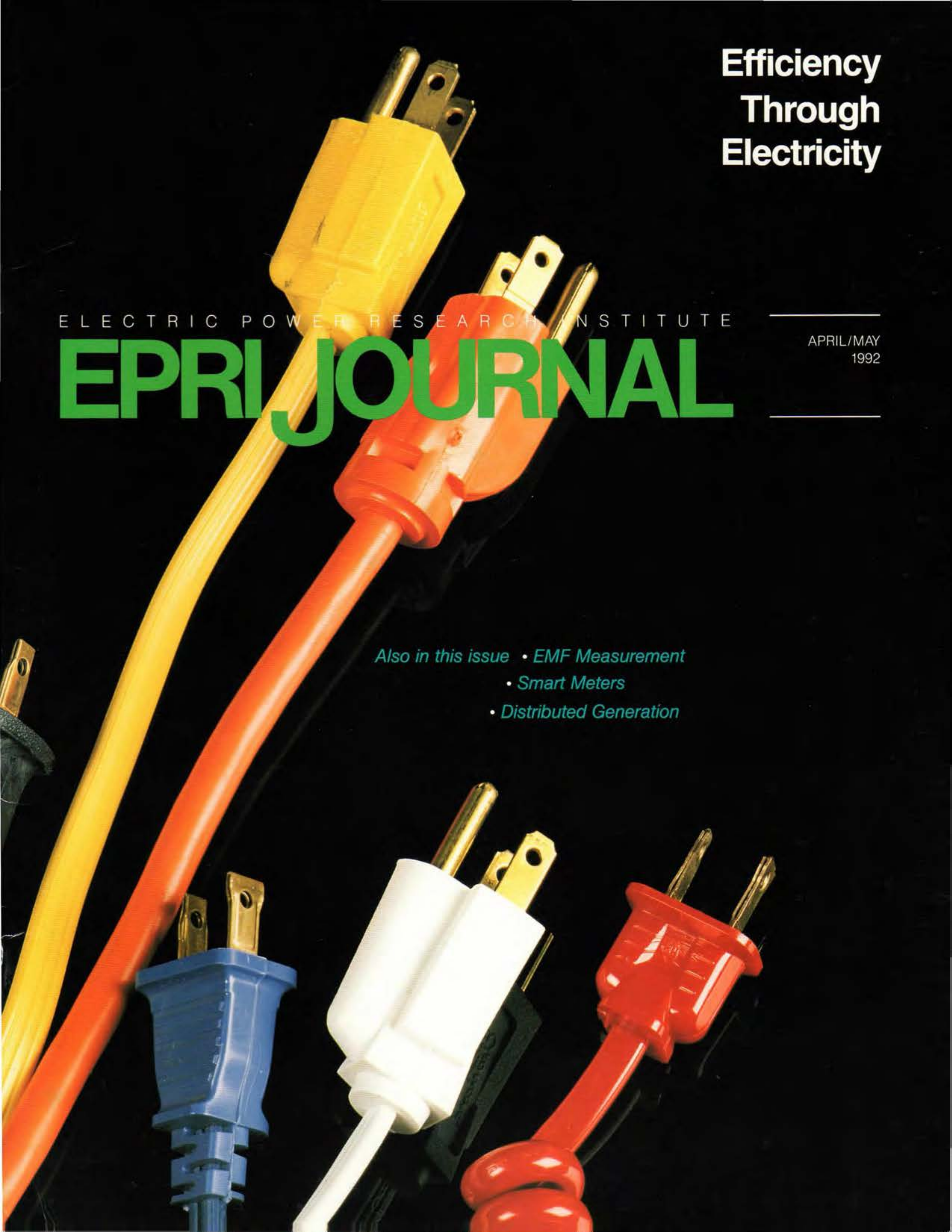

Efficiency Through Electricity

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

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Also in this issue
- *EMF Measurement*
- *Smart Meters*
- *Distributed Generation*

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Cover: Electricity offers higher productivity and more efficient use of primary energy in a wide variety of end-use processes.

Doing More With Less

Electricity's versatility, precision, and ease of use have given rise to a remarkable range of new applications. Whether it's reheating a dinner with microwaves, energizing the beam of an industrial laser, or powering the microsecond-by-microsecond opening and closing of computer circuits, electricity can do more things faster, more easily, and more precisely than any other energy form. Electronic process control alone has revolutionized more than a few industries, improving product quality and enhancing productivity. Indeed, electricity has become the energy standard for virtually all new technologies across the residential, commercial, and industrial sectors.

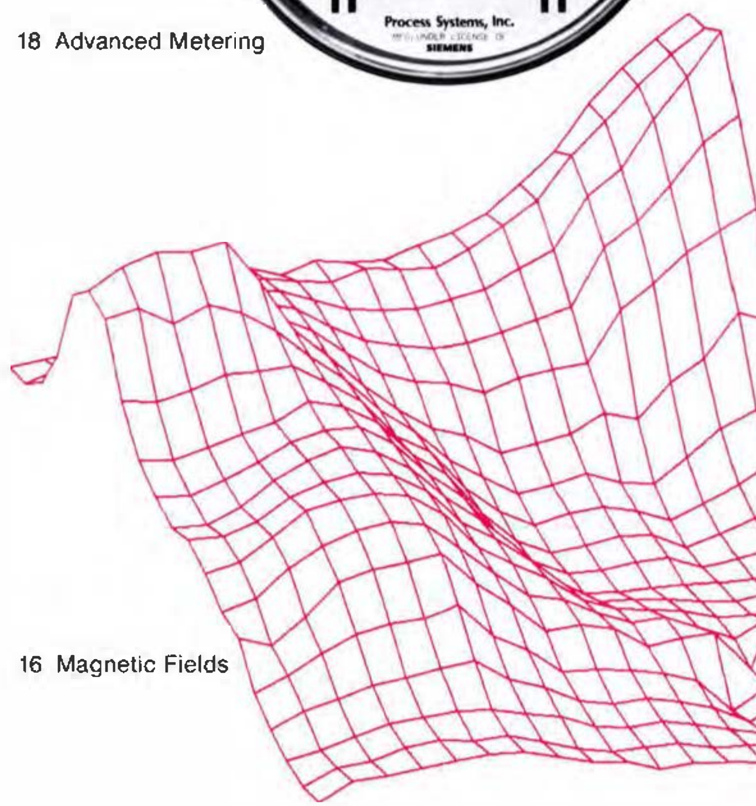
For the most part, we have tended to prize the convenience and expanded capabilities electricity offers above all other considerations. But the same technical attributes that allow it to be controlled and applied to such benefit offer us something else just as important: energy efficiency. Over the past decade, electricity's precision and flexibility have been exploited to improve the end-use efficiency of home appliances, industrial motor drives, and many other common electricity-based technologies, ensuring that we make the wisest use of our limited energy resources.

In addition to boosting the efficiency of existing electrical applications, researchers have developed a broad range of electric technologies that offer clear efficiency improvements over many conventional fossil-fuel-based processes. Beyond the scope of wise electricity use, these innovative replacement technologies form the basis for a corollary that may at first seem counterintuitive: simply put, the *wider* use of electricity to replace other, less efficient energy forms can substantially reduce primary energy consumption and its attendant environmental consequences.

This issue's cover story describes the surprising power behind this concept and outlines a wide variety of application opportunities: residential and commercial heating and cooling, chemical production, food processing, wastewater treatment, even transportation. Tapping the energy-saving potential of electricity is an opportunity custom-made for our time. For the first 100 years of the electric age, we have explored the seemingly endless potential applications of this remarkable energy form. That exploration continues unabated today. But as the issues of a sustainable energy future and a clean and safe environment become more urgent, we may find that the most important value of electricity is not its unparalleled ability to help us do more, but its ability to help us do more with less.

Clark W. Gellings
Vice President, Customer Systems

RESEARCH UPDATE



DEPARTMENTS

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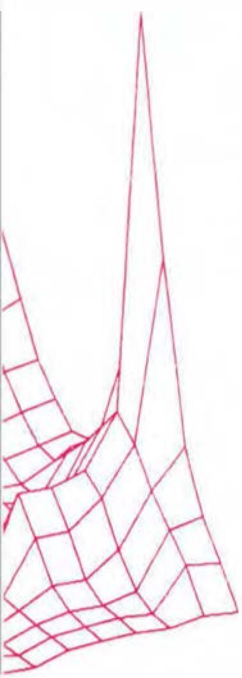


EDITORIAL

COVER STORY

FEATURES

ELECTRICITY FOR INCREASING ENERGY EFFICIENCY

THE STORY IN BRIEF

The increasing electrification of modern society has brought with it capabilities and products that have forever changed our quality of life. But while we take for granted the breadth of electricity's application and its implications for productivity and convenience, other important advantages of this highly refined energy form are largely unappreciated: energy efficiency, conservation of primary energy resources, and reduction of environmental problems. Electricity offers unmatched flexibility and efficiency at the point of use. And studies show that in a growing list of applications, electricity requires less primary fuel to accomplish tasks than direct use of fossil fuels, even when the fuel used to generate the electricity is taken into account. This reduction in primary energy use, in turn, means lower pollutant emissions. The wider application of electric technologies—including some designed specifically for environmental mitigation—offers new solutions to today's pressing energy concerns.

by Peter Jaret

WHEN EPRI'S DEMONSTRATION DAIRY PLANT in Fond du Lac, Wisconsin, marks its first year of operation this September, it will represent more than just a showcase for the advantages of freeze concentration over conventional evaporation methods for processing milk products. The Wisconsin plant also serves as a working demonstration of how the wider use of electricity can save energy, thanks to the development of innovative and highly efficient new technologies.

At first glance, the notion of using electricity to save energy seems paradoxical. It wasn't long ago, after all, that Americans were asked to conserve energy by using *less* electricity. To be sure, conservation efforts have played an important role in promoting the wise and measured use of primary energy sources. But by now, many of the most dramatic benefits of conservation have been achieved. Unless society is prepared to make significant sacrifices in the quality of life, conservation alone isn't the answer.

Fortunately, conservation is only one part of the larger, more powerful concept of energy efficiency. "Saving energy isn't simply a matter of making do with less but of finding ways to get more from the energy we do use," explains EPRI's Clark Gellings, vice president for customer systems. Through the wider use of electricity to power a growing portfolio of highly efficient electric technologies, Gellings believes, the nation and the world can reduce the consumption of primary energy resources even as we increase our use of electricity and enjoy more of the benefits it provides.

Tracking resources from start to finish

To take a true measure of energy efficiency, it is necessary to follow a unit of energy from the moment it is extracted as primary fuel to the moment it provides service in a particular application. This approach considers the total resource requirements for energy production and use. Admittedly, in the early laps of the race for energy efficiency, electricity may seem at a distinct disadvantage to primary energy sources. Because energy is lost in converting primary fuel sources like oil or natural gas to electricity, one unit of primary energy yields only about 0.31–0.33 unit of electric energy from today's typical power plant. Add to that an estimated 8% loss in transmission and delivery, and one unit of primary energy shrinks to only about 0.29–0.31 unit of electric energy by the time it is ready to be used. The most advanced power plants being built today—with conversion efficiencies as high as 53%—can increase this figure significantly, but even then, less than half the original energy is available at the point of use.

In contrast, oil may lose only about 16% of its primary energy content through refining and delivery. Natural gas requires no conversion processes at all; with about 10% typically lost in transmission and delivery, a unit of primary energy extracted from a gas well still provides 0.9 unit of energy for end-use application. But at this point, the race is only half run. Electricity's extremely high end-use efficiency gives it an advantage that's hard to beat at the finish, more than making up for the energy lost in converting primary fuels to electricity.

Consider two plants for concentrating dairy products. One employs the conventional method of evaporating water, which typically uses oil or gas and requires a net of about 700 Btu—a conservative estimate—to extract a pound of water from the milk product. The other employs newly developed freeze concentration technology, which uses electrically driven vapor compression to freeze out water and requires only 114 Btu to extract the same amount of water. Even taking into account the energy lost in converting primary fuels to electricity, the electricity-based process is currently at least twice as energy-efficient as conventional evaporation in terms of total resource requirements and may become as much as six times as efficient when the technology is fully developed (see case study).

Through the wider use of energy-efficient electric technologies like these, Gellings argues, the nation could reduce its consumption of primary energy—in some cases, dramatically. If freeze concentration were to achieve a 10% market penetration in the dairy industry alone,

Freeze Concentration

The basics

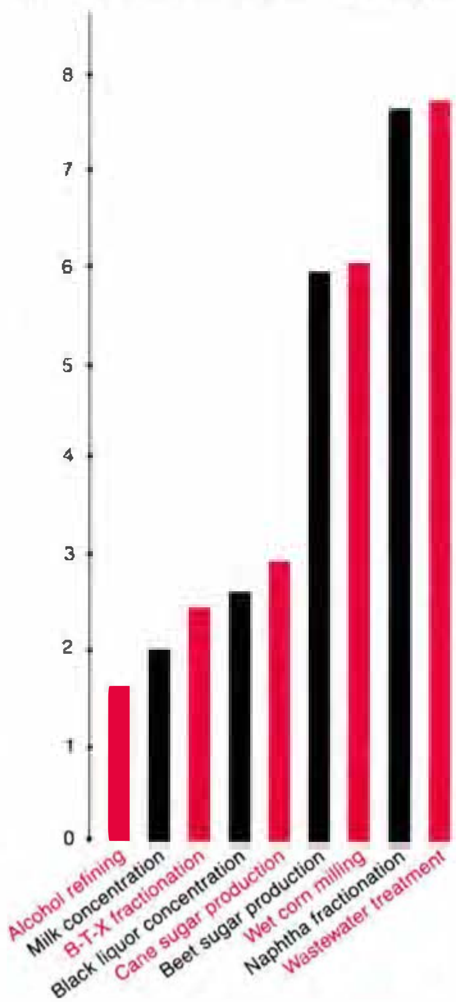
Freeze concentration uses electricity to separate and remove a liquid—water, for example—from a fluid mixture. The technology is already being used worldwide for the concentration of fruit juices and is also being applied in processing beer, wine, vinegar, and coffee. One of the most promising applications for the technology is in the concentration of dairy products: water is frozen out of milk and the ice crystals are skimmed off, leaving a concentrated milk product that can be packaged directly or used in ice cream production. Because freezing water takes only 15% of the energy that boiling it off takes, the freeze concentration technology is much more efficient than conventional evaporation processes. The dairy industry is so large that even a 10% penetration of the new technology could save 3.4 trillion Btu of primary energy a year. Over two dozen other promising applications have been identified for a number of industries, including industrial and municipal wastewater treatment, alcohol refining and fractionation of benzene-toluene-xylene mixtures (organic chemicals production), and concentration of caustic soda (chlor-alkali industry).

Potential applications for freeze concentration technology span a wide variety of industries, with significant primary energy efficiency savings projected for each. The total resource efficiency advantage for one application not shown here—caustic soda concentration—is over 40 to 1.

Beyond the basics

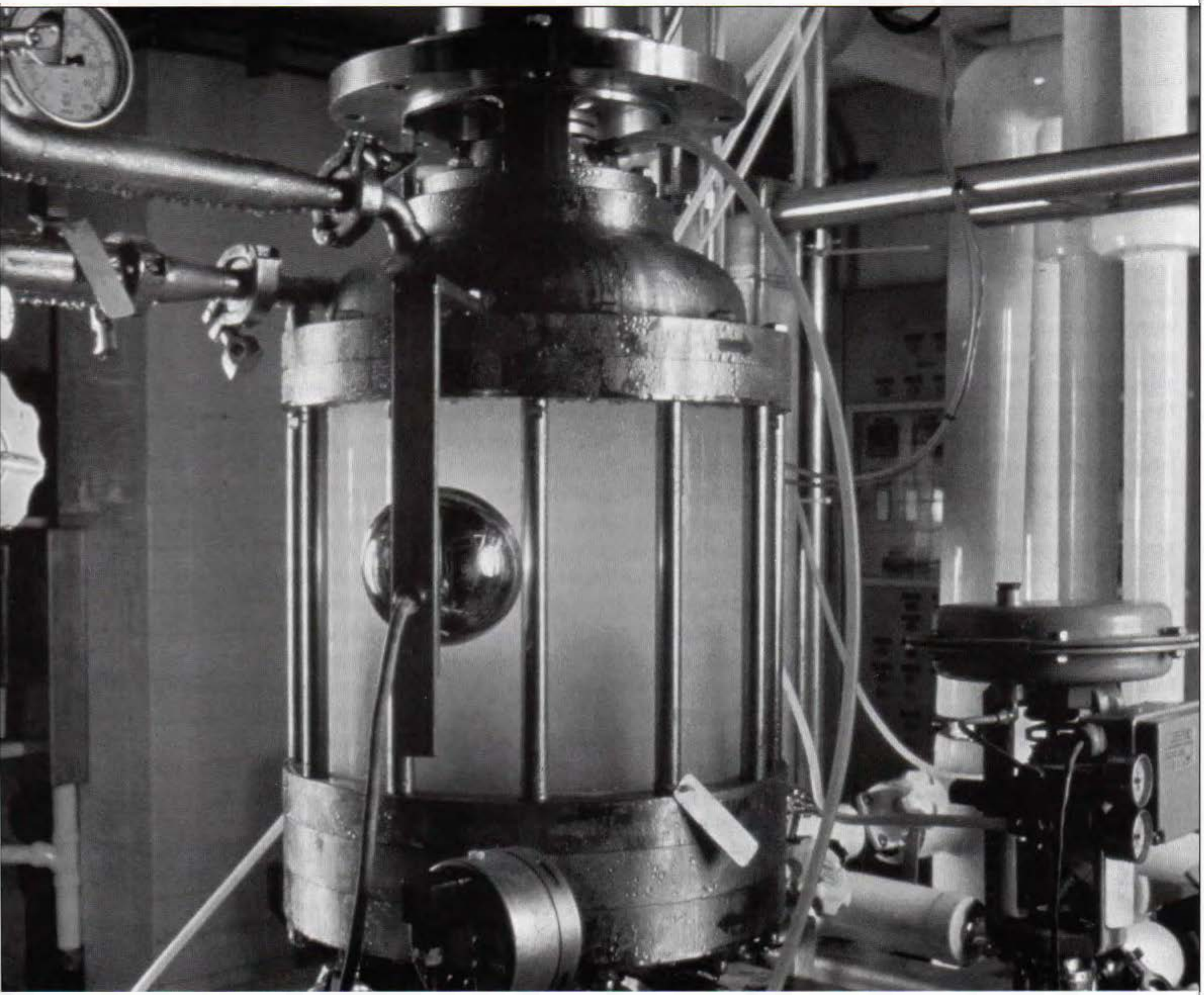
In addition to greater energy efficiency, freeze concentration offers a number of side benefits. In dairy applications, for example, conventional heating processes often change the taste of milk products; the low operating temperatures of freeze concentration retain volatile flavor and aroma compounds, increasing overall product quality. And while evaporation processes recover only half the solids from whey, a by-product of cheese making, freeze concentration can reclaim all the solids and significantly reduce the bulk of waste liquids for disposal. The fact that freeze equipment operates at very low temperatures compared with evaporation methods can be especially important for equipment used in chemical and wastewater treatment applications, leading to fewer corrosion problems, lower maintenance and repair costs, and the opportunity to use less-expensive construction materials.

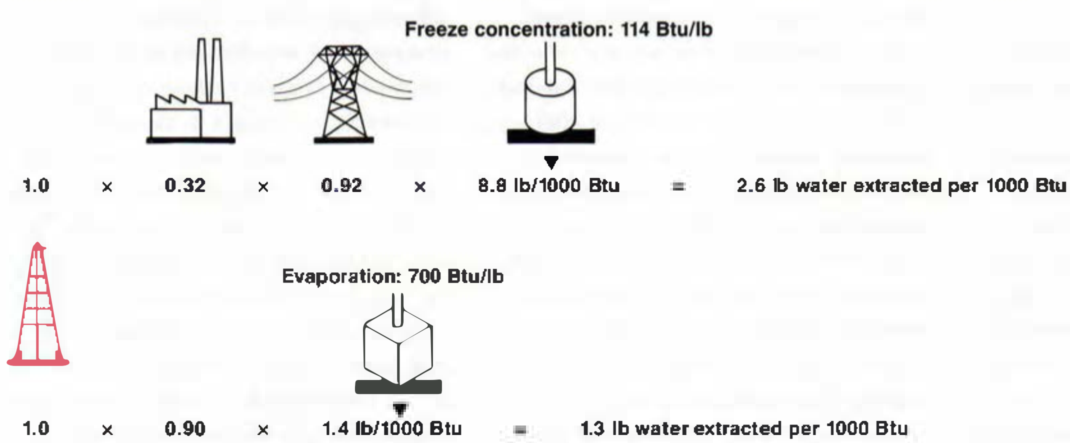
Relative Primary Energy Efficiency:
Freeze Concentration vs. Conventional Methods



Total resource efficiency

Following the use and losses of primary energy from the wellhead through actual end use demonstrates why electric freeze concentration technology is twice as efficient as conventional gas-fired evaporation processes in concentrating milk products. Converting the natural gas to electricity in a typical power plant uses over two-thirds of each unit of primary energy, and transmission losses account for another 8%. Natural gas used directly retains about 90% of its primary energy, losing about 10% in delivery. But the extremely high efficiency of the electric technology at the point of use more than makes up for electricity's conversion losses. Freeze concentration can extract a pound of water from milk with only about a sixth of the equivalent energy input required to extract a pound by evaporation, leading to a 2-to-1 total resource efficiency advantage. As advanced generation technologies raise power plant efficiencies, the advantage will become even more pronounced.




Freeze concentration: 114 Btu/lb
1.0 × 0.32 × 0.92 × 8.8 lb/1000 Btu = 2.6 lb water extracted per 1000 Btu
Evaporation: 700 Btu/lb
1.0 × 0.90 × 1.4 lb/1000 Btu = 1.3 lb water extracted per 1000 Btu

considered by many analysts to be a relatively conservative estimate, nationwide energy savings would total a remarkable 3.4 *trillion* Btu of fossil fuel per year. "That's just one electric technology applied to one industry," points out Gellings. In a recent study, EPRI identified nearly a dozen new and highly efficient electric technologies that could offer similar energy savings across a wide range of residential, commercial, and industrial applications.

Electric heat pumps, for instance, are already reducing the amount of primary energy required to heat and cool homes and offices. "In essence, heat pumps are solar machines, drawing heat from either the air or the ground," Gellings explains. "As a result, they can achieve operating efficiencies far greater than those of conventional heating and cooling systems."

