Emerging Markets for PV

Also in this issue • Selling Efficiency • Airport Electrification • Erosion-Resistant Alloys

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

OCTOBER/
NOVEMBER
1994

EPRI JOURNAL is published eight times each year (January/February, March, April/May, June, July/August, September, October/November, and December) by the Electric Power Research Institute.

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

EPRI JOURNAL Staff and Contributors
David Dietrich, Editor
Taylor Moore, Senior Feature Writer
Leslie Lamarre, Senior Feature Writer
Susan Dolder, Technical Editor
Mary Ann Garneau, Senior Production Editor
Debra Manegold, Typographer
Jean Smith, Staff Assistant

Brent Barker, Manager
Corporate Information

Graphics Consultant: Frank A. Rodriquez

Address correspondence to:
Editor
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

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Cover: Pacific Gas and Electric operates a 500-kW photovoltaic system near its Kerman substation to provide grid support—a PV application seen as having tremendous untapped market potential. (Photo courtesy of Siemens Solar Industries.)

EPRI JOURNAL

Volume 19, Number 7 October/November 1994

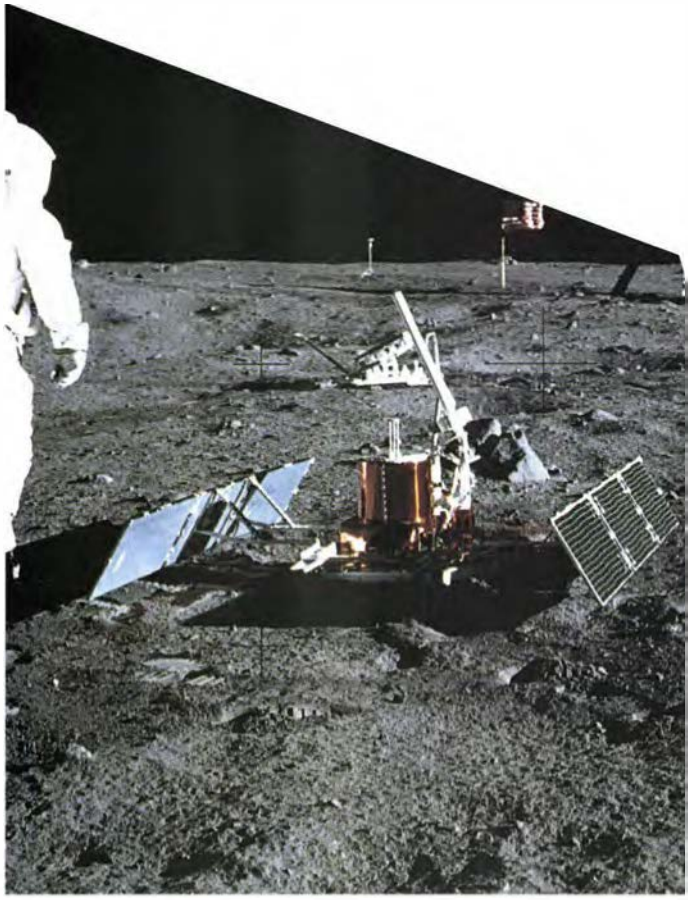
COVER STORY

FEATURES

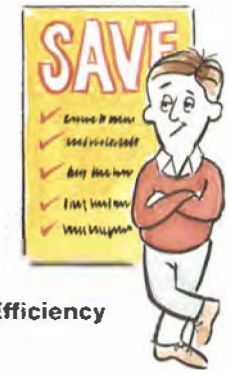
DEPARTMENTS

LISTINGS

RESEARCH UPDATES



6 Photovoltaics



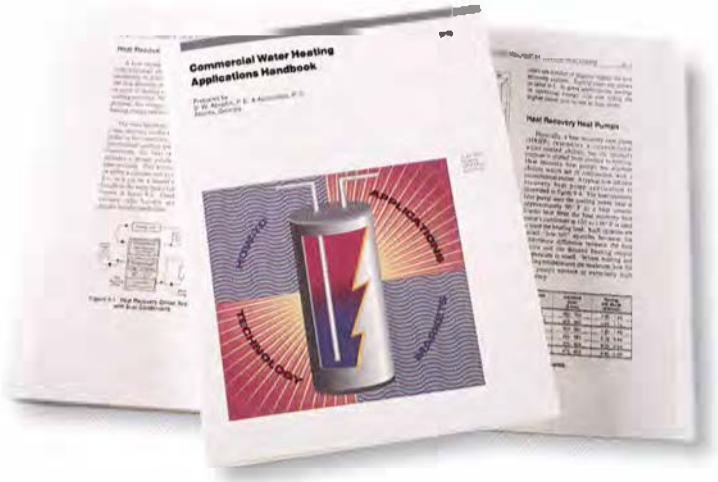
16 Efficiency

24 Airports

HOTCALC 2.0

Specially developed to help utilities and their customers design and evaluate commercial water heating systems, HOTCALC is the tool of choice for comparing high-efficiency electric alternatives with conventional water heating systems. Users can simulate the performance of five available commercial water heating technologies, swiftly assessing alternative system designs to make the best decision for a given site. Weather data, load profiles, and other data provided with HOTCALC can be used directly or modified to more accurately reflect a given case. Also, unlike other water heating software programs, HOTCALC can examine the complex interactions between water heating and space cooling loads. And its help function offers cross-references to EPRI's *Commercial Water Heating Applications Handbook* (TR-100212).

