11	Grid constraints	9
Burning of waste product	6	Power quality	3
Rate structure	7	Unknown	4

Endnotes

1. Joseph A. Orlando, Cogeneration Design Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1996.
2. F. William Payne, Ed., Cogeneration Management Reference Guide, Fairmont Press, Inc., Lilburn, GA, 1997.
3. Etan Z. Gumerman, et al., Evaluation Framework and Tools for Distributed Energy Resources, LBNL-52079, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, February 2003.
4. W. P. Poor, *et al.*, Connecting Distributed Energy Resources to the Grid: Their Benefits to the DER Owner/Customer, Other Customers, the Utility, and Society, ORNL/TM-2001/290, Oak Ridge National Laboratory, March 2002.
5. S. W. Hadley, *et al.*, Quantitative Assessment of Distributed Energy Resource Benefits, ORNL/TM-20, Oak Ridge National Laboratory, 2003.
6. S. W. Hadley, *et al.*, The Effect of Distributed Energy Resource Competition with Central Generation, ORNL/TM-2003/236, Oak Ridge National Laboratory, 2003.
7. CHP is also often used to represent combined heat and power.
8. Carl Segneri, "Reversal of Fortunes," Transmission and Distribution, May 1, 2001.
9. Interim Report of the U. S. Department of Energy's Power Outage Study Team, Findings from the Summer of 1999, Paul Carrier, Chairman, U.S. Department of Energy, January 2000.
10. Meeting Electric Infrastructure Constraints with Distributed Generation, Case Study—Commonwealth Edison Service Territory, American Gas Association, August 2001.