Taking into account the 10% lost in gas transmission and distribution, a gas furnace operating at 96% efficiency (a highly efficient furnace) achieves an estimated 86% efficiency—impressive by most standards. But by tapping heat from the environment, commercially available electric heat pumps can turn one unit of electricity input into a remarkable 3.4 units of heat output—more than enough to compensate for the energy lost in converting raw fuel to electricity. Commercially available heat pumps already offer a total resource efficiency of 100%. That means that for every unit of primary fuel consumed in an electric power plant, a full unit of useful energy can be used to control temperature in a building that uses electric heat pumps—compared with only 0.86 unit for a gas-powered furnace (see case study).

Gas-driven heat pumps now under development are also likely to offer improvements over furnaces of the future. But the end-use efficiency of the Carrier HydroTech 2000™ electric heat pump—already commercially available—is twice as great for heating and almost five times as great for cooling as that of the prototype gas heat pumps now being tested. The electric technology's inherently superior cooling capabilities will allow it to continue to hold a clear efficiency advantage.

Such savings are just the beginning. "While many applications of primary energy sources, such as space and water heating, are nearing their maximum technical efficiency," says Gellings, "electricity-based technologies are just beginning to develop their energy-saving potential." Technical refinements of electric heat pump technology, for instance, could potentially double the overall energy efficiency of current models.

A refined energy source

What accounts for the remarkable efficiency of electricity? In a very real sense, it is the most "refined" of all energy sources. It is *pure* energy without any cumbersome physical substance and can be turned effortlessly to the full range of end-use power needs. Because electricity has no inertia, its energy input can be instantly varied in response to changing requirements. That flexibility allows electricity to be concentrated and controlled far more precisely than other forms of energy. Computers, for instance, depend on the microsecond-by-microsecond flow of precisely controlled electric currents to open and close circuit gates. Lasers and electron beams can be focused to produce energy densities at the work surface a million times more intense than an oxyacetylene torch—making it possible to heat-treat manufactured parts precisely at points of maximum wear and thus eliminate the need to heat and cool an entire piece.

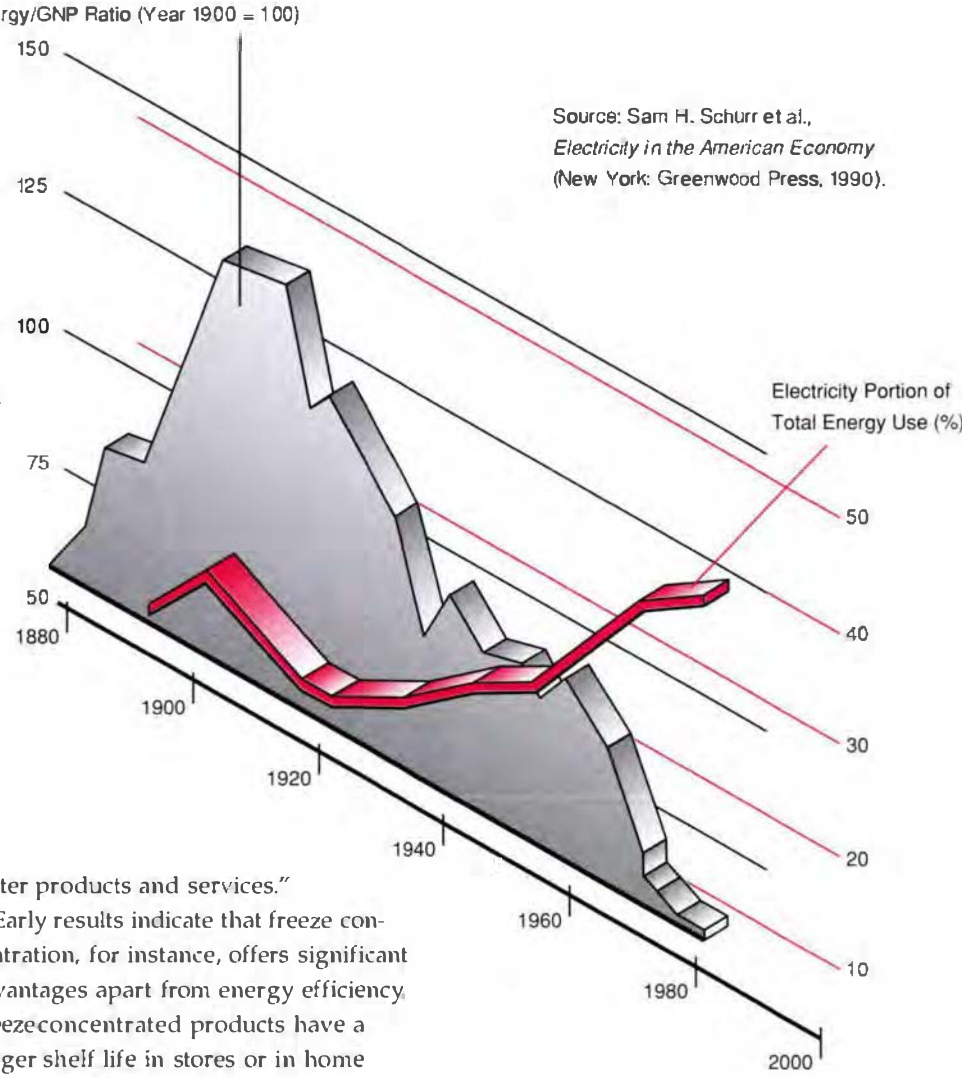
Fossil fuels have traditionally been the preferred energy source for heating, but even here, electricity's technical attributes can provide unique advantages. Combustion processes are limited by what physicists call adiabatic flame temperature, which sets a practical limit of about 3000°F for fossil fuels burned in air. In contrast, because there is no inherent thermodynamic limit on electric heating, temperatures of 10,000°F and higher are routinely achieved with electric-arc-produced plasmas. Even higher temperatures are technically feasible.

Unlike fossil fuels, which typically heat at the surface through radiation and convection, electricity can generate heat within a material itself. Using microwave or radio-frequency radiation instead of surface heating methods to dry moist materials such as paper or textiles can save significant amounts of energy by cutting the drying rate and improving product yield.

Electric arc melting for the manufacture of steel provides another example. Conventional blast furnace steelmaking requires 16.6 million Btu per ton of steel produced, while an electric arc furnace requires only 7.3 million Btu per ton, including conversion losses in generating the electricity. Thus, even taking conversion and transmission losses into account, electric arc melting is over twice as energy-efficient as conventional fossil-fuel-fired technologies.

Because electricity is a refined energy source, its electrolytic, electrothermal, and electromotive effects sometimes combine to create additional, synergistic advantages. The electricity used in reducing alumina to aluminum, for instance, keeps the cryolite bath in a molten state while electrolysis separates out the aluminum for collection at the cathode. In a coreless induction melting furnace, electromagnetic induction heats and melts the charge while also inducing a strong electromotive stirring action. The result: enhanced heat transfer to the solid material and greatly improved homogeneity of the melt.

Electricity also offers crucial economic advantages. Because combustion-based processes are usually tied to the availability of a specific fuel source, they are vulnerable to changes in the price or availability of these fuels. Converting to alternative fuels can be costly. Electricity, on the other hand, can be produced from a variety of primary fuels. That means that electricity-based manufacturing processes can rely on an unchanging energy source while utilities are free to select from among the most economical primary energy sources to generate electric power. And with the development of renewable energy sources like



ELECTRICITY FEEDS PRODUCTIVITY
Electrification has been a potent force for increasing energy efficiency and productivity since early in the century. Energy intensity—the ratio of overall energy consumption to the gross national product — began to fall steadily in the 1920s with the introduction of electric motor drives for manufacturing. As electricity was increasingly substituted for other, less efficient forms of energy, its fraction of the energy whole increased steadily, and energy use per unit of GNP decreased.

wind and solar, an increasing proportion of electricity can be produced without tapping any of our limited primary energy resources.

Saving more than energy

There's nothing new about the idea that highly efficient electric technologies help make more-efficient use of primary energy resources. During the 1920s, for instance, productivity soared while energy use relative to output declined an average of 4.3% per year. The principal reason: widespread electrification of industrial processes during the 1920s transformed the way manufacturing was done, leading to dramatic improvements in overall energy efficiency. Today, the United States uses only 7% more primary energy than it did in 1973, yet the gross national product has increased some 46%—in significant part because the wider use of electricity has allowed us to do more with far less energy.

It's important to remember such lessons, says Gellings. "The tendency to think of electricity as part of the 'problem' of energy consumption and its effects on the environment misses an important point. Efficient electrification offers ways to reduce our consumption of primary energy without sacrificing comfort, productivity, or quality of life. The wider use of electricity can help reduce environmental emissions. And it can do all that while providing even better products and services."

Early results indicate that freeze concentration, for instance, offers significant advantages apart from energy efficiency. Freeze-concentrated products have a longer shelf life in stores or in home freezers. And because the process causes lactose to crystallize for easy separation, it may be possible to produce milk and other dairy products for people with lactose intolerance.

Historically, such practical benefits of electrification—from improved product quality to enhanced labor efficiency—have been the driving force behind the wider use of electricity. Offices don't use fax services to save energy, after all; they use them to save time and improve service quality. Manufacturers have switched to electric technologies not because they reduce our consumption of primary energy resources but because they improve production and enhance product quality. Indeed, the ability of highly efficient electric technologies to save energy has long been one of the hidden benefits of electricity. Only now, as the issues of energy use and environmental impact play an increasingly important role in business decisions and national policy, have we begun to take a second look at the potential of beneficial electrification.

The environmental advantage

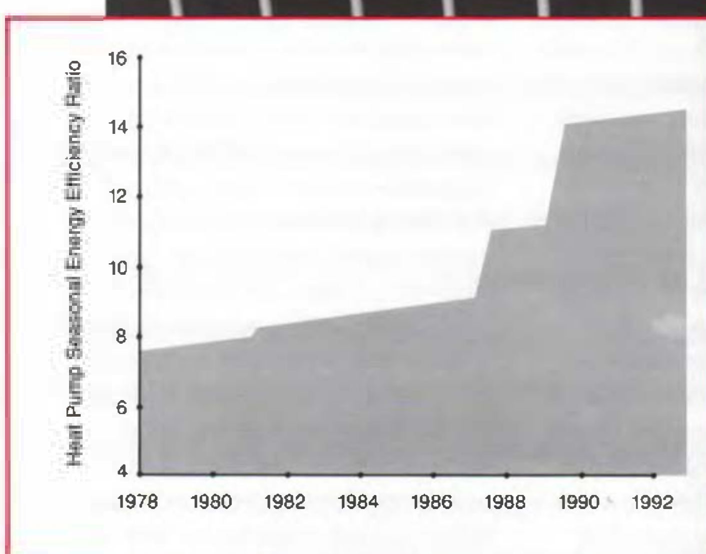
Electric transportation offers one of the best examples of the environmental advantages of electric technologies. Unlike gasoline-powered cars and trucks, electric vehicles (EVs) do not produce emissions during operation. Since all emissions are limited to the electric generating plant, they can be more efficiently and effectively controlled. The widespread use of electric vehicles is expected to substantially reduce nitrogen oxides, carbon monoxide, carbon dioxide, and volatile organic compounds in the urban environment.

Today, electricity-based transportation

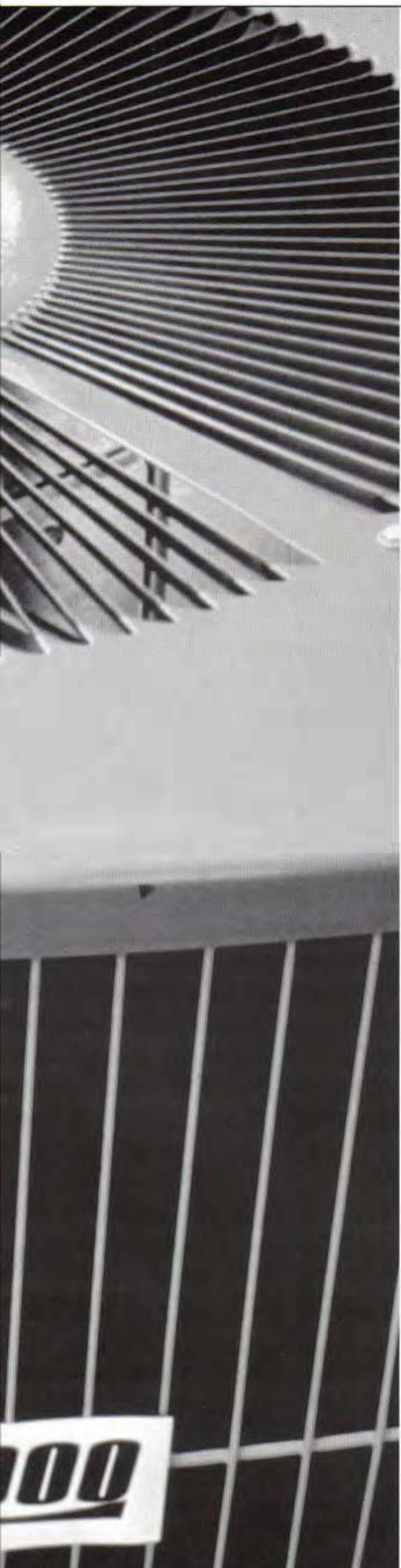
Heat Pumps

The basics

Heat pumps are actually solar energy devices. Instead of burning natural gas or oil as furnaces do to provide heat, the heat pump uses electricity to collect and concentrate heat from ambient air or the ground, both of which are warmed by solar radiation. Since this solar heating resource is free, the heat pump can deliver significantly more energy for heating than it consumes in electric power—over three times more for the most advanced units. The device can also cool a building by reversing the process, collecting indoor heat and transferring it outside the structure. In large office buildings, heat pumps can be used to optimize temperature distribution, removing heat from the sunny side of a building or from a room full of computers, for example, and transferring it to interior offices or a basement. Studies indicate that by the year 2010, the increased use of heat pumps in the residential sector alone could reduce net primary energy consumption by 1.13 quads.



Advances in heat pump design have led to tremendous efficiency gains for the technology over the last five years. Market introduction of the HydroTech 2000 in 1989 boosted the top seasonal energy efficiency ratio for available equipment by a full 30%.

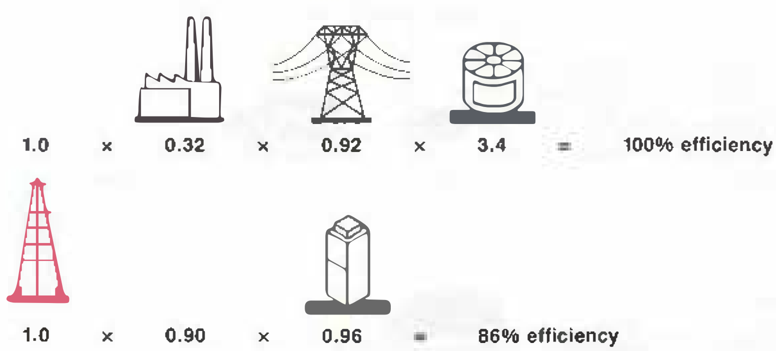


Beyond the basics

Versatility is another key attribute of heat pumps. In addition to providing efficient space-heating and -cooling capability in a single package, units can be designed to handle water heating as well. While gas furnace–electric air conditioner combinations still serve the largest share of the nation's space-conditioning needs, heat pumps are being developed to penetrate particular market niches. An advanced ground-source heat pump, for example, shows great promise for homes in northern climates, and two new dual-fuel heat pumps are being offered as single-package direct replacements for furnace–air conditioner combinations in the residential and commercial sectors. To further ensure primary energy and cost efficiencies, the dual-fuel unit can be programmed to automatically switch between electric and gas-fired operation, depending on the ambient temperature and relative price of fuels.

Total resource efficiency

How does the most efficient heat pump stack up against the most efficient gas furnace? Without the losses inherent in primary energy conversion, the gas technology once again takes the lead in the early going. But by tapping solar energy from the environment, the Carrier HydroTech 2000 heat pump can provide 3.4 units of heat output for each unit of electricity input. Thus the heat pump achieves a remarkable 100% total resource efficiency. By contrast, a pulse combustion furnace—at 96%, the most efficient gas option available—yields a total resource efficiency of 86%; if the energy required to run the indoor fan were also accounted for, the figure would be reduced another 10%. This furnace's performance is just about at its theoretical efficiency limit; the heat pump's coefficient of performance of 3.4, on the other hand, may be increased to a practical value of over 7 through further development.



Electric Vehicles

The basics

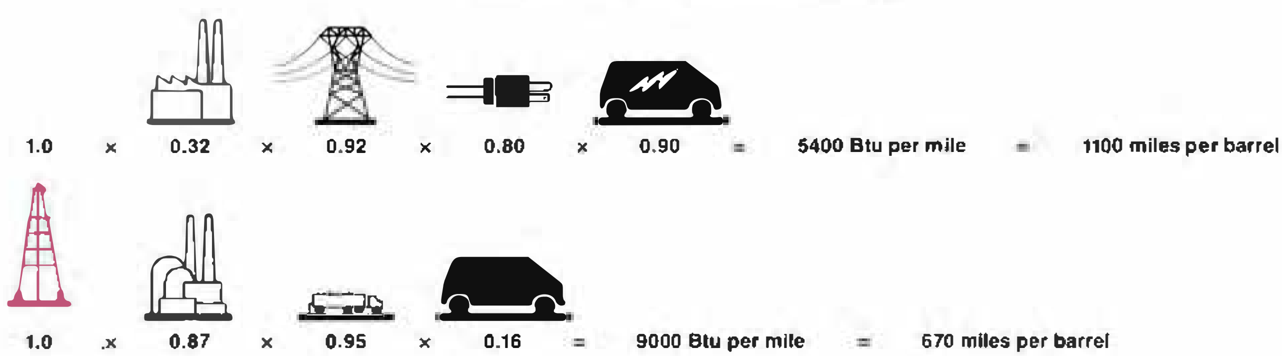
All major U.S. automobile manufacturers have now made a commitment to the commercial production of electric vehicles. Regulatory pressure to improve urban air quality is largely behind this recent renewal of interest. Unlike gasoline-powered vehicles, EVs produce no pollutant emissions at the point of use, and since all electricity generation emissions are centralized at power plants, they can be controlled far more effectively and efficiently than vehicle emissions. In addition, power plants are generally situated outside urban areas, which are the locations of greatest concern for automobile emissions. But aside from environmental issues, electric transportation also has significant efficiency advantages: calculations of primary energy efficiency give the next generation of electric fleet vans about a 60% efficiency advantage over their gasoline counterparts. Electric buses are about 85% more efficient per passenger mile than diesel-powered buses, and shipping freight by electrically driven trains is about 45% more efficient per ton than shipping by semitrailer truck.

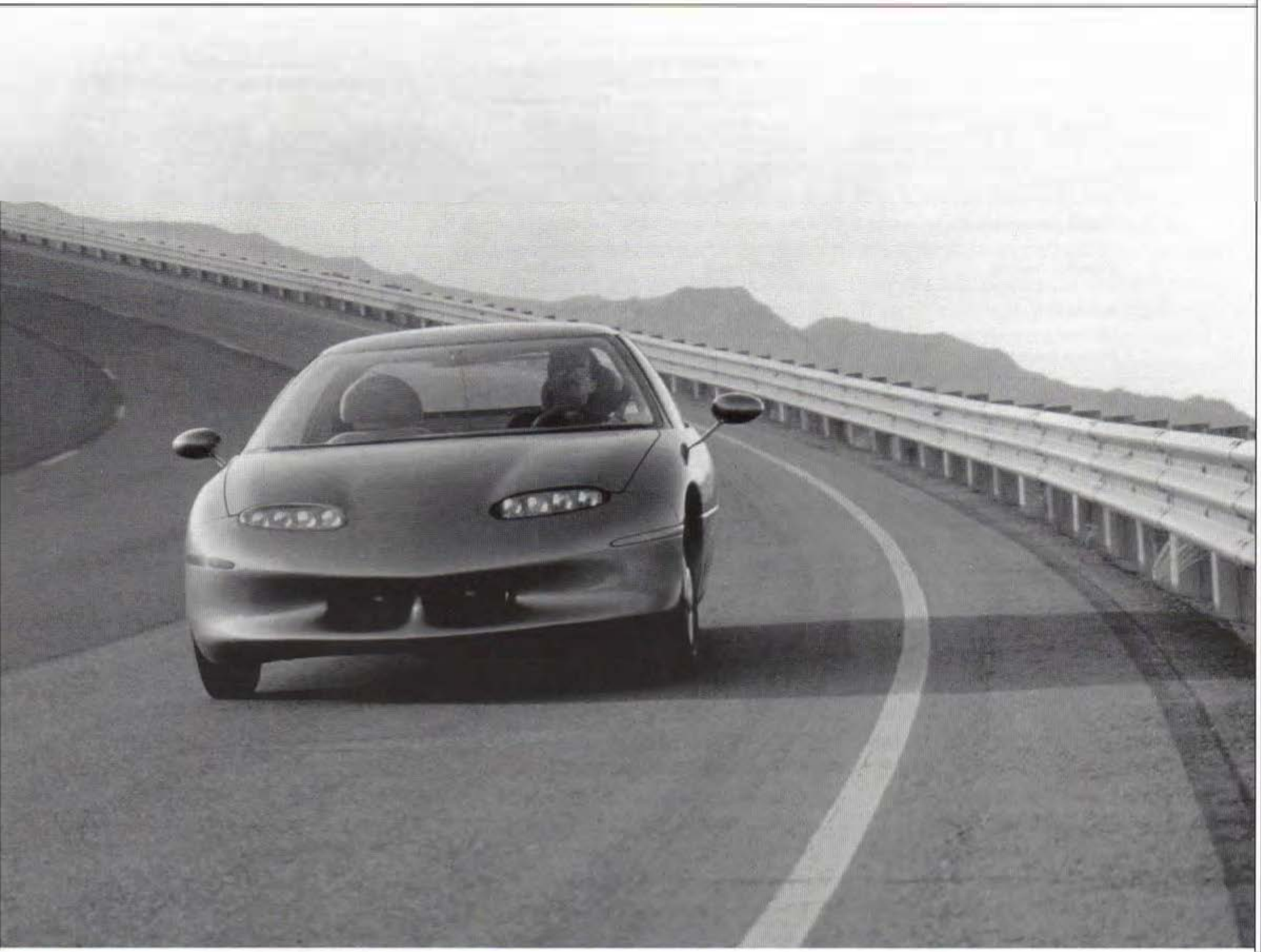
Beyond the basics

While their efficiency and emissions advantages are impressive, EVs offer other benefits for the consumer, utilities, and society. Because EVs are powered by a motor and batteries rather than an internal combustion engine, they are extremely quiet, reducing noise pollution. And because the whole power train is operationally simpler and has fewer moving parts, EVs are expected to have much lower service and maintenance costs. Vehicle batteries are most likely to be charged up at night, when the cost of electricity generation is lowest, improving utility load shape and potentially reducing the owner's cost of operation. Finally, since power plants can produce electricity from a wide variety of fuels, EVs will shift transportation energy use toward a broader fuel base, reducing our national dependence on foreign oil.