EPRI project manager: Carl Hiller. To order, call the Electric Power Software Center, (800) 763-3772.



Heat Pump Water Heater

Designed for both residential and small commercial applications, the EPRI/E-Tech heat pump water heater, manufactured by Crispaire Corporation, can reduce utility customers' water heating bills by one-half to two-thirds. The product achieves its high efficiency by using vapor compression technology to heat water by absorbing warmth from the air. Special features include the capability for ducting to enable effective cooling, dehumidification, and ventilation, as well as the flexibility to employ waste heat from laundry rooms, kitchens, or attics. The unit is about one-third the size and one-half the weight of similar technologies on the market today and sells for about half the price. It's also easier and less costly to install.

EPRI project manager: Carl Hiller. To order, call David Shuford at Crispaire Corporation, (404) 458-6643.

CHECWORKS

browitz Engineering Corrosion Workstation, or CHECWORKS, is the HEC family of computer software developed by EPRI. CHECWORKS capabilities of the CHECMATE, CHEC-NDE, and CHEC-T programs, ady in use at all U.S. nuclear plants as well as some fossil plants. rovides plant owners with a powerful new capability to evaluate w-accelerated corrosion, which affects piping and other plant components. Users can determine the structural adequacy of each inspected component through susceptibility evaluations and the interpretation of nondestructive evaluation data. CHECWORKS is also being used to quantify the benefits of changes in water chemistry, piping materials, and system operation to reduce corrosion rates.

or more information or to order, contact Bindi Chexal, (415) 5-2997.

Water Heating Handbook

The *Commercial Water Heating Applications Handbook* (TR-100212) helps users make informed decisions when selecting high-efficiency electric water heating systems. The handbook covers water heating loads, technologies, and applications, providing guidelines and a checklist for system selection, design, performance evaluation, and operation and maintenance. Appendixes present data on water heating fundamentals, case studies, equipment costs, product directories, and information resources. This product is a companion to HOTCALC, EPRI's commercial water heating performance evaluation software. *EPRI project manager: Carl Hiller.*
To order, call the EPRI Distribution Center, (510) 934-4212.

DYNAMICS

Which units should we commit today? Should we buy or sell power during the next 1–24 hours? How should we respond to changes in fuel prices and emission constraints? When should we schedule maintenance outages? How good are today's decisions? These are just some of the questions utilities can answer confidently with the help of EPRI's new DYNAMICS software code. A leading-edge unit dispatch and transaction scheduling model, DYNAMICS helps system dispatchers and planners make the most cost-effective, timely decisions possible. This product incorporates a number of significant features unavailable in conventional models, such as the capability for detailed modeling of energy storage and bulk power transactions.
For more information, contact Robert Schainker, (415) 855-2549. To order, call the Electric Power Software Center, (800) 763-3772.

Fish Population Models Demonstrated

When the Electric Consumers Protection Act of 1986 stipulated that fish and wildlife concerns be given equal consideration with other issues in the licensing of hydroelectric plants, it placed a new emphasis on the need to better understand how natural populations react to increased mortality and loss of habitat. In particular, there is a continuing need to evaluate the impacts of power generation facilities relative to other resource uses.

Traditional assessments have taken an unrealistic "equivalent adult" modeling approach, in which the loss of fish eggs, larvae, or juveniles is treated simply as a unit reduction in overall population size. In fact, fish populations may show remarkable compensatory responses to such age-specific mortality—such as better survival, faster growth, and accelerated reproduction. These compensatory relationships have long been recognized but remain poorly understood in a quantitative sense.

In 1987, EPRI launched a major long-term effort to consolidate the existing base of ecological knowledge in a series of new, more sophisticated fish population models and to stimulate basic research in this critical area by the academic and resource management communities. Called COMPMECH (for compensatory mechanisms), this program has grown from a pair of contracts with Oak Ridge National Laboratory and the Sport Fishing Institute to include a diverse group of collaborators from utilities, universities, regulatory agencies, and resource management agencies.

One focus of COMPMECH is the development of computerized population models for groups of fish species

selected to represent survival strategies that are particularly susceptible to power generation impacts. These include bay and northern anchovies, yellow perch and walleye, California halibut and winter flounder, striped bass, smallmouth bass, and rainbow and brown trout. The models extrapolate from power plant effects on individual fish at various life stages to determine short-term responses of age cohorts and long-term responses of the population as a whole. COMPMECH models have now been adapted for use at four demonstration sites.