Total resource efficiency

Electric and gasoline-powered vehicles can be difficult to compare in overall use because they have different operational characteristics—pickup and range, for example. Still, comparing the electric TEVan with its gasoline-powered counterpart in the same function—urban commercial fleet use—shows that the electric version is more energy-efficient for that application. A barrel of oil loses a lot of its primary energy content in being converted to electricity. But oil must be refined into gasoline to burn in a car, and an internal combustion engine is very inefficient—for fleet vehicles, less than half as efficient as a conventional electric power plant. The TEVan loses about 20% of its electricity input in charging the batteries and is about 90% efficient in using the electric energy it does store to propel the vehicle. When all these factors are considered, the electric van, using advanced nickel-cadmium or nickel-metal hydride batteries, offers about 60% greater mileage from the same amount of primary energy.





FLEET MINIVAN EMISSIONS
(grams per mile)

	Gasoline-Powered Van		Electric Van		
	California	U.S.	Current L.A. Basin Generation Mix	Current U.S. Generation Mix	Post-1995 U.S. Generation Mix
VOCs	0.7	1.0	0.01	0.01	0.01
NO_x	1.1	1.8	0.08	1.2	0.3
CO	9.0	10.0	0.01	0.05	0.05
CO_2	690	690	195	315	320

Electric vehicles can significantly reduce the emissions that contribute to urban air quality problems from vehicles—volatile organic compounds (VOCs), nitrogen oxides (NO_x), and carbon monoxide (CO)—as well as carbon dioxide (CO_2), the emission of primary concern for global warming. The table compares gasoline-powered van emissions based on current California and 1989 U.S. emissions standards with EV emissions under three different generation mix scenarios. The EV emissions take into account all emissions directly or indirectly associated with electric power production.

Energy Savings Up, CO_2 Production Down Substituting efficient electric end-use technologies in applications traditionally served by fossil fuels can save a great deal of primary energy and decrease production of carbon dioxide over the next 20 years.

	Net Primary Energy Savings (quadrillion Btu)		Net CO_2 Emissions Reduction (millions of tons)	
Electric Technology	Year 2000	Year 2010	Year 2000	Year 2010
Heat pumps	0.69	2.79	8	100
Freeze concentration	0.07	0.35	3	18
Induction heating	−0.05 to 0.05	−0.1 to 0.1	−2 to 8	−4 to 17
Arc melting	0.19 to 0.23	0.39 to 0.48	22 to 27	46 to 56
Plasma processing	0.01	0.04	3	7
Ultraviolet/infrared technology	0.02	0.14	1	6
Electric vehicles	0.01	0.07	1	6
Electric transit and freight	0.03	0.12	2	10
Total	**0.97 to 1.11**	**3.80 to 4.09**	**38 to 53**	**189 to 220**

is going farther and doing more but using less primary energy than conventional gasoline- or oil-based transportation technologies. Studies by the Energy Research Group have shown that for public transit, electric rail systems are 50% more energy-efficient per passenger mile than automobiles, and electric buses are about 85% more efficient than conventional diesel buses. Electrically powered trains also do better for shipping freight: ton for ton, mile for mile, they require less than 70% of the primary energy used by semitrailer trucks. And the less primary fuel consumed, the lower the total emissions.

Of course, gasoline-powered automobiles still own the road. But electric vehicles have already begun to show their promise. Under the stop-and-go, short-haul conditions of most urban fleet driving, one of the most popular gasoline-powered vans on the road today gets about 10 miles per gallon, consuming approximately 14,400 Btu of primary energy per mile. The electric G-Van, even though it represents an early stage in the development of electric vehicles, already offers a fuel efficiency of 1 mile per kWh, or only 10,800 Btu per mile. Chrysler's gasoline-powered minivan currently gets 16 miles a gallon, using 9000 Btu per mile. Its electric counterpart, the TEVan, averages 2 miles per kWh when equipped with advanced batteries and uses only 5400 Btu per mile (see case study).

Comparison of electric and gasoline-powered passenger cars is difficult, since there are no EVs in large-scale production that are designed for personal use. Improvements in both types of vehicle are likely. Certainly gasoline-powered cars have the potential of achieving greater energy efficiency than many now offer, and it is possible that legislation will set higher minimum mileage standards. But rapid advances in batteries and overall vehicle design are just as likely to improve the efficiency and range of electric vehicles dramatically. So far, EV designs have been based almost entirely on modifications of existing conventional cars. General Motors' electric Impact—admittedly a "concept" car—is the first EV to be specially designed from the ground up. It already boasts some impressive capabilities, being able to travel 120 miles on an 8-hour charge at a cost of little more than that of a gallon of gas.

Public policies have begun to take into account the environmental advantages of electric transportation. With an estimated 60% of the air pollution in Los Angeles blamed on petroleum-burning transportation, the California Air Resources Board has mandated that by 1998, 2% of all cars and light trucks sold in the state —20,000 cars a year—must be powered by electricity. Five years later, the same regulations will require that 10% of all new cars sold, or 100,000 a year, run on electricity.

Carbon dioxide, as it relates to concerns about possible global climate change, is another environmental concern that is fast becoming a public policy issue. And as with other combustion products, the less fossil fuel the world burns, the less CO_2 will be released into the atmosphere. There is growing evidence that the resource efficiencies offered by the wider use of electricity could play an important role in this issue. Even using conservative estimates of potential market penetration, studies suggest that eight key electric technologies available today could reduce CO_2 emissions by 38 million tons by the year 2000 and 189 million tons by 2010. If electrification meets estimates of its highest potential, CO_2 emissions could be reduced by as much as 53 million tons at the end of the century and 220 million tons in 2010.

Many industrial-scale electric technologies offer inherent advantages that will help mitigate other potential environmental problems at the point of use. Electric infrared paint curing, for example, provides more than just a smoother, shinier, more durable automobile finish; because it eliminates the need for gas-fired hot air, the new technology also eases the problem of volatile organic compounds that "flash off" from solvent-based paints during conventional gas-powered curing. Direct-current plasma arc furnace techniques used in metals fabrication promise to provide a method of recovering valuable aluminum typically lost during resmelting—saving an estimated 700 million kWh per year even as it provides an easy way to separate out potentially hazardous heavy metals for disposal. By reducing the amount of coke required in steelmaking, electricity-based plasma torches have already been shown to reduce emissions associated with its use.

Meanwhile, innovative electricity-based technologies are proving their ability to directly control emissions and treat environmental waste products. Freeze concentration, for instance, shows promise as a way to treat wastewater, and electroacoustic methods are being investigated as a means of increasing the removal of water from waste sludge. Electron beam irradiation is being demonstrated as a way of disinfecting both municipal wastewater and medical wastes. And an innovative process combining ultraviolet radiation and ozonation has been developed that can destroy organic pollutants in groundwater without creating harmful by-products. In solid-waste beneficiation, an infrared-heated fluidized-bed sand reclaimer under development may soon allow metal-casting foundries to reuse the millions of tons of sand that would otherwise be discarded in landfills each year.

From small steps to great leaps

Electric vehicles, electric heat pumps, and plasma torches represent incremental improvements in traditional ways of doing things. Sometimes, however, innovative technologies come along that completely alter the way work is performed, leading to dramatic leaps in energy efficiency.

Information technology provides a case in point. Not long ago, the speed of air travel determined how long it would take—and how much energy would be required—to send a document from San Francisco to New York. Today, that same document can be sent instantaneously in a radically different way, via electronic facsimile, or fax. Recent studies have shown that fax machines use only one-seventh to one-half the energy required to send a document via overnight delivery services. That means the energy derived from a single barrel of oil can be used to send and deliver more than 175,000 pages by fax, compared with roughly 25,000 pages by courier.

Information technology has also made telecommuting a reality—an alternative to traditional commuting that would have been unimaginable 50 years ago. In 1990, a Congressional Research Service report estimated that telecommuting could save 95 billion barrels of oil a year in direct fuel savings and, by relieving traffic congestion, an additional 3 billion in indirect fuel savings. Teleconferencing, the same report noted, could save the nation the equivalent of 7.9 million barrels of oil a year.

No doubt the wider use of such technological advances will increase electricity use. EPRI has estimated that by 2000, information technologies alone could increase demand by 80,000 GWh; the increase could be as much as 95,000 GWh by 2010. But as the application of beneficial electric end uses expands, primary energy use will fall. Estimates suggest that information technologies alone could yield net energy savings of as much as 1.6 quads by 2000 and between 2 and 4 quads by 2010.

The wide range of such a prediction indicates the uncertainties with which any analysis of primary energy savings must wrestle. If it is difficult to predict the market penetration of new technologies, it is even harder to anticipate the technological advances that could dramatically improve efficiencies or provide radically new ways of performing work. Who, 50 years ago, could have foreseen the computer revolution? The advent of the laser? The development of superconducting materials? No doubt revolutionary new technologies will expand the use of electricity in ways that are impossible to predict today.

Still, it's tempting to wonder how much primary energy could be saved by the widespread application of advanced electric technologies. Even conservative estimates suggest the enormous potential. EPRI studies indicate that electric technologies already available today, including information technology, could reduce primary energy use by as much as 3 quads by the end of the century and 7 quads by the year 2010.

"Estimates like these, as we look toward the future, should play a key role in shaping the way we think about electricity and electrification," says EPRI's Clark Gellings. "It's far too simplistic to lump all energy use together and see it all simply as part of the problem. The evidence from the past 60 years—and from analyses of future trends—tells us that the widening use of beneficial electrification can help us maintain or enhance the quality of life even as we reduce our consumption of primary energy. Far from being part of the problem, electrification is a crucial part of any solution to the challenges of energy use." ■

Background information for this article was provided by Clark Gellings and Phil Hanser of the Customer Systems Division.

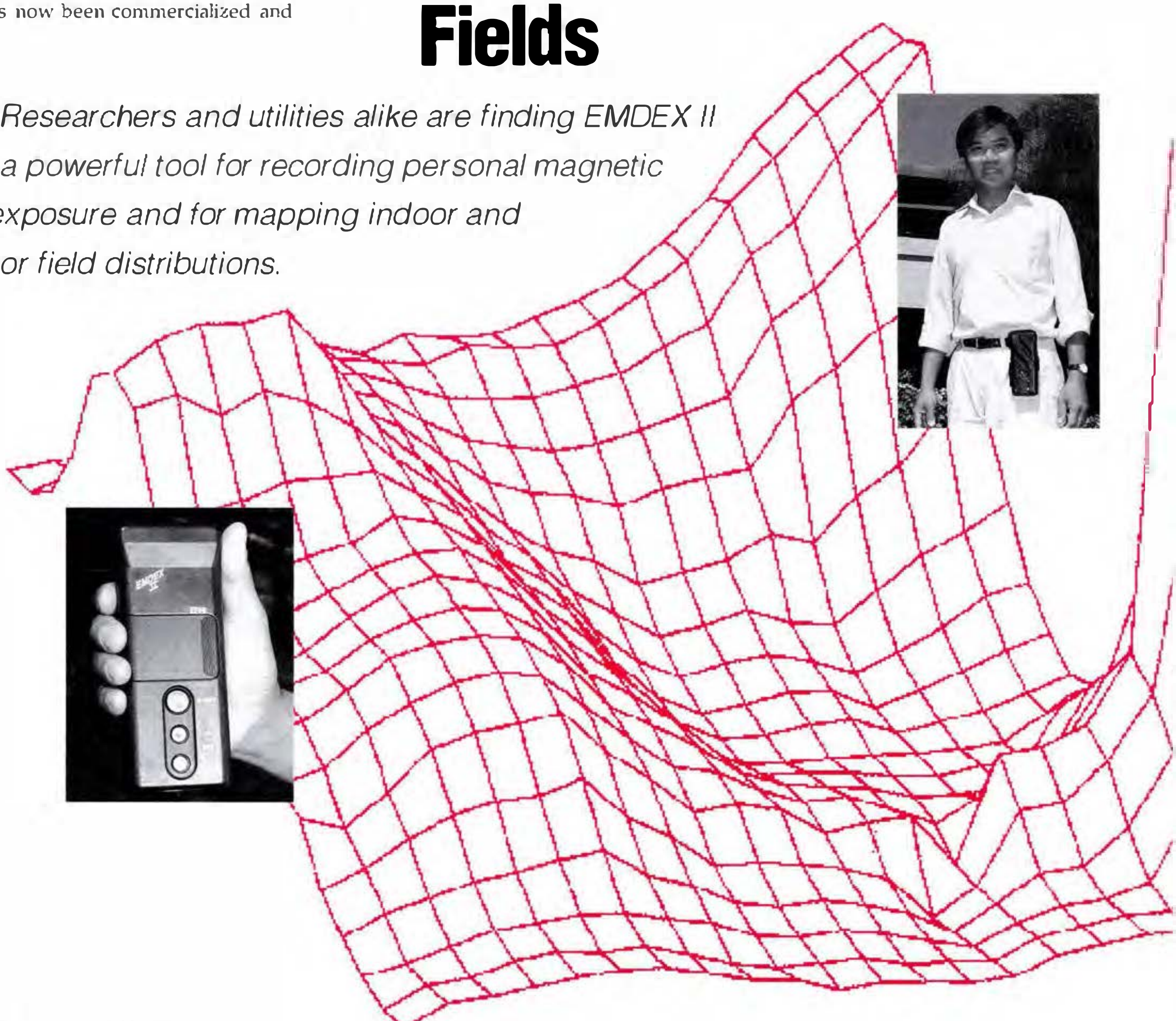
by John Douglas

Taking the Measure of Magnetic Fields

Researchers and utilities alike are finding EMDEX II to be a powerful tool for recording personal magnetic field exposure and for mapping indoor and outdoor field distributions.

ONE OF THE MOST DIFFICULT ASPECTS of research aimed at determining whether exposure to magnetic fields can cause health problems has been measuring the exposure itself. The epidemiological studies that first raised questions about potential health effects, for example, did not include actual field measurements but instead used "wire codes"—qualitative descriptions of utility lines near residences—as an approximate indicator of exposure. In order to improve researchers' capabilities to measure exposure to power-frequency magnetic fields directly, EPRI sponsored the development of a small, highly portable instrument that would sample and record field levels at specified time intervals. The EMDEX II, an improved version of the original instrument, has now been commercialized and is proving to be highly popular with utilities as well as researchers.

Assessing human exposure to magnetic fields is complicated by several factors. People cannot ordinarily detect the presence of a field. Power-frequency fields are so ubiquitous that identifying an unexposed control group may be impossible. Defining suitable exposure surrogates—such as wire code classifications—is difficult because the relative importance of various field sources is not well understood. And the intensity of fields to which average people are exposed changes constantly as they move about their homes and workplaces.



"The EMDEX family of instruments has provided us with an unprecedented ability to measure a person's exposure to fields as he or she goes about daily activities," says Stan Sussman, program manager for EMF health effects research in EPRI's Environment Division. "EMDEX II can easily be worn on a belt, and the next version, EMDEX Lite, will fit in a shirt pocket. A way to use the instrument for mapping field distributions indoors or outdoors has also been developed. Being able to make such measurements easily and accurately will greatly improve our ability to determine whether exposure to magnetic fields is actually related to health problems, and under what specific circumstances."

Fields in time and space

On the most obvious technical level, EMDEX II is a state-of-the-art example of computer and sensor miniaturization. Inside a unit about the size of a Walkman, the instrument packs equipment capable of measuring magnetic fields from 0.1 milligauss to 3.0 gauss, a computer that analyzes and stores the raw data, and an 8-character liquid crystal display. The computer itself features built-in software and 156-kilobyte (RAM) data storage. Power is supplied by a 9-volt battery. Compared with the previous version, EMDEX II has about 25% less weight and half the volume and does not have to be started via connection to a desktop computer.

By itself, EMDEX II can be used either for quick surveys, in which magnetic field data are displayed but not recorded, or for time-dependent sampling. In the latter mode, a user chooses a sampling rate between 1.5 and 327 seconds, and the instrument automatically records exposure levels at the appropriate times. In addition, the user can push a button labeled "Event" to indicate when he or she changes location—leaves the office to go home, for example—so that the exposure record can be compared against a log of event sites. Also, by plugging an external sensor into the EMDEX II unit, exposure to electric fields can be measured.

When used with the LINDA measurement wheel system, EMDEX II can conveniently survey magnetic field patterns across designated areas and generate three-dimensional plots of field strength.

One important new feature of EMDEX II is its ability to measure magnetic fields in two bandwidths: 40–1000 Hz and 100–1000 Hz. The significance of this capability is that it allows researchers to determine what part of exposure is being caused by the fundamental 60-Hz frequency of the line power and what fraction results from higher-frequency harmonics. Such harmonics are created by the electronic controls that are increasingly being used in a variety of devices—for example, in light dimmers for residences and in adjustable-speed-drive motors for industry.

The EMDEX II can also be used in conjunction with a measurement wheel to map field strengths along a given path. Known as the LINDA (Linear Data Acquisition) system, this hand-manipulated measurement wheel sends a signal to the EMDEX II denoting the distance traveled. The EMDEX II unit, which is mounted on the LINDA support structure, makes field measurements each time it receives a signal from the wheel. A magnetic compass is used to keep track of angular changes in the motion of LINDA as it crisscrosses an area. Special software included with the LINDA system converts these spatially dependent measurements into a three-dimensional plot of magnetic field patterns. Another EPRI-developed product, Field Star 1000, is also commercially available for making magnetic field surveys.

Research and customer service

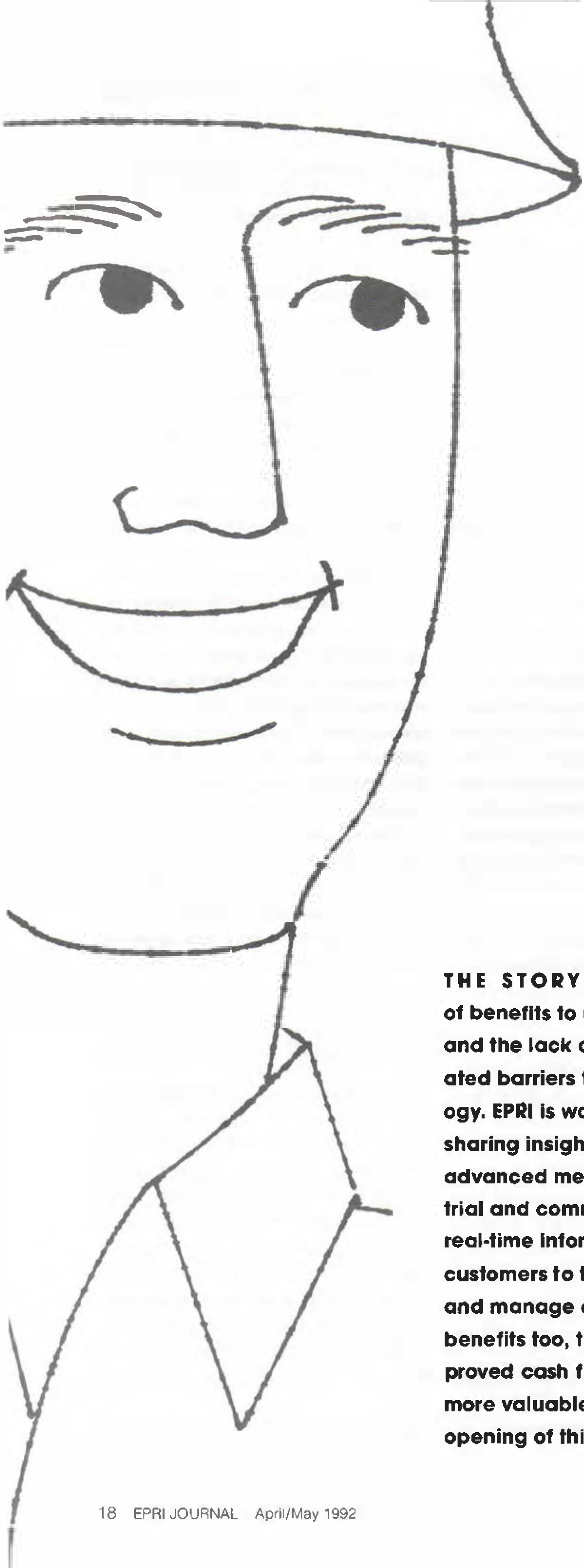
Because of their unique combination of abilities and small size, the EMDEX instruments have effectively become the standard choice for field measurements related to research on magnetic field exposure, according to Sussman. Already, members of the EMDEX family have been used in landmark health research, such as the University of Southern California study of childhood leukemia and the Johns Hopkins University study of leukemia among telephone workers.

EMDEX units were also used at 55 participating electric utility sites to determine occupational exposure to fields in various utility environments. In this study, volunteers wearing EMDEX units kept logbooks of their activities at home and at work. The study produced a total of 50,000 hours of exposure data, 70% of which came from the workplace. EMDEX II is also being used in a study of residential exposures, which is focusing on relationships between wire codes, magnetic field measurements in the home, and personal exposure data.

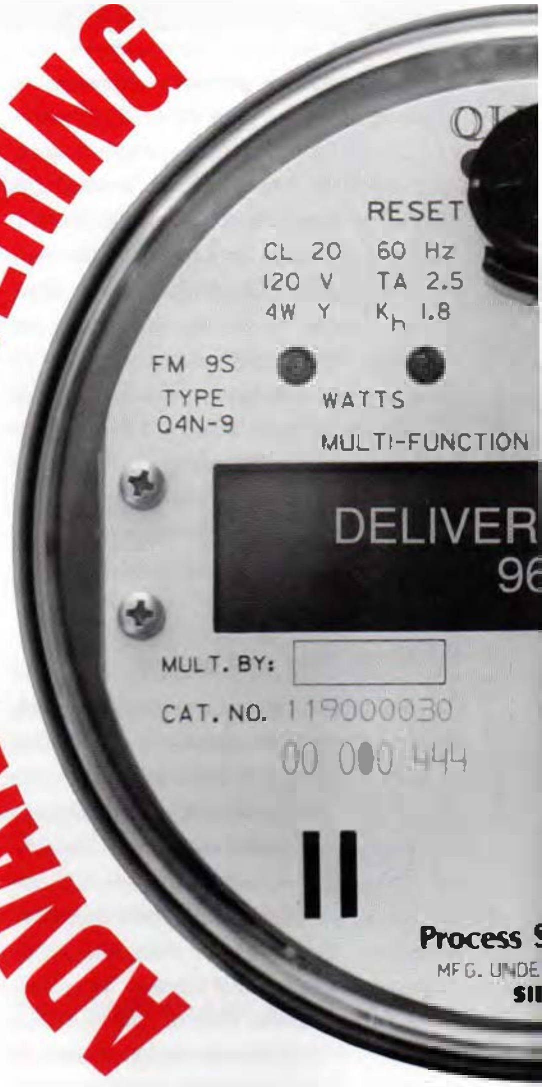
In addition to research, EMDEX has found a growing market for more routine uses by utilities in some dozen countries. So far, more than 400 EMDEX II units have been sold to more than 100 users. Utilities are employing the instruments both for in-house field surveys and for customer service, responding to requests for field measurements in the home.

Florida Power Corporation is one of the utilities that have made extensive use of EMDEX instruments. "We originally bought 10 units for our program to measure fields in customers' homes on request," says Harry Brown, principal engineer at FPC. "The program has been very pleasing to customers, because they get to see how fast field levels fall off with distance away from appliances or power lines. In addition, I bought an EMDEX II to use with LINDA to make measurements under transmission lines, which helps demonstrate compliance with Florida's rule on field limits along rights-of-way. Closer to home, it is helping us solve a problem that developed in the company's office building when fields from transformers on one floor began to interfere with computer monitors on another floor. EMDEX is a valuable asset to Florida Power." ■

Background information for this article was provided by Stanley Sussman of the Environment Division.

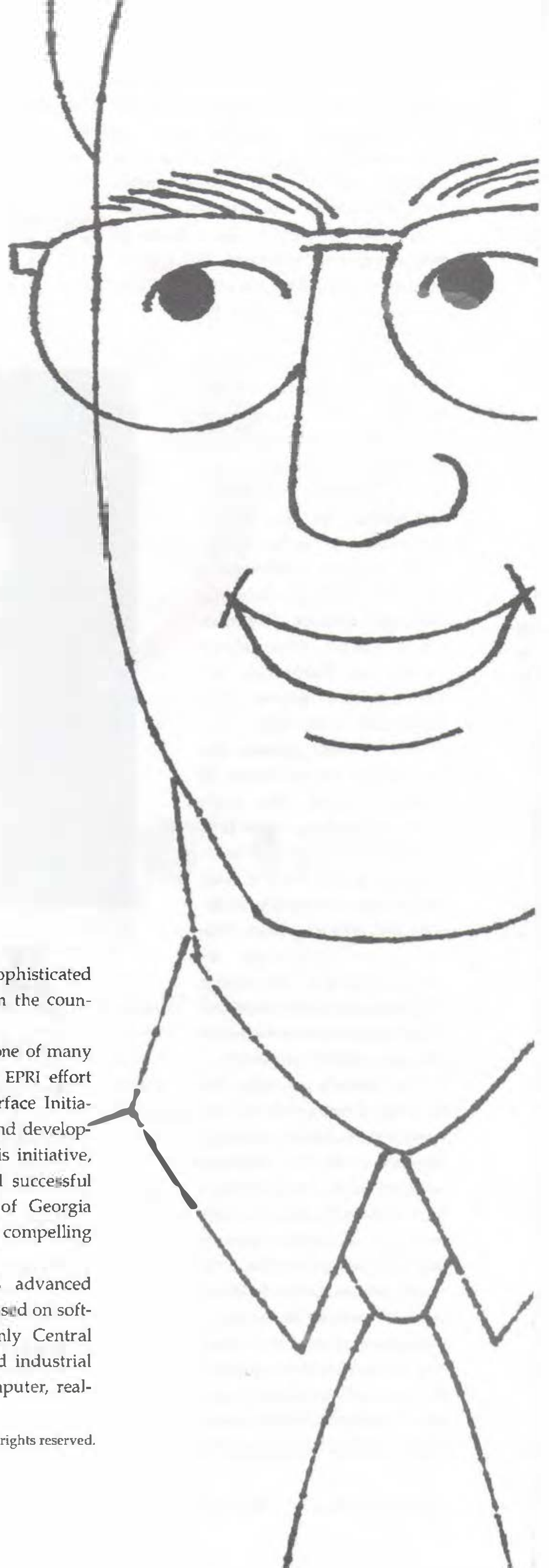


ADVANCED METERING



THE STORY IN BRIEF Advanced metering provides a number of benefits to utilities and their customers, but factors such as cost and the lack of standards to govern equipment design have created barriers to the widespread implementation of the technology. EPRI is working to help level some of these barriers, in part by sharing insights from successful case studies like Georgia Power's advanced metering program. Through this program, large industrial and commercial customers use personal computers to access real-time information from their electric meters. This allows the customers to take full advantage of cheaper rates and to monitor and manage energy consumption at multiple sites. Georgia Power benefits too, through reduced billing and service expenses, improved cash flow, and simplified accounting procedures. Even more valuable is the enhanced customer trust that comes with the opening of this sophisticated communication channel.

BENEFITS ON BOTH SIDES



by Marcy Timberman

SIX YEARS AGO, COLONIAL PIPELINE COMPANY APPROACHED GEORGIA POWER COMPANY with a nagging problem: the utility's billing cycles, which had different start and end dates in different locations, were not synchronized with Colonial's monthly pumping cycles. As a result, Colonial had difficulty managing the cost of the electricity required to move petroleum products through its vast pipeline network, part of which spans the state of Georgia. With energy costs representing 40% of the company's annual operating expenses, this was no small concern.

Colonial asked Georgia Power for common-cycle billing for its operations in the utility's service territory. As it turned out, this request was the catalyst for the establishment of one of the most sophisticated advanced metering systems in the country today.

Advanced metering is just one of many facets of a recently launched EPRI effort known as the Customer Interface Initiative. As part of the research and development planning process for this initiative, the Institute analyzed several successful utility projects. The efforts of Georgia Power represent an especially compelling case study.

Through Georgia Power's advanced metering program, which is based on software called ROCS* (Read-Only Central Station), large commercial and industrial customers can access, by computer, real-

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time information from their electric meters. With these data, they can take advantage of cheaper rates while monitoring and managing energy consumption at multiple sites. Georgia Power benefits from the system too, through reduced billing and service expenses and simplified accounting procedures. But perhaps even more significant, the utility has won improved customer trust by opening up a valued communication link.

Advanced metering systems like ROCS, which uses state-of-the-art technology to provide customers with the tools they need to read their own meters and analyze the data, are not yet widely used in the electric utility industry. Although a number of utilities (including Northeast Utilities, Baltimore Gas & Electric, Consolidated Edison, and Pacific Gas and Electric) have systems with capabilities similar to those of ROCS, these systems do not provide the full array of customer benefits that ROCS does. Feedback at a recent EPRI workshop indicated that barriers such as cost, lack of standards to govern equipment design and communication protocols, and risk factors involved in using the developing technology have blocked the widespread implementation of advanced metering systems.

EPRI intends to help its members overcome these barriers. The workshop brought together utilities, metering vendors, and electric power regulators to examine the barriers and to identify research and development efforts EPRI could undertake to facilitate wider acceptance of advanced metering and customer interface technologies. In addition, the Institute's Customer Interface Initiative includes a number of advanced metering projects. Part of EPRI's overall strategy is to illustrate the benefits of this technology by sharing information and insights from successful case studies like Georgia Power's ROCS program.

"All we were really looking for was exact calendar monthly billing. But we ended up with so much more than that."

Mike Richeson

Power Optimization Coordinator
Colonial Pipeline Company

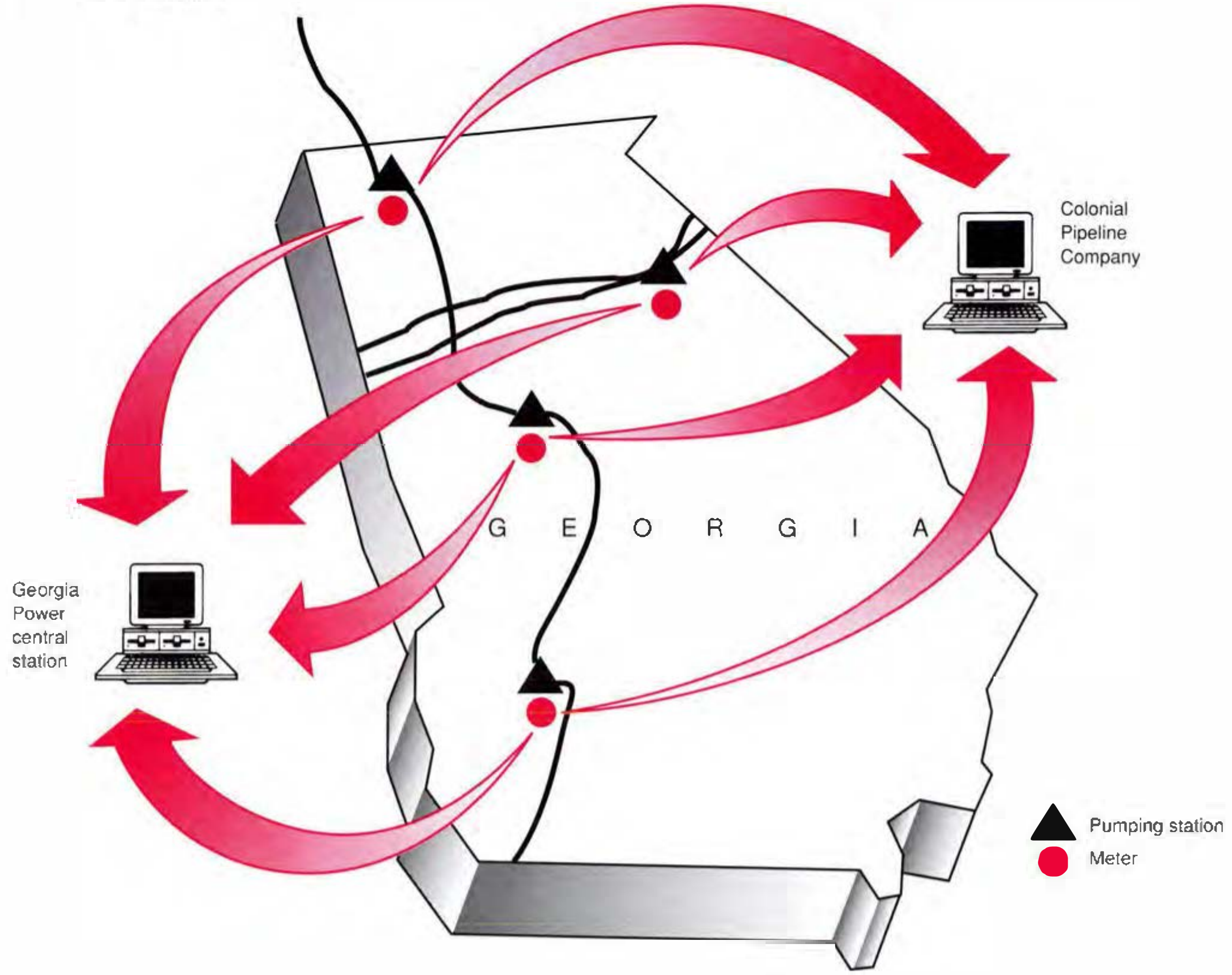
How ROCS came to be

Moving petroleum products through a distribution network that spans 14 states and two time zones is a complex task requiring a lot of electricity. In 1990 alone, the Colonial Pipeline Company consumed 1.8 billion kWh at a cost of nearly $94 million. Colonial's system, which stretches from Houston, Texas, to the New York harbor, includes 5200 miles of pipeline and 73 mainline booster stations. One of the world's greatest-volume operators of pipelines for refined petroleum products, Colonial is among Georgia Power's largest industrial customers.

But back in 1986 Colonial wanted more from its utility. Not only were its pumping cycles not synchronized with the utility's billing cycles, but the company never knew over what time period the utility calculated its demand charges—monthly fees based on the highest electricity load demanded by the company. Since Colonial's electricity bill is calculated on the basis of both actual energy consumption and demand charges, the time at which the company's meters are read is critical. If Colonial knew when in a given month its highest demand charges would be calculated, it could optimize its pumping schedule to ship more barrels of petroleum products for each energy dollar spent. For instance, if a relatively high-demand shipment ended in a low-demand month, the company could defer the shipment and defray the increased cost to the next month's bill.

Colonial wanted all its meters to be read simultaneously, at midnight on the last day of each month. This presented a challenge for the utility: because many of Colonial's stations are in remote areas, simultaneous on-site reading by human meter readers was not possible. Coincidentally, though, Georgia Power was in

How ROCS Works Georgia Power's ROCS program provides participating customers with access to real-time information from their electric meters. At Colonial Pipeline Company, load profile recorders collect data from meters at each of the company's pumping stations. Colonial can access this information via a modem and telephone line and download the data to its personal computers for analysis.



the process of evaluating the use of remote metering systems for other purposes, and it appeared that such a system might satisfy Colonial's needs as well.

Georgia Power agreed to provide the simultaneous meter reading service to Colonial and established a study team to decide how to accommodate the request. Representatives from the utility's metering and marketing departments, from Colonial, and from HydeCo, a local consulting and engineering firm that was involved in the utility's remote metering evaluations, met to determine the best way to provide common-cycle billing.

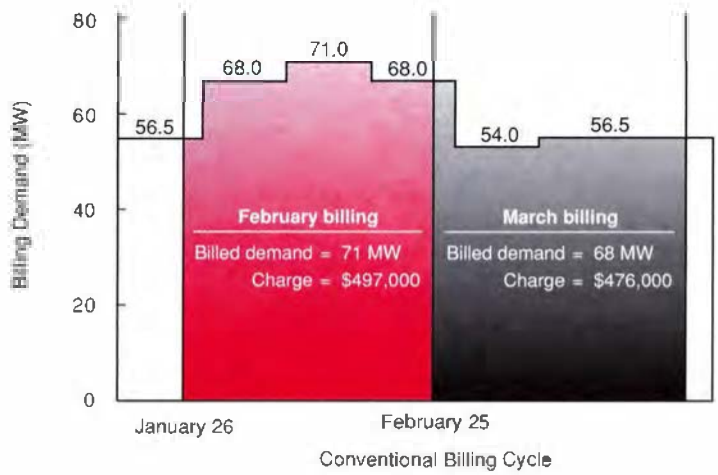
Drawing from the findings of Georgia Power's previous evaluations, the team recommended the implementation of a metering system that could be read remotely. Such technology would certainly meet Colonial's demand by enabling the utility to retrieve data simultaneously from multiple locations. Better yet, as the studies had demonstrated, remote metering systems produced readings that were more accurate and reliable than those taken manually from the existing cartridge recorders. Also, remote systems could regularly monitor meter performance, so that any failures could be readily detected. As an added benefit, the recorders with remote capabilities were about 25% cheaper than cartridge recorders.

Once the team agreed to go with a remote metering system, Georgia Power had to determine the communication medium. Telephone-based systems had already been field-tested and used successfully in the industry. Making this alternative even more attractive, Colonial offered to provide the telephone line that would allow it to access information from the meter. This simplified Georgia Power's installation requirements and enabled the utility to avoid monthly charges for telephone service on the line.

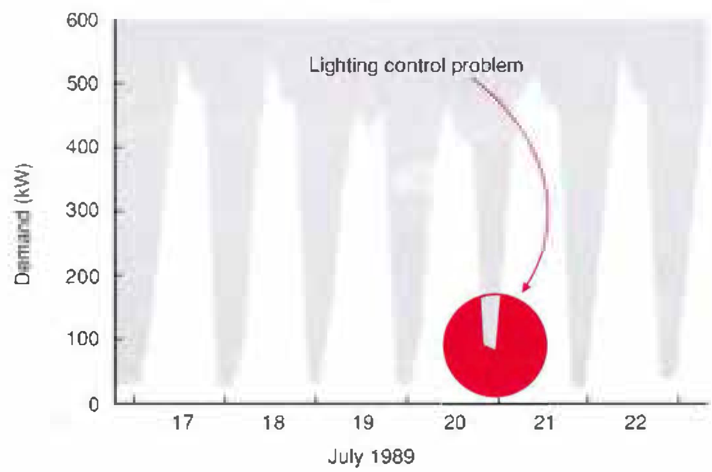
The ROCS system went through two years of development, including a year of testing at Colonial. After that, Georgia Power offered ROCS to a targeted group of large commercial and industrial customers. Each customer provided its own personal computer and a telephone line to connect the PC to the meter. Enthusiastic

Key Benefits of the ROCS Program

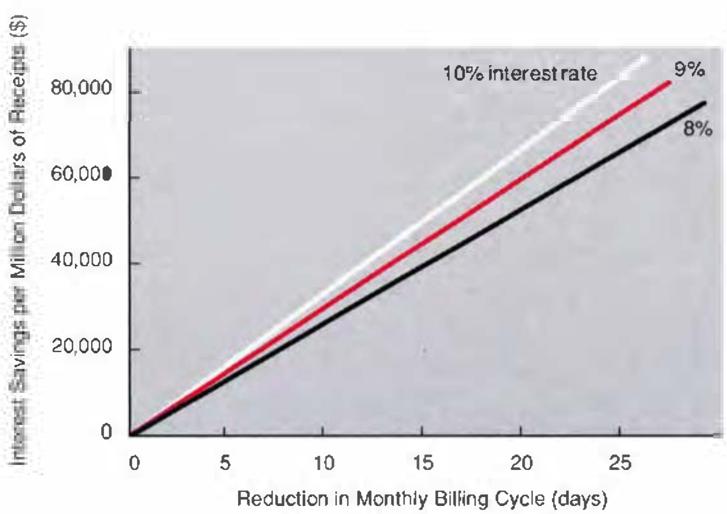
Energy Use Management With common-cycle billing, customers can better manage high-energy-use activities. This diagram shows how the previously varied billing cycles for Colonial Pipeline's pumping stations resulted in a demand charge for the March bill that was based on 68 MW, even though this high demand lasted only briefly during the billing period. Coordinated billing cycles provided by common-cycle billing could have alerted Colonial to this situation, allowing the company to reschedule its petroleum shipments to keep the 68-MW demand within February's billing cycle. This change would have saved the company $81,000.



Real-Time Energy Data By providing real-time energy data, the ROCS program allows customers to pinpoint equipment and operating problems readily. This graph shows how a failed relay at one Rich's department store caused the parking lot lights to stay on. With access to this information, Rich's staff members were able to detect and repair the problem swiftly.



Cash Flow ROCS customers' early payment of energy bills allows Georgia Power to avoid interest charged on money borrowed to cover the revenue lags of conventional collection floats. A 25-day reduction in collection float, assuming an interest rate of 8%, translates into potential savings of about $66,000 for every $1 million billed in a given month.



about the program's advantages, they also agreed to pay their bills on an accelerated schedule, within three days of receipt. Georgia Power provided the remote metering system, the required software, and the technical support to complete the connection.

Today 43 customers are involved in the ROCS program, including firms producing wood products, textiles, industrial fibers, pulp and paper, poultry, copper cable, fiber optics, and frozen foods. Several hospitals, a major university, a military base, two department store chains, and a regional distribution center also participate. The success of the program has prompted other utilities to follow Georgia Power's lead. In 1989 Mississippi Power and Gulf States Utilities, among others, allowed Colonial Pipeline to access its meters via Georgia Power's ROCS program. And last year, Baltimore Gas & Electric and Public Service Electric & Gas also offered the company common-cycle billing.

Making the connection

To query its meters through the ROCS program, a customer needs an IBM-compatible PC, a video display monitor, a modem, and the ROCS software developed by HydeCo. Georgia Power is hooked up to the meters through a similar system designed for high-volume operation. ROCS allows users to examine their data privately at any time, without involving the utility. Security is maintained through multiple password protection, hardware security keys, and the limited read-only functions of ROCS, which ensure the operating integrity of the recorder.

Once gathered from the meter, information is stored in the ROCS database, allowing both utilities and their customers access to the same data. Customers can monitor and audit daily energy use at multiple locations and even predict their energy bills. Among other advantages, these capabilities can help customers plan their production schedules and evaluate demand-side management alternatives.

The benefits to the utility are equally significant. Thanks to the ROCS system's remote diagnostic capabilities, Georgia Power not only recaptures revenues previously lost through underestimated bills but also reduces maintenance expenses. In addition, the utility benefits from its customers' accelerated payments. The early remittance allows Georgia Power to avoid the interest charges on money it has had to borrow to cover revenue lags ranging from 28 to 35 days. Such lags, or collection float, typically tie up 8–10% of the company's annual revenues. This means that the utility has the potential to reduce interest expenses by approximately $66,000 per $1 million billed per month. Improved investment and cash forecasting practices, reduced paperwork, and more efficient operation are just some of the other advantages.

Further benefits of the ROCS program are just starting to emerge at Georgia Power. The system's remote meter reading capabilities could enable customers to take advantage of time-of-use programs, which offer reduced rates based on when customers use power. Also, the utility is currently replacing its existing paper billing process with an Electronic Data Interchange (EDI) system that promises to eliminate several manual processing steps to speed up the billing and collection cycle, eliminate paperwork and mailing costs, and reduce customers' paperwork and handling costs. The same hardware and software that service ROCS can also service EDI transactions.

First associated with inventory and just-in-time manufacturing processes, EDI can be applied to many activities, including inquiries, acknowledgments, invoices, payments, and financial reporting. Many view

"Customers don't understand their rates today. They need tools to better understand what we provide."

Tim Leigh

New Business Development
Southern Company Services

it as the business communication tool of the future. EDI is supported by utility networking specifications recently developed by EPRI. Key components in EPRI's Customer Interface Initiative, EDI and the supporting specifications enable utilities and their customers to share information more effectively.

According to Charles Eldred, manager of Georgia Power's cash planning and operations, ROCS provides the perfect means to convert Georgia Power to complete EDI format. "The trend," he says, "is to make it smooth all the way through. We want to close the business loop and develop a true electronic interface between Georgia Power and its customers."

Colonial is the first customer to use this electronic pipeline, remitting payment each month directly to Georgia Power through EDI. Until the system is fully implemented, the utility is using fax transmission to bill other ROCS customers.

A customer's perspective

John Shaw, properties manager of Rich's Department Stores, is one of the ROCS program's most enthusiastic participants. With headquarters in Atlanta, Rich's has 24 stores in Georgia and nearby states. The department store chain has been involved in energy management for almost 20 years, and that effort has involved much more than simply turning off lights.

Since 1973, the Rich's facilities have reduced their energy use per square foot by over 44%. That adds up to approximately 623 million kWh and $33,854,691 over the past two decades. Before the ROCS program was established, energy management experts at Rich's plotted electricity use information on graph paper by hand—and information from the utility wasn't always easy to come by. "When Georgia Power asked us if we would like to be involved in this project, I thought I was going to kiss them," says Shaw. "I had no idea the system was available."

A store in Atlanta was the first Rich's facility to participate, joining the program in 1989. "It's been a real success story," says Shaw. "The information they've been able to furnish me is fantastic." Shaw likes having direct access to Georgia Power's meter and being able to determine the exact demand for which his company will be billed. This information helps him audit and verify Rich's power bills and better manage the chain's energy costs. The now-synchronized billing cycles make it easy to compare energy use at the stores' various locations.

In Shaw's mind, though, the best outcome of ROCS is that other utilities are following suit. The Rich's chain now gets the same kind of service from Alabama Power and South Carolina Electric & Gas, among others. "It's an exciting relationship, when utilities are trying to help you cut your power bills," says Shaw. "This is real-time, on-line energy management. If we participate in programs like these, we save on consumption of power, reduce the number of power plants to be built, and contribute to a better environment for everyone. And my calculator doesn't go high enough to show how much that's worth."

"If we participate in programs like these, we save on consumption of power . . . and contribute to a better environment for everyone. And my calculator doesn't go high enough to show how much that's worth."

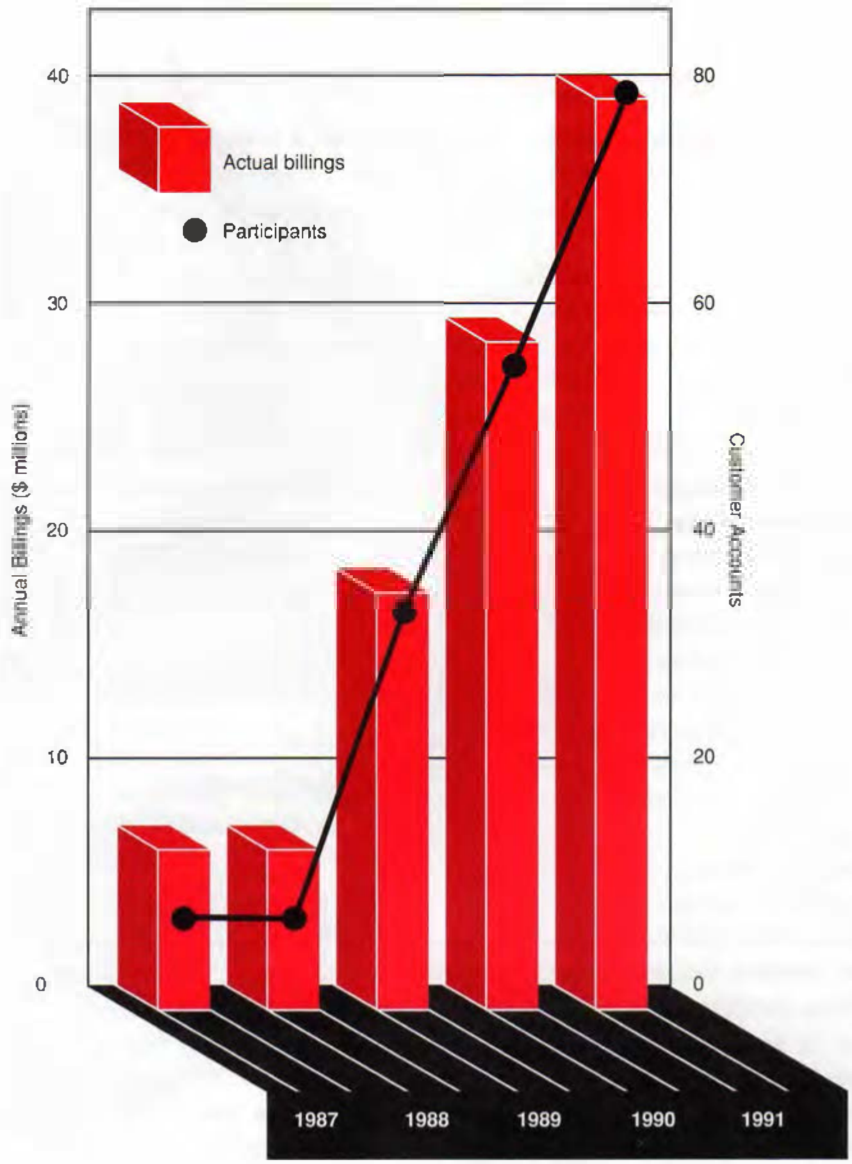
John Shaw

Properties Manager
Rich's Department Stores

Customer relations

Georgia Power is pleased with the value that ROCS has added to its customer relations. Initially, by focusing on Colonial Pipeline's need, the utility was able to provide the company with exactly what it had asked for—common-cycle billing. Converting this experience to a formal product useful to other customers presented a series of technical challenges, but at each stage of the ROCS program's development, the utility tailored its existing technologies to fit the precise needs of the customer.

Through the process of implementing ROCS, Georgia Power has developed strong customer relations based on



Program Participation Over the five years of its existence, the ROCS program has grown to include more than 40 large industrial and commercial customers, representing nearly 80 individual accounts. Georgia Power has identified nearly 1200 more prospective participants.

trust and confidence. The program has provided a valuable new customer service while adding significantly to the utility's competitive edge. And with 1200 additional prospective ROCS participants, the value of the program keeps going up.

EPRI is working hard to make advanced metering technology more accessible to other utilities. Having identified the problems that block the widespread implementation of this technology, the Institute launched the Customer Interface Initiative to help overcome them. Through the initiative, the Customer Systems and Electrical Systems divisions are working together to provide a unified approach to demand-side management and distribution automation implementation.

In the first phase of the effort, EPRI has done the following:

- Demonstrated ROCS and other integration and automation technologies at national conferences and other industry events
- Made progress toward commercializing the Customer Communications Gateway (CCG), an electronic technology that will allow utilities and their customers to tap the full potential of services and opportunities offered by advanced metering
- Initiated—in a project jointly funded with Northern States Power—a forum on standards through which utilities and vendors will meet regularly to achieve the interoperation of different customer interface technologies
- Documented—in a report being produced by Levy Associates—utility case studies to help assess the business value of advanced metering
- Begun a demonstration that uses price-responding control strategies based on the CCG concept to integrate real-time pricing into the energy management system of a commercial building

Future work under the Customer Interface Initiative will include efforts to explore the use of fiber optics for automation and communications, address regulatory barriers to the implementation of advanced metering and communications systems, and help develop a consistent methodology for evaluating the benefits of both distribution automation and demand-side management.

Georgia Power's ROCS program is widely regarded as a model of how beneficial advanced metering systems can be. As Clark Gellings, EPRI's vice president for customer systems, points out, "ROCS is a prime example of a utility offering a service completely oriented to a customer's need, yet achieving substantial utility benefit." EPRI is working to spread the word about ROCS and other successful advanced metering programs. By encouraging other utilities and assisting them in the development of similar customer interface systems, EPRI aims to help utilities and their customers become closer allies in energy management. ■

Background information for this article was provided by Larry Carmichael and Wade Malcolm, Customer Systems Division.

TECH TRANSFER NEWS

Bundled Systems Offer Software Convenience

In order to streamline the transfer of EPRI software, member utilities are being offered the option of buying or leasing computer hardware with selected EPRI software packages already installed. The first such "bundled" computer system is currently available from the Generation and Storage Division. Similar systems are expected shortly from other Institute divisions, working in collaboration with the Delivery Systems Office.

Bundling provides several advantages to users of EPRI software. The systems are ready for immediate use upon delivery, preconfigured for a specific application. A utility does not have to search for a suitable computer to run the software or bother with the complexities of software installation. Delays associated with hardware-software incompatibility are eliminated. The computer itself is a powerful (486/33-MHz) PC clone, sized to accommodate a utility's own programs and databases in addition to the EPRI software and offered at below market price.

Two hardware configurations are available. The basic computer, Model 101, has a 16-MB memory and a 337-MB hard drive, with a super-VGA monitor and a built-in modem for access to EPRINET and EPRI's remote maintenance system, RemoteLink. Model 102 is additionally equipped with CD-ROM to handle multimedia optical disks.

The Generation and Storage Division bundled system comes with one of three software packages installed. These packages are designed for power plant applications and relate to either coal or oil/gas power generation. The number of codes per package currently ranges from 10 to 18, depending on the package chosen. Additional optical disk products, such as the PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) Workstation, are available for use on Model 102.

Each bundled computer system comes with a variety of support services. As part of a pilot program, EPRI provides a one-day set-up and familiarization program on-site, including a demonstration of each installed program. Maintenance is provided through EPRI's Customer Assistance Center, which can dial into the computer and use the included RemoteLink software to analyze problems. Also, utilities that purchase or lease a bundled system are automatically eligible to take advantage of group training sessions or users groups associated with the included software.

"Bundled systems can help overcome some of the last front-end barriers to wider utility use of EPRI software by providing direct access to our products through a turnkey-type system," says Greg Lamb, manager of the Generation and Storage Division's electronic tech transfer operations. "Also, since we anticipate that future software products will require the type of powerful computer included in these systems, we're helping establish a solid hardware base for new programs designed to these specifications. Indeed, bundled computer systems may become the routine way of delivering products from various EPRI divisions in a standardized format." ■ *EPRI Contacts: Greg Lamb, (415) 855-2449, and Jane Choi, Delivery Systems Office, (415) 855-2377*

Bundled system

Utilities Test SA•VANT for Turbine Troubleshooting

Five utilities are gaining firsthand insight into the potential—as well as testing the limits—of current prototypes of EPRI's SA•VANT portable expert system. They're providing important feedback to hardware and software developers in the evolution of an interactive, multimedia intelligent advisor for gas turbine plant operators and maintenance technicians. SA•VANT gives users technical data and images on twin computer screens from a hard disk integrated in a field-portable system that includes a keyboard and a modem. The first software developed for this advanced platform for hands-on O&M assistance is an intelligent advisor for troubleshooting a startup failure. Only the first of many possible SA•VANT programs, the startup advisor could prove to be of growing value as utilities increasingly turn to combustion turbines for meeting peak demand for electricity.

Personnel at two utility plants—Carolina Power & Light's Darlington County station and Jersey Central Power & Light's Sayreville station—are evaluating SA•VANT and a version of the startup advisor for a popular model of Westinghouse turbine. Meanwhile, engineers and technicians at Public Service Electric & Gas's Essex station, Consolidated Edison's Ravenswood plant, and Northeast Utilities' Cos Cob station are using software specific for a widely used Pratt & Whitney turbine model. EPRI's Combustion Turbine Center in Charlotte, North Carolina, is coordinating the field testing.

Informal comparisons suggest that, with SA•VANT, novices and seasoned technicians alike can troubleshoot a failure-to-start in less time. "SA•VANT gives a person who has no experience troubleshooting a unit the necessary technical support to go through a logical sequence and know that he's doing it right," says Richard Brevogel, station engineer at JCP&L. "It can ask questions and tell you what to look for. It can tell you the calibration information for specific valves on different turbine systems. Or it can show you in a diagram where the overspeed trip valve is located. If those aren't things you work with every day, it's a real help to have that kind of information available in one location."

With its potential for incorporating and combining extensive databases of operational specifications, plant drawings, and still-video images with the distilled knowledge and experience of a veteran turbine expert, SA•VANT has value not only as an on-the-job O&M tool, but also in the areas of training and simulation. Project plans call for testing an interactive tutor application at CP&L's Darlington County plant this summer.

"Especially with new people, we could use SA•VANT to show how different details about a turbine fit into the bigger picture and give them an opportunity to really understand the system before ever going out to a unit," says plant supervisor Pat Faircloth. "That's an advantage that would be worth a lot. But the other major scenario, in our view, is helping an already experienced technician quickly apply his experience in fixing a unit by providing technical data, schematics, and control set points at his fingertips."

Future generations of SA•VANT hardware are expected to be lighter weight and will perhaps incorporate hands-free, voice-command operation. Next up in software on SA•VANT is a turbine rotor balancing advisor, possibly integrating online vibration data from an operating unit; initial testing is expected to begin later this year. Researchers believe a commercial version of SA•VANT and the first software packages could be available by 1993. ■

EPRI Contact: George Quentin, (415) 855-2524

HTSC Power System Consortium Proposed

An industry working group has proposed the formation of a national consortium—tapping resources and expertise from both the public and private sectors—for the development of superconducting components for the electric power system. By building these components from so-called high-temperature superconductors (HTSCs), the consortium backers hope to leapfrog foreign competitors, whose programs are still generally focused on superconducting components that require expensive liquid helium cooling. EPRI has been a leader in this initiative by helping form the ad hoc Industry Working Group on Power Applications of High-Temperature Superconductors, which has proposed the consortium. Enabling legislation is currently being considered in Congress.

Flexible HTSC tape

A report issued by the ad hoc working group concludes that "unless both U.S. industry and government mobilize for a concerted effort in power applications of the new HTSCs, the country's prospect of a lead position in this field may be irretrievably lost." According to the report, the United States increasingly lags behind its international competitors in efforts to develop the high-current HTSCs needed for power applications. U.S. manpower devoted to HTSC development, for example, is about equal to that of China and is less than that of Japan or Europe. Progress is also hampered by lack of capital, a sluggish domestic market for electrical equipment, and a lack of coordination—both within the industrial sector and between the federal government and industry.

The proposed program would be based on vertically integrated, multidisciplinary research teams that would concentrate on specific HTSC technologies and include members from industry, government laboratories, and universities. Each team would aim at producing a demonstration prototype for HTSC technology at a precompetitive level. Such prototypes are likely to include superconducting motors, generators, transmission lines, transformers, and magnetic storage systems. ■

EPRI Contact: Thomas Schneider, (415) 855-2402

Modular Power Systems

Distributed Generation

by Daniel Rastler, Generation and Storage Division

Distributed generation has been a visionary idea for many years at EPRI. It is defined as any modular technology that can be sited throughout a utility's service area to maximize the benefits of matching the characteristics of the generator with the electricity demand and the economic and environmental characteristics of the site. Examples of distributed-generation technologies include small-scale photovoltaics, reciprocating engines, small gas turbines, fuel cells, and batteries.

In general, the benefits of distributed generation are driven by its size flexibility and its siting advantage over large central power stations. The ability to site small-scale generation close to the customer holds potential for improving the reliability of delivered service and promises new options for managing important industrial and commercial clients through tailored energy services. Also, locating small resources near or on an existing distribution substation could help defer costly transmission and distribution (T&D) upgrades; and local generation could improve the efficiency, operation, and management of the distribution system by facilitating load shifting and providing voltage and power quality support. Accounting for these benefits can provide insights as to the true cost of delivered service and can help determine whether distributed generation has potential for lowering the cost of service at the customer's meter.

EPRI is developing three technologies that could have a dramatic impact on the realization of distributed generation. These new options are fuel cells, batteries, and photovoltaics (Table 1). Though each has unique characteristics, constraints, and costs, there are important similarities: they all come in modular sizes, can be easily sited, have attractive operational features, and are environmentally superior to any of today's central station power supply options. Quantifying the value of these characteristics, referred to as the distributed benefits, holds the key to offsetting the economy-of-scale advantages that central power stations currently have over distributed generation.

Resource planning tools used by utilities are unable to accurately assess resources smaller than 100 MW and are therefore inappropriate for quantifying the value of distributed generation. Distributed resource options must be evaluated on a site-specific basis, with consideration given to specific customers, location, and distribution system constraints.

To help utility resource planners evaluate emerging distributed-generation technologies, EPRI has developed methods and a unified framework for explicitly quantifying their benefits, as well as a process for identifying high-value applications within a utility system. A 1990 study by Pacific Gas and Electric on photovoltaics in the distribution system provided a starting point for this effort.

ABSTRACT *Distributed generation—in the form of modular technologies featuring size and siting flexibility—holds many potential benefits for utilities and their customers. Interest in these emerging technologies is being spurred by recent technical advances, as well as by growing utility investments in transmission and distribution and in emissions control—areas where distributed generation could offer advantages. Traditional planning tools do not capture the benefits of distributed-generation options, however; thus EPRI has developed methods to help utilities quantify these benefits in site-specific studies.*

Case studies: fuel cells

Fuel cells are an especially promising category of distributed generation. Fuel cells currently under development have many of the features desired for modern central power stations: they are easily dispatchable, they can use a variety of fuels, and they have very high efficiencies (52–60%) and extremely low emissions.

Case studies involving six utility systems have identified high-value applications, costs, and benefits of 2-MW-class molten carbonate fuel cell power modules. These studies had the following objectives:

- To develop methods and a framework for evaluating distributed generation
- To define and quantify the potential benefits of distributed generation
- To determine whether distributed generation near the point of demand could provide a lower cost of delivered service
- To help utilities understand the implications of distributed generation
- To develop insights into important re-

quirements for emerging fuel cell power modules

A bottom-up approach was developed to define sites and applications where distributed generation may provide high value. Methods were first developed with the collaboration of the Los Angeles Department of Water & Power (LADWP). They were further tested and refined with the help of Central and South West Corporation (CSW) and Oglethorpe Power Corporation (OPC). Two cases were examined at each of CSW's four operating companies. In the OPC case study, the methodology was used to assess the cost-effectiveness not only of fuel cells but also of distributed diesels and batteries.

Because distributed generation is modular, EPRI's approach was to examine site-specific situations. In each utility study, a task force of experts established siting criteria and brainstormed high-value sites for as wide a range of applications as possible. Utility members on the task force included generation planners, T&D planners, power control and dispatch managers, fuel procurement specialists, and personnel from large customer accounts, regulatory affairs, and research and development.

In general, 2-MW molten carbonate fuel cell power modules were evaluated at four levels of application: off a primary distribution circuit, off a subtransmission system, at an existing generation station, and at large customer sites. The voltage at interconnection ranged from 4.8 to 34.5 kV. At each point of interconnection, the potential range of distributed benefits was quantified and the true cost of delivered service was estimated. The preliminary results are shown in Tables 2 and 3.

The most significant drivers of distributed benefits for fuel cells were low emissions, deferral of T&D expenditures, transmission loss savings, freed-up transmission capacity, and fuel diversity. The fuel diversity benefits stemmed from the opportunity to use inexpensive refinery off-gases, coal-seam methane gases, or shut-in natural gas at several of the sites considered.

For each site-specific application, the net cost of delivered power was calculated by subtracting the value of the fuel cell's potential distributed benefits from its gross busbar cost. To determine cost-effectiveness, the net cost of fuel cell power at the point of delivery was compared with the avoided cost of new resources and the result expressed as a benefit/cost ratio (i.e., the ratio of avoided cost to cost). For LADWP and OPC, the avoided (deferrable) resource was a large combined-cycle power plant. For CSW, the identified deferrable resources were either repowering projects,

Table 1
EMERGING DISTRIBUTED-GENERATION TECHNOLOGIES

	Batteries	Fuel Cells*	Photovoltaics
Size	500–10,000 kW	500–5000 kW	1–1000 kW
Footprint	2–4 kWh/ft²	0.44 kW/ft²	100 kW/acre
Timing of market entry	1992–2000	1997–2000	1995–2000
Cost per kW[†]	$600 (1 hour of storage), $900 (3 hours)	$1500 down to $1000	$5000 down to $2500
Fuel/energy	Off-peak electricity at incremental cost	Natural gas, liquefied petroleum gas, propane, landfill gas, shut-in gas	Solar energy

*Molten carbonate fuel cells at 52–60% electrical efficiency.
[†]For batteries, learned-out costs for first-generation 500-kW plants are shown; later-generation technologies and/or larger plants are expected to be less expensive. For fuel cells and photovoltaics, cost will decrease as manufacturing production increases.

Table 2
DISTRIBUTED BENEFITS FOR 2-MW FUEL CELLS
($/MWh in 1991 dollars)

Benefit	LADWP	CSW	OPC
Spinning reserve	1.1	1.8	2.0
Peak operation	0.6	0.7	1.4
Reserve margin	Not quantified	0.9–1.7	1.7–3.4
T&D deferral	1.1–7.1	1.7–13	1.5–4.8
Energy loss savings	1.9–16	4.1–17.1	3.6
Improved reliability	0–1.3	2.7–13	0
Low emissions*	8.1–21	0.2–58	0.1–38
Thermal waste heat	0–5.8	0–8.4	0–12
Fuel diversity	0–8.4	8–20	0

Note: Distributed generation may also offer benefits in the areas of load shifting and minimizing capital-at-risk. Although not quantified in the above case studies, these potential benefits may be significant and will be considered in the EPRI guidelines.
*The CSW and OPC cases considered NO_x, SO_x, and CO_2; LADWP, NO_x only.

Table 3
BENEFIT/COST RATIOS FOR 2-MW FUEL CELLS

	LADWP	CSW	OPC
Gross levelized cost ($/MWh)			
Market-entry unit*	73	87	109
Commercial unit[†]	49	64	85
Range of distributed benefits by site ($/MWh)	14–46	22–85	9–64
Cost of deferrable resource ($/MWh)	52–60	54–73	92
Benefit/cost ratio			
Market-entry unit	0.9–2.3	0.8–3.4	0.9–1.6
Commercial unit	1.7–15	1.6–7	1.2–4.3

Note: All dollar amounts are in 1991 dollars. Financial assumptions varied by utility.
*$1500/kW, available in 1997.
[†]$970/kW, available in 2000.

combined-cycle plants, or coal-fired plants, depending on the year considered.

Results are summarized in Table 3 for market-entry ($1500/kW) and commercial ($970/kW) fuel cell units. The principal conclusion from each of the case studies was that, with moderate (65%) availability, market-entry 2-MW fuel cells are likely to be competitive at sites where distributed benefits can be realized. As was expected, the benefit/cost ratio was more favorable if the baseloaded market-entry units could achieve a 90% capacity factor. In general, the lower-cost, commercial fuel cell units were competitive irrespective of the distributed benefits. For certain cases in the CSW system, however, low-cost coal-based central stations were projected to be more competitive than distributed generation.

The case studies have confirmed that distributed generation can provide new tools for better management and utilization of T&D assets and can offer utilities new options for managing important industrial and commercial customers. But although distributed benefits are real and can be potentially significant, they are very site-specific.

Distributed generation is unlikely to replace future needs for large-scale central station generation. However, if cost, performance, and reliability targets are achieved—through volume production—distributed generation can have far-reaching implications with respect to siting future generation resources, ratemaking, and competition.

Utility participation in the detailed case studies has afforded important market insights about critical technology needs and product requirements and about areas for future emphasis in research, development, and demonstration. Although these studies focused on fuel cells, the methods developed by EPRI can be used to evaluate the cost-effectiveness of other distributed-generation options. For example, efforts are under way to apply the methods to the evaluation of photovoltaics and battery storage on other utility systems.

Future work will be directed at preparing generic guidelines to enable EPRI members to evaluate distributed generation. The first EPRI workshop on distributed generation is planned for September 29–30, 1992, in New Orleans.

Commercial Systems

Commercial Building Energy Analysis Tools

by Karl Johnson, Customer Systems Division

The analysis of energy use in commercial buildings is receiving a major boost this year with the introduction of a new water-heating analysis model, HOTCALC™, and the release of enhanced software for two existing codes, COMTECH™ (Commercial Technologies Screening Tool) and micro-AXCESS. Part of a growing family of easy-to-use energy analysis tools, these microcomputer programs help utilities give customers quick answers to difficult capital investment questions.

Version 3.0 of COMTECH—an interactive screening tool to evaluate the capital and operating costs of alternative lighting, heating, and cooling technologies—will be available late in the second quarter of this year. An enhanced version of micro-AXCESS, a building energy analysis tool that performs detailed simulations of the hourly energy use of commercial buildings, will also be released in the second quarter.

EPRI introduced the first of its commercial building analysis models, COOLAID (Commercial Cool Storage Evaluation Tool), in 1987. As the development effort has proceeded, EPRI members have used the resulting programs with increasing frequency, finding them to be valuable for a variety of purposes:

- Helping customers evaluate alternative technologies in terms of energy use and economics
- Performing energy audits
- Advising customers on energy-efficient construction methods
- Assessing demand-side management options, including alternative rate structures and incentives
- Analyzing markets
- Training staff

In response to popular acceptance, EPRI is expanding its commercial building analysis portfolio to include more-specialized analytical programs (e.g., HOTCALC) that work in conjunction with COMTECH and micro-AXCESS. As new links between models are added, the programs are being made increasingly similar in screen design and in the operation of field-movement keys.

Versatility is a key feature of the EPRI programs. Each can be used either to develop quick, general answers on the basis of default parameters or to provide more-detailed analyses on the basis of in-depth, site-specific data.

HOTCALC

EPRI and Empire State Electric Energy Research Corporation (ESEERCO) have cosponsored the development of HOTCALC to help utility marketing representatives and design professionals analyze applications of commercial water-heating systems. Using detailed hourly calculations, HOTCALC models common water-heating systems and provides a full range of results for evaluating and comparing performance.

Thermal, energy, and cost calculations can be performed for these system types: conventional gas and electric storage water heaters, heat pump water heaters, refrigeration heat recovery systems, and waste heat recovery systems. Unlike existing software for analyzing heat pump water heaters, HOTCALC examines the complex interactions between water-heating and space-cooling loads, as well as the dynamic influences on unit performance. It also includes a comprehensive recirculation-loop-system model.

HOTCALC can be customized for specific utilities and individual users through on-line text files, default values, and data files. Printed summaries of results are available in an attractive format suitable for direct use with clients.

In a typical session, the HOTCALC user follows four steps. First, via the Common Data menu, the user describes the water-heating load, operating costs, and weather conditions. The user can select and edit standard hourly load profiles and weather data for 74 sites, including at least one site per state. Many variables, such as energy cost and hot water use, can be scheduled on a monthly basis.

Next, via the System Data menu, the user selects and defines the water-heating system. Then the Run option is used to simulate the system's performance. Finally, via the Output menu, the program displays results in the form of tables and graphs. Results can also be written to an ASCII file for use in word processing, desktop publishing, or spreadsheet software.

HOTCALC's Diagnostics feature offers suggestions for fine-tuning and optimizing water-heating system performance. The Comparisons feature allows users to examine differences between alternative systems.

HOTCALC runs on any IBM-compatible microcomputer with a DOS 3.1 (or newer) operating system, 512 kilobytes of available random-access memory (RAM), and a hard disk. A graphics card is necessary to access graphing features, and a math coprocessor significantly improves calculation speed.

HOTCALC's pull-down menus are selected by a mouse, cursor keys, or the keyboard. Context-sensitive help is available at any time and includes cross-references to the forthcoming *Commercial Water-Heating Applications Handbook*, also cosponsored by EPRI and ESEERCO. HOTCALC also includes full file management functions, a DOS shell, and a pop-up calculator.

ABSTRACT *To help utilities give customers fast and accurate answers to difficult capital investment questions, EPRI researchers are developing a family of easy-to-use tools for analyzing commercial building energy use. By translating general theories into specific numbers, these computer models offer reliable data and save time. This year a new water-heating analysis program, HOTCALC, is being launched, as well as an enhanced version of COMTECH, which evaluates alternative lighting, heating, and cooling technologies. In addition, a forthcoming upgrade of micro-AXCESS, a detailed building energy model, features greater analysis capabilities in an easier-to-use format.*

Users can create a HOTCALC water-heating loads file for use in Version 3.0 of COMTECH. The link between the two programs allows users to perform a detailed analysis of water-heating systems in the context of a building's overall heating, ventilating, and air conditioning (HVAC) operations, including an evaluation of utility bills using COMTECH's rate structures.

COOLAID and COMTECH

COOLAID, the first program in EPRI's portfolio, makes cost evaluations of cool storage and conventional electric cooling in commercial buildings. The current version, COOLAID 2.2, was released last year. Over 300 copies of the software have been distributed to more than 100 EPRI members since it first became available in 1987. In addition, more than 30 engineering firms have purchased COOLAID.

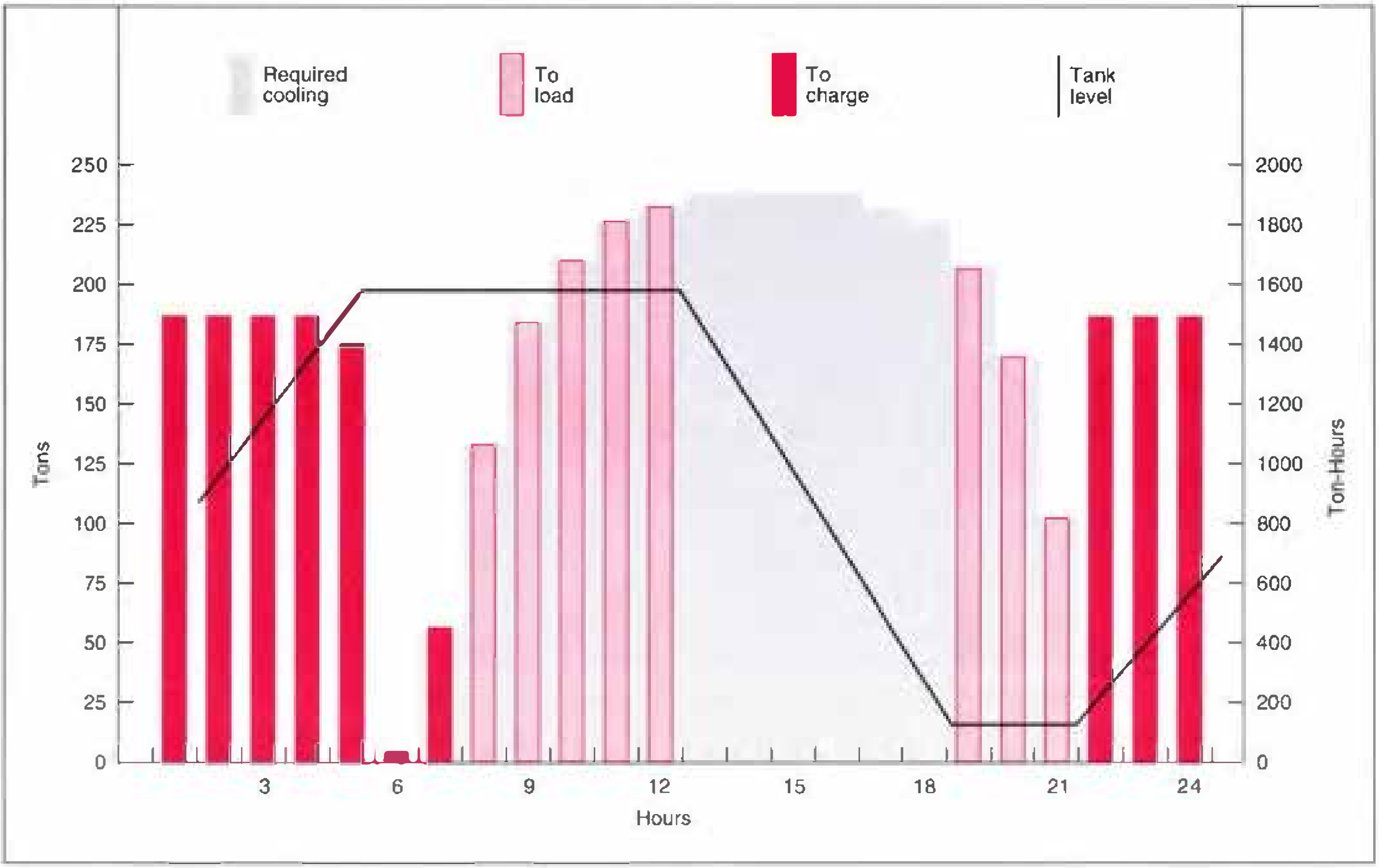
Initially COOLAID was an economic analysis tool, but recent releases have added engineering elements while keeping the program simple enough for nontechnical users. COOLAID enhancements have expanded the types of cool storage systems the program can analyze and have added customized reports to the list of available results. Future plans for COOLAID include the addition of heat recovery and heat storage analysis.

The success of COOLAID stimulated the development of a screening tool with a broader technology focus—COMTECH—that builds directly on COOLAID logic. Version 1.0 of COMTECH, introduced in 1989, focused on evaluating electric alternatives to cogeneration. Subsequent improvements to the program have made it more flexible and easier to use and have added technology options. Version 3.0 adds lighting to the options already available:

- Conventional and high-efficiency cooling, space-heating, and water-heating systems
- Heat recovery chillers and heat pumps
- Heat pump water heaters
- Cool storage systems
- Gas engine and absorption chillers
- Cogeneration with heat recovery and/or absorption cooling
- Air-source, dual-fuel, and water-loop heat pumps

COMTECH 3.0 is one of the first analysis tools capable of evaluating specific lighting systems. Users will be able to select from a default database of lighting options or to input their own data. This enhancement will allow marketing representatives to demonstrate customer savings from high-efficiency lighting systems. It also will permit utility analysts to evaluate the potential impacts of

Figure 1 This COMTECH graph illustrates the operation of a cool storage system on a typical summer day. The gray shaded area represents the cooling load, the bars indicate chiller operating status, and the black curve indicates the tank storage capacity (in ton-hours). Both COMTECH and COOLAID feature graphs that help explain the operation of the technologies being modeled.



alternative lighting equipment on building operations.

Other Version 3.0 enhancements include a revised prototype database, which allows users to apply their own weather data in developing building profiles; the incorporation of makeup water costs for water-cooled chillers; and expanded treatment of rate structures.

To date, COMTECH has been distributed to over 250 people at more than 100 utilities and government agencies. The program is used primarily by analysts and engineers who support utility marketing representatives. For example, a marketing representative might want to present options to a customer who is considering the replacement of an old cooling system. Perhaps the utility has a special cool storage incentive rate that should be considered in the evaluation. COMTECH can be used to produce a customized report that includes tables and graphs tailored to the customer's situation (Figure 1).

COMTECH can also help utilities perform demand-side management analysis and rate and rebate design. It can be used for prototypical as well as individual customers, quickly and easily evaluating alternative rate or rebate scenarios for each customer or customer segment.

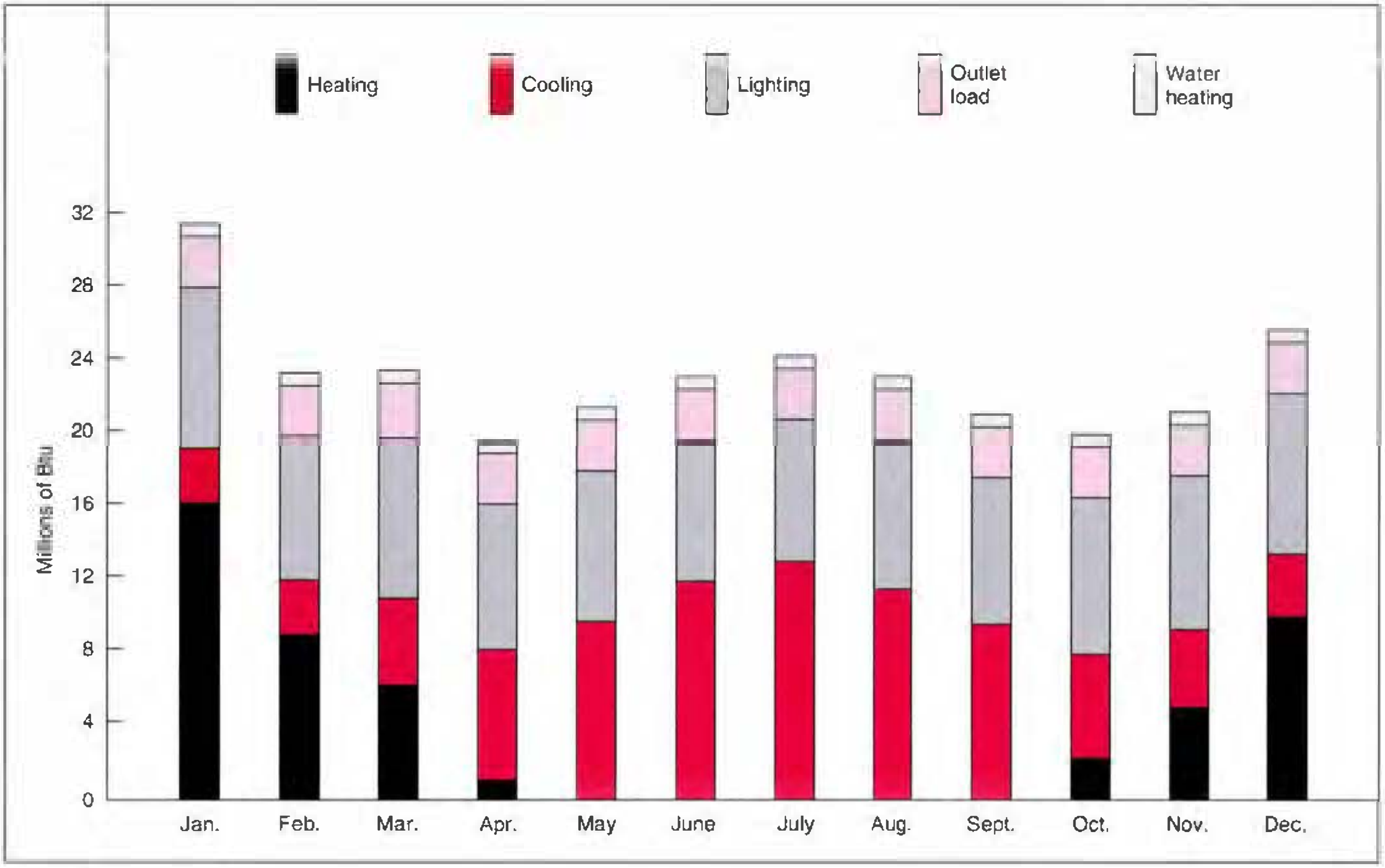
Compared with other end-use and technology software packages, COMTECH has these advantages:

- It includes lighting analysis.
- It is suitable for both technical and nontechnical analysts.
- It is comprehensive, providing estimates of load profiles, monthly energy use, utility bills, and equipment costs.
- It offers speed and flexibility. A user can execute a COMTECH run in about 1 minute and can easily make changes to run alternative scenarios or perform sensitivity analyses.
- Because of the program's interactive features, results are immediately available in tables and graphs.

The ideal hardware configuration for COMTECH is a 386-based personal computer, with at least 640 kilobytes of memory, 20 megabytes of available hard disk space, a color VGA monitor, and a math coprocessor. However, COMTECH also runs on 286-based machines, and a math coprocessor and color monitor are not necessary.

COMTECH can be directly linked with HOTCALC, as noted earlier, and can also be used with other models in EPRI's commercial building analysis portfolio. For example, a link between COMTECH and micro-AXCESS allows users to import micro-AXCESS load shapes directly into COMTECH. With these, users can screen a variety of technology options, reviewing energy use, utility bills, and equipment costs. If they need more detail, they can return to micro-AXCESS and perform a more rigorous technology analysis.

Figure 2 Micro-AXCESS supplies detailed graphs like this one, which shows monthly energy consumption by end use for an office building with electric air conditioning and space heating. Utility representatives can use such graphs to give customers an instant overview of their energy consumption patterns.



Micro-AXCESS

Designed specifically for use by utility staff, micro-AXCESS is the central player in EPRI's commercial building analysis portfolio. With a HOTCALC-produced energy use profile for commercial water-heating systems and its own detailed analysis of other building components, micro-AXCESS provides a comprehensive analysis of building loads and energy use.

Micro-AXCESS uses a building description, together with hourly weather data for the building site, to provide hourly load and energy use profiles for any period up to one year. Unlike competing analysis tools, micro-AXCESS performs hourly simulations of each building component on a standard personal computer with an extremely user-friendly interface. Hourly analysis allows accurate estimates of energy use and demand levels on a monthly basis (Figure 2), as well as comparisons of alternative technologies in all parts of a building. The easy interface gives utility staff facing time pressures a fast and reliable way to answer complex questions.

Since EPRI introduced micro-AXCESS 10.0 in October 1990, more than 300 copies have been distributed to utilities across the country. Marketing staff use the program to provide customers with energy use information for alternative building configurations. Field staff and auditors use it to estimate the energy impacts of commercial building retrofits. And utility representatives also use micro-AXCESS to promote rebate and conservation programs.

Version 10.1, the forthcoming release, features several major enhancements that add analysis capabilities and further improve ease of use:

▫ A new program unit makes it possible to apply utility rate schedules to energy use and demand calculations in order to estimate monthly customer costs for specific energy use items.

▫ A more unified and flexible method of describing building data, which vary by time of day and season of the year, allows such items as occupancy and lighting levels to be easily scheduled throughout the simulation period.

▫ New pop-up windows, including scroll bars, facilitate rapid selection of files and options.

▫ Screen information has been reorganized to provide a more logical progression through a building's description.

The operational changes improve the feel of the program, making the user's job easier and thus reducing the potential for analysis errors. The new energy cost segment allows easy determination of the economic bottom line of alternative technologies. Utility staff can describe the full range of energy rate schedules to provide customers with the information they need for making decisions.

Micro-AXCESS includes full on-line help

for each item on every screen, help that is instantly available through a single keystroke. An average utility analyst familiar with energy analysis can become a productive program user within a few days.

Micro-AXCESS runs on any IBM PC-AT or 100%-compatible system with 500 kilobytes of available RAM, 10 megabytes of available hard disk space, and a math coprocessor. However, use of a 386- or 486-based personal computer is advisable. To produce bar charts, a CGA or VGA graphics card and compatible color monitor are also necessary.

To obtain any of the programs in EPRI's commercial building analysis portfolio, contact the Electric Power Software Center at (214) 655-8883.

Nuclear Safety

Outage Risk Management

by S. Pal Kalra, Nuclear Power Division

ABSTRACT *EPRI is developing risk assessment and management tools that will support utility efforts to ensure safety and maximize efficiency during refueling and other outages at nuclear plants. These tools include comprehensive guidelines and associated software to help utility personnel conduct safety assessments of outage plans, evaluate the risk impacts of proposed changes in outage schedules, monitor safety during a shutdown, and plan and implement contingency actions.*

In planning and overseeing refueling and other nuclear plant outages, utility managers must ensure personnel and plant safety while also addressing the need for maximum efficiency. Such a balanced perspective is key to successful outages. To assist in this process, EPRI is developing a package of outage risk assessment and management (ORAM) tools. These products will help utility personnel make sound, informed risk-based decisions during outage planning and control activities. The ORAM tools include outage safety evaluation methods, risk management guidelines, and contingency guidelines. A corresponding software package is being developed to facilitate implementation of the ORAM process.

EPRI is closely coordinating the ORAM effort with utilities, the Nuclear Management and Resources Council, and the Institute of Nuclear Power Operations to ensure that the resulting products are useful in outage planning and control environments, simple to use, and consistent with NUMARC and INPO guidelines.

In parallel with the ORAM work, R&D efforts are being conducted under EPRI's overall outage management program to support long-term utility needs. These efforts include R&D in the areas of human reliability during maintenance, testing, and inspection activities; shutdown database development; and fire protection and prevention.

Developing risk management guidelines

The ORAM effort is developing a systematic process for assessing and managing risk associated with plant outages. Specifically, the process focuses on seven key safety functions and determines the level of support provided to each of these functions during a plant shutdown. The functions are:

- Reactivity control and monitoring
- Shutdown cooling (fuel in vessel)
- Inventory control (fuel in vessel)
- Fuel pool cooling (fuel in pool)
- Electric power control (ac and dc)
- Vital support system control
- Containment integrity and cooling

The first step in the ORAM process is to examine outage plans and to divide an outage into discrete stages, or plant states. Each plant state is reviewed relative to the seven safety functions, and the status of systems that support those functions is determined. Plant state and system availability data are then input into shutdown safety function assessment trees (SSFATs), which are being developed for each safety function. The relative reliability of a given safety function during a given plant state is determined on the basis of the SSFAT decision logic.

For each plant state, the SSFAT assigns a color to the safety function under review to indicate the degree to which it is supported. Green indicates that the function is supported to the full design and operational capability of the plant. Yellow indicates that the function has adequate support. Orange and red represent reduced and minimum levels of support. Together these assessments indicate the plant's overall defense-in-depth during the outage.

For each safety function for each plant state, researchers are developing guidelines to support risk-based decisions for conducting safe and efficient outages. The resulting dos and don'ts should help identify possible rescheduling options, as well as mitigation and contingency actions that can either preclude certain events or prevent them from reaching undesirable end states. In developing the guidelines, the researchers are drawing on the insights gained from ORAM safety assessments and on industry operating experience and utility-specific guidance. The guidelines will be available both in print and as part of the ORAM software package to give utility users maximum flexibility.

Four reports on the ORAM work to date are forthcoming from EPRI's Nuclear Safety Analysis Center. Two will document surveys of BWR and PWR plant personnel on shutdown safety practices and risk management needs, and two will document safety assessments of BWR and PWR risk during shutdown operations. NSAC-173 and -175 are the BWR reports; NSAC-174 and -176 are the corresponding PWR reports.

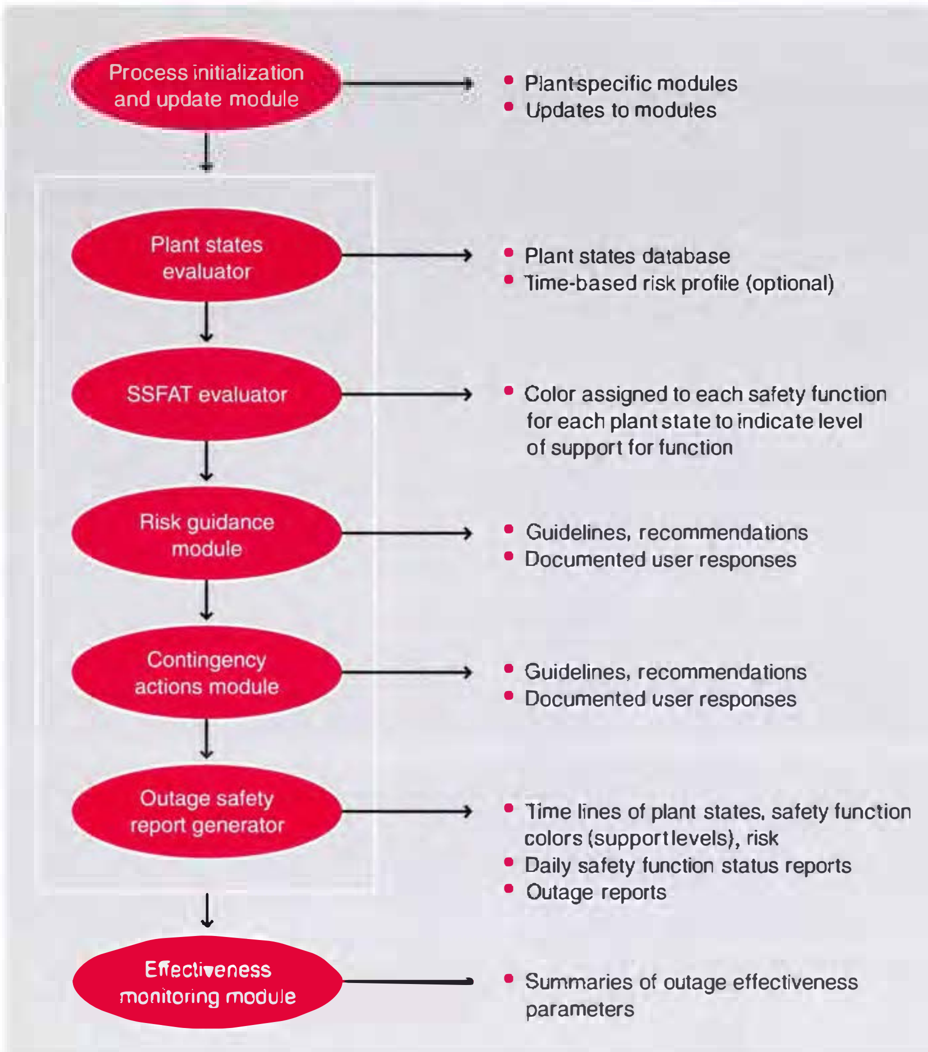
Key utility uses

The risk management guidelines are intended for use by utility outage planners, operations and outage managers, and safety personnel. These key people can use the documents in several ways:

- To identify, before an outage, vulnerable time periods from the perspective of safety functions
- To monitor these vulnerable time periods during the outage
- To help assess the effects of schedule changes during an outage
- To ensure that adequate plans for mitigation and contingency actions are in place before an outage
- To guide postoutage critiques and identify areas for improvement from a safety function perspective

The guidelines will describe key accident scenarios that pose a risk to a given safety function, including initiating events and potential subsequent failures found to be of importance in industry experience or in the probabilistic shutdown safety assessments. Also addressed will be scenarios that lead to various undesirable end states, including bulk boiling, core damage, fuel bundle uncovery, fuel pool boiling or draindown, and cold overpressurization of the vessel.

Figure 1 ORAM-TIP software modules and their output. The software divides an outage into manageable stages, or plant states; determines the level of support afforded to seven key safety functions during each plant state; provides risk management and contingency guidelines for each function for each state; and generates easy-to-understand time lines and reports. The user can enter at the appropriate module for planning, tracking, modifying, or reviewing an outage.



The guidelines will list cautions, concerns, recommendations, and considerations pertinent to the conditions under review and will describe the technical basis or other reason for each guideline element. They will also offer insights on potential initiating events, ways to improve safety function reliability and availability, detection of adverse conditions, and appropriate response actions. In addition, the guidelines for a given safety function will consider any factors that might adversely affect other safety functions.

Software package

The ORAM risk management process lends itself to computerization for efficient application at a plant. Thus, using a modular approach, the products developed in this project are being combined into a software package that corresponds closely to the outage risk management framework (Figure 1). One objective of the software, called ORAM-TIP (for technology integration package), is to allow users to input information about outage schedules and equipment status directly from currently used planning and scheduling software. Therefore, developers are seeking the best practical interface between scheduling software and ORAM-TIP.

The software package includes a report generator module that will provide several useful kinds of output, including time lines of plant states and safety function colors (i.e., support levels) for the outage and daily safety function status reports. For plants with probabilistic shutdown safety assessment models linked to ORAM-TIP, the report generator can also produce a time line of plant risk for the duration of the outage.

The initial version of the ORAM-TIP software will be demonstrated at a meeting on outage risk assessment and management in Orlando, Florida, on June 25 and 26. For more information about this meeting or about the ORAM effort in general, contact the EPRI project manager, S. Pal Kalra, at (415) 855-2414.

Utility Planning

Managing Corporate Assets to Maximize Value

by Lewis Rubin, Integrated Energy Systems Division

As utility managers seek to make the best possible use of resources and to enhance the value of electricity service, they are growing interested in new methods of asset management. The concept of asset management itself is not new—it has always been fundamental to the running of electric utilities. In recent years, however, several aspects of this traditional concept have begun to change.

First, value has come to be more broadly defined in the electric utility environment. Value delivery is no longer limited to the minimization of revenue requirements. It also includes notions of customer service quality, environmental stewardship, corporate earnings performance, additional revenues from the servicing of nonnative load, and the provision of value-added services to customers. In many cases, the values of different stakeholders can conflict, requiring that managers explicitly evaluate trade-offs between them. And the values of different stakeholders are frequently measured in different units, which further complicates comparisons.

Second, decentralization of decision making has begun to take hold in the utility industry in response to a variety of stimuli, including cost control, efficiency improvements, a growing customer orientation, the popularity of cost and quality management programs, and reorganization into business units. Some of these changes are driven by real or anticipated competitive pressures, and some are driven simply by good business practices.

Whatever the root causes, decentralized decision making brings challenges as well as benefits. The most important challenge is to ensure that the basis for decision making is consistent throughout the decentralized organization—that is, that all parts of the operation are driven by the same overall goals. If this is not true, assets can potentially be managed in suboptimal ways. Such problems have always existed, but they become even more acute as decentralization progresses.

In response to this situation, EPRI has been developing a research program in asset management. Basically, the research follows two related but distinct approaches. The first focuses on exploring, refining, and applying to utilities the cost and quality techniques most used in American industry. The second approach involves a formalized asset management methodology—a set of tools that can help managers discover the best use of their assets to deliver the greatest value to stakeholders.

The EPRI program is broad and spans several Institute divisions. In the Generation and Storage Division, ongoing research is applying these principles to fossil power plants. In the Customer Systems Division, similar techniques are being studied to help understand customer wants and how to satisfy them. In the Integrated Energy Systems Division, the principles are being applied to corporate-level plans and analyses.

Cost and quality management: doing things right

Initiated in Japan, cost and quality management—which is sometimes called total quality management—seeks continuous improvement in all intracompany processes, empowers employees to make decisions at

ABSTRACT *As the utility industry environment becomes more complex, pressures grow for managers to make more effective use of all their assets—including fuel, equipment, and personnel. Improving the management of assets leads to the delivery of greater value to ratepayers, stockholders, and society. EPRI is sponsoring a broad research program to help utilities effectively apply the tools needed in these changing business conditions, especially the latest in cost and quality management and asset management techniques.*

the lowest possible level, and sets customer needs as the basis for both short- and long-range planning. This management philosophy has helped businesses as diverse as Westinghouse Nuclear Fuel, Tandem Computer, and Federal Express become leaders in cutting costs and satisfying customers.

Cost and Quality Management: Key Characteristics of Successful Organizations

- Top management commitment
- Cost and quality strategy that supports business objectives
- Consistent and broad communication across organization
- Cost and quality strategy supported by actionable tasks and measurement systems
- Redefined relationship between manager and employee
- Effectively resourced infrastructure
- Improvement viewed as a process, not a program

Nearly half of all U.S. utilities have been experimenting with cost and quality programs, sometimes with frustrating results. In order to shed light on useful cost and quality techniques as they apply to utilities, EPRI's Integrated Energy Systems Division has just published a five-volume guidebook, *Putting Strategy to Work: Tools for Cost and Quality Management in the 1990s* (TR-100052). Cosponsored by the American Water Works Association Research Foundation, this guide compiles extensive information about quality programs from a survey of several hundred utility and nonutility companies and presents in-depth case studies of 17 companies. On the basis of the information gathered, the guide offers readers insights into what techniques work and what types of management conditions lead to success. Companies that have effectively implemented cost and quality management were found to share seven key characteristics, which are presented in the accompanying list.

The principles set forth in the guidebook were tested in a 1991 case study at a member utility. EPRI and its contractor worked with a project team of 12 senior managers from across the utility to reach consensus on objectives and lay the groundwork for a companywide quality process. Although several divisions of the utility had already tried certain cost and quality techniques—such as increasing employee involvement in decision making—the project team found that a successful transition needed far greater commitment from top management. In its final report, the team recommended that the utility take the following measures during the first year of changeover:

□ Commit 10–20% of the executive committee's time to cost and quality leadership

□ Create a steering team of managers, employees, and union officials

□ Rather than striving for massive change, focus on pilot initiatives in order to boost chances for success

In related work in EPRI's Generation and Storage Division, researchers conducted interviews with fossil plant managers at 11 member utilities and engaged in on-site studies at gas turbine plants owned by Carolina Power & Light, Georgia Power, and the Tennessee Valley Authority (TVA). The interviews and site studies revealed these major barriers to facilitating cost and quality management: resistance to change, insufficient effort on developing employee initiative and self-esteem, a lack of understanding of the importance of internal customers, and traditional management practices, as represented by the top-to-bottom organization chart. The resulting Phase 1 research report (TR-100377) highlights these findings and the attitude changes needed to overcome the barriers. In Phase 2 of the study—cofunded by EPRI and TVA—the project team is helping TVA apply cost and quality management to the planning and operation of its 500-MW Allen gas turbine plant.

Two research efforts in EPRI's Customer Systems Division are concentrating on customer desires. The first has produced the report *Delivering Customer Value: The Application of Quality Function Deployment to Demand-Side Management* (TR-100239), which offers utility managers techniques for translating customer needs into appropriate technical requirements. The second effort is developing a customer-focused planning guidebook to help utility managers answer two basic questions—what do customers want and how do utilities listen?

Asset management: doing the right things

Asset management complements cost and quality management by helping managers decide which activities to work on—that is, which ones are the most important in terms of delivering maximum value. Cost and quality techniques can then be implemented to improve the worth of those activities by reducing costs, increasing efficiency, and building customer satisfaction.

Asset management techniques can help utility managers do the following:

□ Identify their direct internal and external customers and learn how they create value for those customers

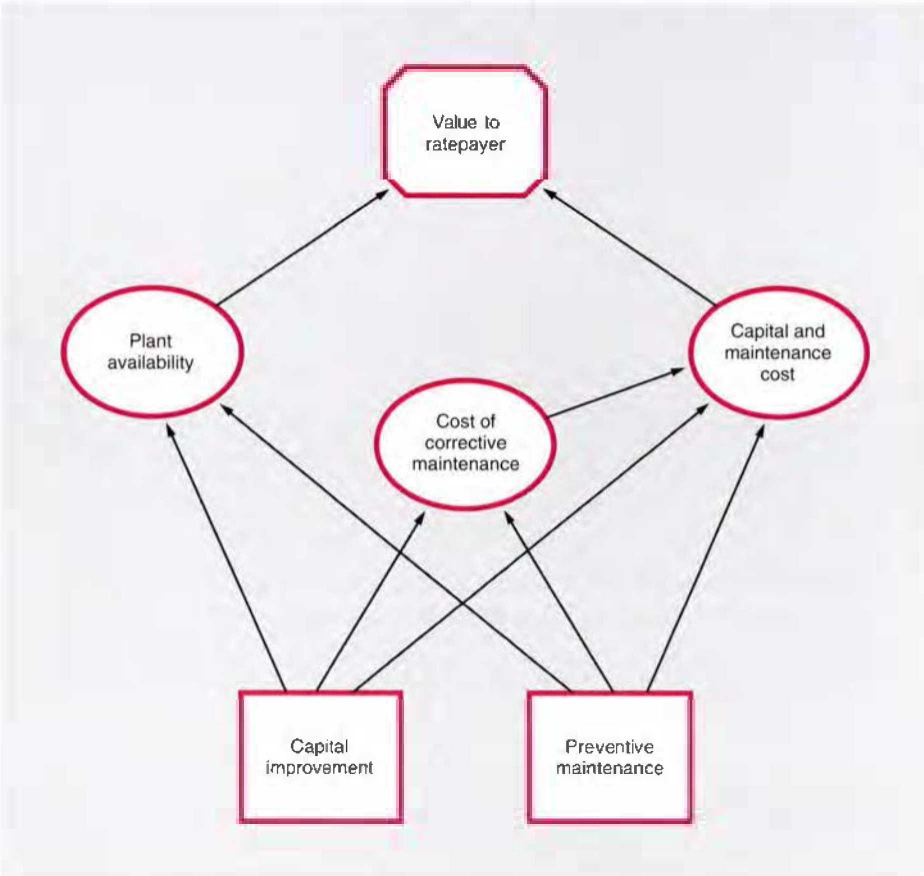
□ Make decisions that are compatible with corporate objectives and that take into account the often conflicting desires of ratepayers, stockholders, and society

□ Pinpoint the activities of highest value to the utility

Asset management is a body of techniques for gathering data and evaluating alternative courses of action. A trained analyst takes decision makers through a series of questions about their activities, their customers, and what their customers expect of them. The information is then translated into what is called an influence diagram—an explicit representation of all activities, the important uncertainties affecting them, and how they influence customer value. The simplified influence diagram in Figure 1, for instance, illustrates how capital improvements and/or increased preventive maintenance affect value.

The asset management framework can be used to analyze many variations of the structure, explore key uncertainties, and arrive at a robust understanding of the activities that have the highest expected value and should be pursued. An analysis of this type can, for example, provide power plant managers with insights into the value of a

Figure 1 A key asset management tool is the influence diagram, which shows how decision alternatives (rectangles) and their effects (ovals) create value (octagon). This simplified example maps how ratepayer value is affected by power plant capital improvements (e.g., buying a new pump or motor) and/or increased preventive maintenance. The costs of these actions are weighed against their benefits—improved plant availability and reduced corrective maintenance. Associated software can explore uncertainties and quantify the effects of various levels of investment.



reliability improvement versus the value of a heat rate improvement.

In 1991, EPRI and its contractor worked with the steam generation department of Pacific Gas and Electric (PG&E) to test the methodology in evaluating the prioritization of maintenance projects. The analysis suggested that the duration and number of outages, both scheduled and forced, were the key influences on ratepayer value. Other factors, such as the number of human errors made during outages, turned out to be less important. The analysis further indicated that spending more money on preventive maintenance procedures—that is, on training and on upgrading the quality of maintenance and planning procedures—seemed to provide the greatest value to ultimate stakeholders.

Another important outcome of this case study was that it demonstrated the ability of the asset management methodology to document and justify decisions in a structured, logical, and quantitative way. Since the methodology explicitly captures relationships, uncertainties, and value measures and analyzes them quantitatively, it has the potential to be very useful for explaining decision rationales as well as for providing decision guidance. PG&E steam generation department staff are continuing to work with the methodology in 1992, testing it on actual resource allocation decisions.

Next steps

Several activities are in the works to further advance the techniques discussed above and to help managers hone skills at using fuel, equipment, and personnel in ways that maximize value. In the cost and quality management arena, an on-line clearinghouse is being planned through EPRINET to help users share research results and retrieve non-EPRI literature; it will serve as a question-and-answer bulletin board for utility managers who are responsible for cost and quality programs. In addition, EPRI's Integrated Energy Systems Division sponsors an annual conference on cost and quality management; the next one is scheduled for this November.

In asset management, a two-year project funded by EPRI's Generation and Storage Division and Integrated Energy Systems Division is now getting under way. Investigators hope to transform lessons learned from the PG&E case study and upcoming case studies into tools useful to managers of fossil plants. The contemplated user-friendly workstation will come complete with tutorials.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Demand-Side Management Guidebook (RP2342-16)	$86,500 7 months	Barakat & Chamberlin / *P. Meagher*
UCA-Compatible Customer Communications Gateway (RP2568-19)	$249,600 9 months	Honeywell / *L. Carmichael*
Evaluation of R-22 Low-Temperature Refrigeration for Supermarkets (RP2569-22)	$213,800 18 months	Foster-Miller / *M. Khattar*
Consumer and Trade Research Program Compact Fluorescent Lighting (RP2597-31)	$58,500 3 months	Macro Corp. / *J. Kesselring*
Desalination at Florida Power & Light Power Plants (RP2662-23)	$199,900 8 months	General Atomics International Services Corp. / *M. Jones*
Efficient Utilization of Electric Power for the Impulse Drying of Paper (RP2782-16)	$99,000 12 months	Institute of Paper Science and Technology / *A. Amarnath*
Voltage Distortion Caused by High-Efficiency Adjustable-Speed-Drive Heat Pumps (RP2935-19)	$50,000 7 months	University of Arkansas / *M. Samotyj*
Motor and Drive Technology and Applications in the Textile Industry (RP3087-15)	$150,000 18 months	North Carolina Alternative Energy Corp. / *B. Banerjee*
Electrical Systems		
System Control Center Operator Training Simulator, Phase 3: UNIX Operating System Version With Multiple EMS Links (RP1915-6)	$802,700 27 months	National Systems & Research Co. / *G. Cauley*
System Control Center Operator Training Simulator: Conversion to UNIX (RP1915-8)	$302,300 11 months	Empros Systems International / *G. Cauley*
Interutility Data Exchange: Scoping Phase (RP2949-11)	$82,200 13 months	Energy & Control Consultants / *B. Blair*
Flexible AC Transmission System: Thermal Models for Real-Time Monitoring of Transmission Circuits (RP3022-7)	$1,087,200 34 months	Power Technologies / *S. Lindgren*
Scoping Study for Substation Design Workstation (RP3193-1)	$119,900 6 months	Power Technologies / *B. Damsky*
Environment		
Flue Gas Desulfurization Laboratory Research (RP1031-17)	$199,900 11 months	Radian Corp. / *D. Owens*
Field Studies of Fungal Conversion of Hydrocarbons in Soils: Quality Assurance and Control (RP2879-17)	$116,600 8 months	Geo Engineers / *I. Murarka*
Toxicity Characteristic Leaching Procedure Analysis of Crankcase Oils and Oil Residues (RP2879-18)	$58,600 1 month	Envirosystems / *J. Goodrich-Mahoney*
Retrofit NO_x Guidelines (RP2916-7)	$187,200 13 months	William Nesbit & Associates / *D. Eskinazi*
Cellular Responses to Low-Frequency Electric and Magnetic Fields: Signal Transduction Mechanisms (RP2965-20)	$272,300 34 months	University of Kentucky Research Foundation / *C. Rafferty*
SO_x-NO_x-RO_x-BO_x Flue Gas Cleanup Demonstration Project (RP3004-40)	$515,500 19 months	Babcock & Wilcox Co. / *R. Chang*
Electrostatic Precipitator Technical Support (RP3005-2)	$90,800 15 months	Kilkelly Environmental Associates / *R. Altman*
Exploratory and Applied Research		
Diamond Synthesis at Atmospheric Pressure (RP2426-45)	$578,900 38 months	Stanford University / *J. Stringer*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Evolution of High-Temperature Growth Stresses in Metal- or Alloy-Oxide Systems (RP2426-47)	$309,300 35 months	University of Minnesota / *J. Stringer*
Fabrication of Nanophase Ceramic/Metal Composite Coatings by Electrochemical Infiltration of Sol-Gel Films (RP8002-32)	$50,700 8 months	Stevens Institute of Technology / *T. Schneider*
Feasibility of On-line Monitoring of Stress Corrosion Cracking in Rotating Components (RP8002-35)	$75,100 5 months	CAPCIS March / *B. Syrett*
Whitings: A Potential Model for CO_2 Abatement (RP8003-31)	$186,900 18 months	University of South Florida / *R. Goldstein*
Advanced Model-Based Control for Coal-Fired Boilers (RP8004-13)	$207,600 41 months	Texas Tech University / *M. Divakaruni*
Evaluation of Pressure-Sensing Concepts (RP8004-14)	$98,000 9 months	Martin Marietta Energy Systems / *J. Weiss*
Generation and Storage		
Assessment of the Benefits of Distributed Fuel Cell and Diesel Generators in the Oglethorpe Power Corp. System (RP1677-24)	$80,400 7 months	Barrington-Wellesley Group / *D. Rastler*
Development of Advanced Control Strategies for Combined-Cycle Generation Systems (RP2101-12)	$174,900 16 months	Research Foundation of CUNY / *G. Quentin*
Technical Assessment of Advanced Aeroderivative Gas Turbine Power Plants (RP2387-9)	$180,700 18 months	Sargent & Lundy Engineers / *A. Cohn*
Gas Turbine Inlet Air Cooling by Ice Storage (RP2832-10)	$153,000 16 months	Lincoln Electric System / *H. Schreiber*
Research on Overtopping of Dam Embankments (RP2917-28)	$130,000 45 months	U.S. Bureau of Reclamation / *D. Morris*
Japanese Power Plant Survey (RP2923-12)	$57,900 5 months	University of Kansas Center for Research / *M. Blanco*
Integrated Energy Systems		
Integration of Gas Supply and Electricity Generation (RP3201-1)	$96,300 3 months	Putnam, Hayes & Bartlett / *H. Mueller*
Interface Between the Electric Utility and Natural Gas Industries (RP3201-4)	$110,000 10 months	Energy Ventures Analysis / *H. Mueller*
Environmental Externalities Clearinghouse (RP3231-1)	$180,200 15 months	Barakat & Chamberlin / *L. Williams*
Nuclear Power		
Microstructural Effects on the Corrosion Behavior of IN718 and Related Superalloys (RP2181-9)	$110,500 20 months	University of Texas, Austin / *L. Nelson*
Development of a Model for Stress Corrosion Crack Initiation in Low-Alloy Steels (RP2812-9)	$67,400 8 months	S. Levy, Inc. / *R. Pathania*
Stationary Battery Maintenance Guide (RP2814-46)	$61,900 7 months	Edan Engineering Corp. / *W. Johnson*
Emergency Battery Lighting Unit Maintenance Guide (RP2814-47)	$53,800 7 months	Edan Engineering Corp. / *W. Johnson*
Corrosion and Deposition Sourcebook (RP3052-6)	$185,000 12 months	Puckorius & Associates / *R. Edwards*
Performance of Electropolished and Preoxidized Feedwater Flow Venturis (RP3097-3)	$275,000 30 months	GPU Nuclear Corp. / *H. Ocken*
Assessment of the Effective Dose Equivalent for Photon Radiation (RP3099-10)	$124,400 13 months	Texas Engineering Experiment Station / *C. Hornibrook*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Dr., P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price for which will be equal to the price of EPRI membership. Others pay the listed price. The Distribution Center will send a catalog of EPRI reports on request. To order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

ELECTRICAL SYSTEMS

TLWorkstation™ Code, Version 2.0, Vol. 17: MFAD Manual (Revision 1)
EL-6420 Final Report (RP1493-7); $200
Contractor: GAI Consultants, Inc.
EPRI Project Manager: V. Longo

Compact DC Link, Parts 1 and 2
EL-7101 Final Report (RP213, RP1536-12); $200
Contractor: General Electric Co.
EPRI Project Manager: B. Damsky

Electromagnetic Transients Program (EMTP), Version 2.0: Revised Application Guide
EL-7321 Final Report (RP2149-4); $200
Contractor: ABB Systems Control Co., Inc.
EPRI Project Manager: R. Adapa

Advanced Cable Fault Locator, Vols. 1 and 2
EL-7451 Final Report (RP2895-2); $200
Contractor: BDM International, Inc.
EPRI Project Manager: H. Ng

Field Evaluation of Composite Crossarms, Vol. 1
EL-7461 Final Report (RP796-2); $200
Contractor: Michigan Technological University
EPRI Project Manager: H. Ng

Integrated Distribution Control and Protection System
EL-7462 Final Report (RP1472-1); $200
Contractor: General Electric Co.
EPRI Project Manager: T. Kendrew

Proceedings: Water Treeing and Aging
EL-7479 Proceedings (RP2957-78); $200
Contractor: National Research Council of Canada
EPRI Project Manager: B. Bernstein

Hybrid Transmission Corridor Study, Vol. 2: Phase 2, Full-Scale Tests
EL-7487 Final Report (RP2472-3); $200
Contractor: General Electric Co.
EPRI Project Manager: J. Hall

Utility Communications Architecture, Vol. 4: UCA Specification, Version 1.0
EL-7547 Final Report (RP2949-1); $200
Contractor: Andersen Consulting
EPRI Project Manager: W. Malcolm

Utility Communications Architecture, Vol. 6: Final Report—Project Summary
EL-7547 Final Report (RP2949-1); $200
Contractor: Andersen Consulting
EPRI Project Manager: W. Malcolm

Development of a Dry-Type Shunt Capacitor
EL-7553 Final Report (RP2205-1); $200
Contractor: General Electric Co.
EPRI Project Managers: R. Nakata, V. Tahiliani

Improvement of Current Capacity in Y-Ba-Cu-O Superconducting Materials Above 200 K
TR-100062 Final Report (RP7911-17); $200
Contractor: Wayne State University
EPRI Project Manager: M. Rabinowitz

Removal of PCBs From Transformer Oils of Petroleum Origin
TR-100063 Final Report (RP2028-1); $200
Contractor: General Electric Co.
EPRI Project Manager: G. Addis

Workshop Proceedings: Failed High-Voltage Instrument Transformers
TR-100205 Proceedings (RP3320); $200
EPRI Project Manager: S. Lindgren

ENVIRONMENT

Reproduction, Growth, and Development of Rats During Exposure to Electric Fields at Multiple Strengths
EN-6847 Final Report (RP799-1); $200
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: R. Black

Exposure to Residential Electric and Magnetic Fields and Risk of Childhood Leukemia
EN-7464 Interim Report (RP2964-1); $200
Contractor: University of Southern California
EPRI Project Manager: L. Kheifets

Comanagement of Coal Combustion By-Products and Low-Volume Wastes: A Southeastern Site
EN-7545 Final Report (RP2485-9); $200
Contractors: Radian Corp., GeoTrans, Inc., Battelle PNL
EPRI Project Managers: I. Murarka, J. Goodrich-Mahoney

Electric and Magnetic Field Exposure Associated With Electric Blankets
TR-100180 Final Report (RP2966-3); $200
Contractor: Carnegie Mellon University
EPRI Project Manager: S. Sussman

EXPLORATORY AND APPLIED RESEARCH

Proceedings: International Conference on Fossil Plant Cycle Chemistry
TR-100195 Proceedings; $200
EPRI Project Manager: B. Dooley

Advocating Investments in Information Technology, Vol. 1
TR-100233 Interim Report (RP8000-75); $200
Contractor: Competition Technology Corp.
EPRI Project Manager: R. Colley

GENERATION AND STORAGE

Condenser On-Line Leak-Detection System Development
GS-7350 Final Report (RP1689-19); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Tsou

Proceedings: 1992 Joint Symposium on Stationary Combustion NO_x Control, Vols. 1 and 2
GS-7447 Proceedings (RP2154); $500 for set
EPRI Project Manager: A. Kokkinos

Colorado-Ute Nucla Station Circulating-Fluidized-Bed Demonstration, Vol. 2: Test Program Results
GS-7483 Final Report (RP2683-7); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: T. Boyd

NO_x Emissions: Best Available Control Technology—A Gas Turbine Permitting Guidebook
GS-7486 Final Report (RP2936-1); $2500
Contractor: Radian Corp.
EPRI Project Manager: H. Schreiber

Evaluation of a 2-MW Carbonate Fuel Cell Power Plant Fueled by Landfill Gas
TR-100050 Final Report (RP1677-19); $200
Contractor: Haldor Topsoe, Inc.
EPRI Project Manager: D. Rastler

Proceedings: Workshop on Wear Potential of Bed Material in Fluidized-Bed Combustors
TR-100056 Proceedings (RP979-25); $200
Contractor: Argonne National Laboratory
EPRI Project Manager: J. Stallings

Municipal Waste-to-Energy Technology Assessment
TR-100058 Final Report (RP2190-4); $200
Contractor: Battelle Memorial Institute
EPRI Project Manager: C. McGowin

EPRI High-Sulfur Test Center Report: Factors in Limestone Reagent Selection
TR-100137 Final Report (RP1877-1); $1000
Contractor: Radian Corp.
EPRI Project Manager: D. Owens

Condition-Monitoring Guidelines for Rolling Element Bearings
TR-100160 Final Report (RP1864-1); $200
Contractor: Mechanical Technology, Inc.
EPRI Project Manager: J. Scheibel

Evaluation of Boride Diffusion Coatings to Alleviate Erosion of Steam Turbine Components
TR-100208 Final Report (RP1885-2); $200
Contractors: Battelle, General Electric Co.
EPRI Project Manager: T. McCloskey

Field Measurement of Solid Particle Erosion in Utility Steam Turbines
TR-100215 Final Report (RP1885-2); $200
Contractor: General Electric Co.
EPRI Project Manager: T. McCloskey

Field Telemetry Testing of Long-Arc, Low-Pressure Turbine Blading
TR-100216 Final Report (RP1856-3); $200
Contractor: Stress Technology, Inc.
EPRI Project Manager: T. McCloskey

Technical and Economic Comparison of Steam-Injected Versus Combined-Cycle Retrofits on FT-4 Engines
TR-100238 Final Report (RP2565-1), $200
Contractor: Burns and Roe Enterprises, Inc.
EPRI Project Manager: H. Schreiber

INTEGRATED ENERGY SYSTEMS

Putting Strategy to Work: Tools for Cost and Quality Management in the 1990s, Vols. 1–5
TR-100052 Final Report (RP3026-3); $200 each volume
Contractors: Cresap, a Towers Perrin Company; American Productivity and Quality Center
EPRI Project Managers: H. Mueller, L. Rubin

Potential for Reduction in Utility Fuel Oil Consumption Using Natural Gas
TR-100157 Final Report (RP2369-42); $200
Contractors: Energy Ventures Analysis, Inc.; Jensen Associates, Inc.
EPRI Project Manager: H. Mueller

Availability Cost Optimization Methodology
TR-100225 Final Report (RP2462-1), $200
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

NUCLEAR POWER

Computer-Assisted Drawing Information Capture
NP-7197 Interim Report (RP3045-1); $200
Contractor: GTX Corp.
EPRI Project Manager: R. Colley

Post-Earthquake Analysis and Data Correlation for the 1/4-Scale Containment Model of the Lotung Experiment
NP-7305-M Final Report (RP2225-9); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: Y. Tang

Analysis of Ground Response Data at Lotung Large-Scale Soil-Structure Interaction Experiment Site
NP-7306-M Final Report (RP2225-21, -29); $200
Contractor: Geomatrix Consultants, Inc.
EPRI Project Manager: Y. Tang

A Synthesis of Predictions and Correlation Studies of the Lotung Soil-Structure Interaction Experiment
NP-7307-M Final Report (RP2225-9); $200
Contractor: Bechtel Power Corp.
EPRI Project Manager: Y. Tang

ARROTTA-01, an Advanced Rapid Reactor Operational Transient Analysis Computer Code, Vol. 1: Theory and Numerics
NP-7375 Final Report (RP1936-6); $200
Contractor: S. Levy Inc.
EPRI Project Manager: L. Agee

PWR Full-Reactor Coolant System Decontamination: Materials Evaluation After Off-Normal Exposure to the LOMI Decontamination Process
NP-7513-M Final Report (RP2296-20); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: C. Wood

The Qualification of Dilute Chemical Processes for PWR Full Reactor Coolant System Decontamination
NP-7514 Final Report (RP2296-20), $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: C. Wood

Proceedings: MAAP Thermal-Hydraulic Qualifications and Guidelines for Plant Application Workshop
NP-7515 Proceedings (RP3044-1); $200
EPRI Project Manager: P. Kalra

Modification of Alloy Surfaces Using Pulsed Energy
NP-7532 Final Report (RP2614-49), $20,000
Contractor: Failure Analysis Associates
EPRI Project Manager: J. Nelson

Influence of Irradiation and Stress/Strain on the Behavior of Structural Materials, Phase 1
NP-7533-M Final Report (RP2181-3); $200
Contractor: Siemens AG
EPRI Project Manager: J. Nelson

Initiation Strain for Chloride-Induced Stress Corrosion Cracking in Type 316 Stainless Steel
NP-7542 Final Report (RP2812-8), $200
Contractor: University of Newcastle upon Tyne
EPRI Project Manager: D. Cubicciotti

Heat Exchanger Performance Monitoring Guidelines
NP-7552 Final Report (RP3052-1), $200
Contractor: Mollerus Engineering Corp.
EPRI Project Managers: N. Hirota, R. Edwards

Cast Austenitic Stainless Steel Sourcebook
TR-100034 Final Report (RP2643-5); $200
EPRI Project Manager: M. Lapides

Effect of Surface Treatments on Radiation Buildup in Steam Generators, Vol. 1: Manway Seal Plate Tests in the Chinon B1 PWR
TR-100059 Final Report (RP2758-2); $200
Contractor: Radiological & Chemical Technology, Inc.
EPRI Project Manager: H. Ocken

Effect of Surface Treatments on Radiation Buildup in Steam Generators, Vol. 2: Test Coupons in the Doel-2 PWR
TR-100059 Final Report (RP2758-2); $200
Contractor: Radiological & Chemical Technology, Inc.
EPRI Project Manager: H. Ocken

Studsvik Super-Ramp-II: 9×9 Project
TR-100204 Final Report (RP1580-18), $200
Contractor: Studsvik Nuclear
EPRI Project Manager: S. Yagnik

Natural Versus Artificial Aging of Nuclear Power Plant Components
TR-100245 Interim Report (RP1707-13); $200
Contractor: University of Connecticut
EPRI Project Manager: G. Sliter

Proceedings: Methodologies, Tools, and Standards for Cost-Effective, Reliable Software Verification and Validation
TR-100294 Proceedings, $200
EPRI Project Manager: J. Naser

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. EPRI member utilities, in paying their membership fees, prepay all royalties. Nonmember organizations licensing EPRI computer programs are required to pay royalties. For more information about EPSC and licensing arrangements, EPRI member utilities should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Other organizations should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

ACOM: Availability Cost Optimization Methodology
Version 1.0 (PC-DOS)
Developer: ARINC Research Corp.
EPRI Project Manager: Jerome Weiss

AWARE™: Methodology for the Allocation of Water Resources
Version 1.0 (PC-DOS)
Developer: S. Levy, Inc.
EPRI Project Manager: Charles Sullivan

CABAMP: Cable Ampacity
Version 1.01 (PC-DOS)
Developer: Power Technologies, Inc.
EPRI Project Manager: Tom Rodenbaugh

CABLPUL: Maximum Pulling Lengths for Solid Dielectric Insulated Cable
Version 1.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

CLASSIFY-Plus (Commercial): Customer Preference and Behavior
Version 1.0 (PC-DOS)
Developer: National Analysts
EPRI Project Manager: Thom Henneberger

CLASSIFY-Plus (Residential): Customer Preference and Behavior
Version 1.0 (PC-DOS)
Developer: National Analysts
EPRI Project Manager: Thom Henneberger

COOLTA™: Cooling Tower Advisor
Version 1.5 (PC-DOS)
Developer: EPRI (EPRIGEMS)
EPRI Project Manager: John Bartz

CORAL™: Control Retrofits Assessment Library
Version 1.0 (PC-DOS)
Developer: EPRI (Control Simulation and Diagnostic Laboratory)
EPRI Project Manager: Murthy Divakaruni

DIRECT: Direct Stability Analysis Program
Version 3.0 (DEC-VMS)
Developer: Ontario Hydro
EPRI Project Manager: Gerry Cauley

DSAS: Distribution System Analysis and Simulation Program
Version 2.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

FRAMER: H-Frame Design, Analysis, and Reliability
Version 1.0 (PC-DOS)
Developer: EPRI (Transmission Line Mechanical Research Center)
EPRI Project Manager: Paul Lyons

HOTCALC™: Commercial Water Heating Performance Simulation Tool
Version 1.0 (PC-DOS)
Developer: Abrams & Associates
EPRI Project Manager: Karl Johnson

LightCAD™: Lighting Design/Engineering Efficient Lighting Systems
Version 1.0 (PC-DOS)
Developer: Hart, McMurphy & Parks & Weidt Group
EPRI Project Manager: Karl Johnson

MarketTREK™: Market Penetration Forecasting Tool
Version 1.0 (PC-DOS)
Developer: Research Triangle Institute
EPRI Project Manager: Thom Henneberger

QUICKTANKS™: Underground Tank Risk Management Model
Version 3.0 (PC-DOS)
Developer: Decision Focus, Inc.
EPRI Project Manager: Anthony Thrall

RAM (PRAM/HISRAM): Predictive Reliability Assessment Model/Historical Reliability Assessment Model
Version 1.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SCALE: Simplified Calculation of Loss Equations
Version 1.0 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

SURIS: DSM Survey Information System
Version 3.1 (PC-DOS)
Developer: Plexus Research, Inc.
EPRI Project Manager: Paul Meagher

EPRI Events

JUNE

1–3
International Conference on Controls and Instrumentation
Kansas City, Missouri
Contact: Lori Adams, (415) 855-8763

1–3
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

3–5
International Conference on the Interaction of Iron-Based Materials With Water and Steam
Heidelberg, Germany
Contact: Barry Dooley, (415) 855-2458

8–12
High-Voltage Transmission Line Design Seminar
Lenox, Massachusetts
Contact: Dick Sigley, (518) 385-2222

9–11
Acoustic Leak and Crack Detection
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

16–18
Heat Exchanger Performance Prediction Workshop
Eddystone, Pennsylvania
Contact: John Tsou, (415) 855-2220

25–26
Outage Risk Assessment and Management Workshop
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

JULY

6–9
International Conference on Electric Thermal Storage and Thermal Energy Storage
Minneapolis, Minnesota
Contact: Linda Nelson, (415) 855-2127

7–9
2d International Conference on Compressed-Air Energy Storage
San Francisco, California
Contact: Lori Adams, (415) 855-8763

7–9
Workshop on NO_x Controls for Utility Boilers
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

14–15
Retaining Ring Life Assessment Computer Code
Palo Alto, California
Contact: Jan Stein, (415) 855-2390

14–17
Machinery Alignment
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

19–22
EPRI-ASME Radwaste Workshop
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

20–21
Demand-Side Management Training Workshop
Washington, D.C.
Contact: Matt Haakenstad, (612) 473-1303

20–22
COMTECH and COOLAID Training Workshop
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

21–23
Predictive Maintenance Program: Development and Implementation
Eddystone, Pennsylvania
Contact: Mike Robinson, (215) 595-8876

23–24
Low-Level Waste Management Seminar
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

23–24
Micro-AXCESS Training Workshop
Dallas, Texas
Contact: Karl Johnson, (415) 855-2183

28–29
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

AUGUST

3–6
Check Valve Applications, Maintenance, Monitoring, and Diagnostics
Eddystone, Pennsylvania
Contact: Joe Weiss, (415) 855-2751

25–26
Workshop on Optical Sensing in Utility Applications
Philadelphia, Pennsylvania
Contact: Linda Nelson, (415) 855-2127

25–27
3d International Conference on the Effects of Coal Quality on Power Plants
San Diego, California
Contact: Arun Mehta, (415) 855-2895

SEPTEMBER

2–4
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

3–4
13th Annual EPRI NDE Information Meeting
Seattle, Washington
Contact: Mike Avioli, (415) 855-2527

13–16
International Conference on Avian Interactions With Utility Structures
Miami, Florida
Contact: John Huckabee, (415) 855-2589

17–18
Training Workshop on the Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: Hazel Mazza, (413) 494-4356

21–23
5th Incipient Failure Detection Conference
Knoxville, Tennessee
Contact: Lori Adams, (415) 855-8763

23–25
Application of Fluidized-Bed Combustion Technology for Power Generation
Cambridge, Massachusetts
Contact: Linda Nelson, (415) 855-2127

28–30
Power Quality Conference: End-Use Applications and Perspectives
Atlanta, Georgia
Contact: Marek Samotyj, (415) 855-2980

OCTOBER

14–16
Feedwater Heater Technology Symposium
Birmingham, Alabama
Contact: John Tsou, (415) 855-2220

21–23
Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

21–23
Fuel Supply Seminar
Cambridge, Massachusetts
Contact: Susan Bisetti, (415) 855-7919

21–23
National Electric Vehicle Conference
San Francisco, California
Contact: Pam Turner, (415) 855-2010

29–30
FGDPRISM Training Workshop
Austin, Texas
Contact: Rob Moser, (415) 855-2277

NOVEMBER

4–6
Utility Strategic Asset Management
Cambridge, Massachusetts
Contact: Lori Adams, (415) 855-8763

10–12
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

17–19
AIRPOL '92 International Seminar: Solving Corrosion Problems in Air Pollution Control Equipment (call for papers)
Orlando, Florida
Contact: Paul Radcliffe, (415) 855-2720

17–19
Heat Rate Improvement Conference (call for papers)
Birmingham, Alabama
Contact: Pam Turner, (415) 855-2010

17–20
Market Research Symposium
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

DECEMBER

2–4
Noncombustion Waste Seminar
Orlando, Florida
Contact: Mary McLearn, (415) 855-2487

9–11
1992 Advanced Computer Technology Conference (call for papers)
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

MARCH 1993

1–3
International Symposium on Improved Technology for Fossil Power Plants: New and Retrofit Applications (call for papers)
Washington, D.C.
Contact: Stan Pace, (415) 855-2693

Contributors


Gellings


Hanser


Sussman


Carmichael


Malcolm

Electricity for Increasing Energy Efficiency (page 4) was written by science writer Peter Jaret with assistance from two members of EPRI's Customer Systems Division.

Clark Gellings, vice president for customer systems, has been with the Institute since 1982, serving first as manager of a demand and conservation program, later as senior program manager for demand-side planning, and from 1989 through 1991 as division director. He was formerly with Public Service Electric & Gas Company for 14 years, holding several positions in the areas of marketing, rates, and load management. Gellings has a BS in electrical engineering from Newark College of Engineering, an MS in mechanical engineering from the New Jersey Institute of Technology, and an MS in management science from Stevens Institute of Technology.

Phil Hanser is a senior project manager in the Demand-Side Management Program, with primary responsibility for DSM evaluation. He joined the Institute in 1986, after five years as a senior economist with the Sacramento Municipal Utility District. He holds a bachelor's degree in mathematics and economics from Florida State University and a master's in economics and mathematical statistics from Columbia University. ■

Taking the Measure of Magnetic Fields (page 16) was written by John Douglas, science writer, with guidance from **Stanley Sussman** of EPRI's Environment Division.

Sussman, manager of the EMF Health Studies Program, joined the Institute in 1987 as a project manager for EMF exposure assessment studies. A physicist, Sussman previously worked for five years in instrumentation development and, earlier, managed research in systems modeling. He holds a BS from City College of New York, an MS from Stevens Institute of Technology, and a PhD in applied physics from Stanford University. ■

Advanced Metering: Benefits on Both Sides (page 18) was written by Marcy Timberman, science writer, with assistance from two Customer Systems Division staff members.

Larry Carmichael, manager for customer interface and controls in the Power Electronics and Controls Program, joined EPRI in 1985. Before that, he was a project manager with Science Applications International Corporation for two years. His previous experience includes work as a project manager with Systems Control, Inc. He has a BS in chemical engineering from the University of California at Berkeley and an MS in mechanical engineering from Stanford University.

Wade Malcolm has been manager of the Power Electronics and Controls Program since July of last year. Earlier he was a project manager in the Distribution Program of the Electrical Systems Division, on loan from Philadelphia Electric Company. At Philadelphia Electric, Malcolm was an engineer in the Research Division and the Electric Transmission and Distribution Department. He has BS and MS degrees in electrical engineering from Drexel University. ■

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