"Already the COMPMECH project has affected a regulatory proceeding so that additional fish protection measures were not required," says project manager Jack Mattice. "Comparative analyses of the species models have shown that compensatory mechanisms can greatly reduce the effect of losses of eggs or larval fish on the adult population. The COMPMECH models are also being applied in some unexpected areas, such as in evaluations of toxicant effects and global warming on fish populations. We anticipate releasing a full suite of population models for use by EPRI member utilities and others by 1997."

■ *For more information, contact Jack Mattice, (415) 855-2763.*

The Evolution of Electrification

Although the use of electricity as a percentage of total energy continues to climb, the fundamental forces driving the process of electrification are changing. To explore the evolution of these forces, EPRI's Office of Exploratory & Applied Research sponsored a forum, "The Electricity-Society Connection," in February in Carmel, California.

"Historically, the main force that drove electrification was electricity's form value, not its price advantage," according to Sam Schurr, coauthor of *Electricity in the American Economy*. The term *form value*, he explained to the forum, refers to the precision of delivery and the convenience of use that have enabled electricity to revolutionize manufacturing and transform daily life.

Now, however, the relationship between electricity and society has become more complex, encompassing issues of environmental protection and global sustainability. For example, Veronika Rabi of EPRI and Lee Schipper of Lawrence Berkeley Laboratory told the forum that society's best interests would be served if electrification could be

used to improve the energy efficiency and environmental performance of developing countries.

New technologies are also changing the character of electrification. Phillip Schmidt of the University of Texas spoke of "a new wave of electrification characterized by the marriage of electrotechnologies with information-processing technologies." Fax machines and other electricity-based communications technologies, for example, are fundamentally changing commuting and business travel patterns. Such trends will be enhanced if electric utilities and their customers are connected via distributed networks similar to computer networks, as Douglas van Houweling of the University of Michigan believes is likely.

"A new paradigm is emerging that links electrification more closely with broader social and economic issues," says Thomas Schneider, EPRI executive scientist and chairperson of the Carmel forum. "We intend to use input gathered from these discussions to further investigate the electricity-society connection and to develop our technology strategy for the next decade."

■ *For more information, contact Thomas Schneider, (415) 855-2402.*

Theory Predicts Superconducting Critical Temperatures

Scientists have been unsuccessfully trying to explain high-temperature superconductivity since it was discovered in 1986. A theory developed by senior scientist Mario Rabinowitz of EPRI's Power Delivery Group has correctly predicted the critical temperature (T_c) at which many materials become superconducting. It also holds out the promise of many more high-temperature superconductors (HTSCs) to come, including materials that could conduct electricity without loss at room temperature or above.

The phenomenon of superconductivity depends on the pairing of electrons so that they act as a single particle, and on the quantum "condensation" of all electron pairs so that they all move together without loss through a material. Unlike much more complex theories, Rabinowitz's theory assumes that the condensation temperature is less than the pairing temperature. Thus Rabinowitz was able to proceed without having to make assumptions about the pairing interaction.

The result is a simple but far-reaching theory that works well not only for the high-T_c superconductors but for almost all superconductors and superfluids. Conventional metallic superconductors are the only exception. The theory depends on just two parameters: the density of free electrons and their effective mass. Rabinowitz thinks the reason for the theory's success is that the coherence length—the distance between electrons in a pair—is relatively short in most superconducting materials. However, in the metallics,

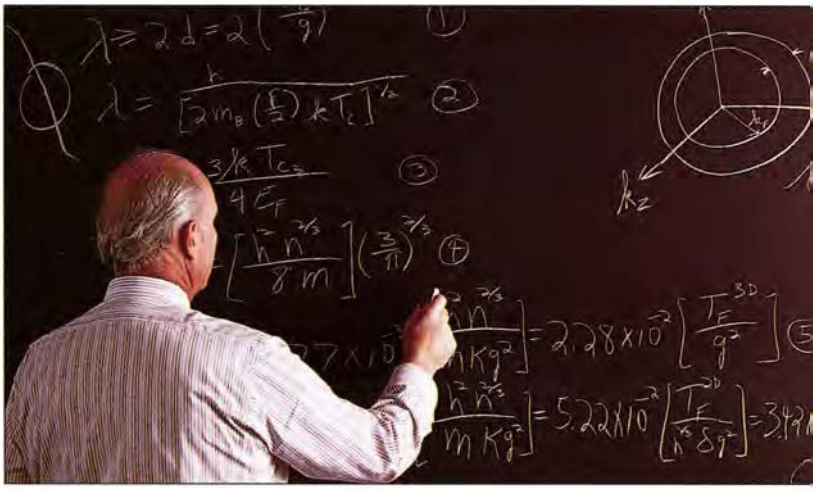


Photo by David Morin

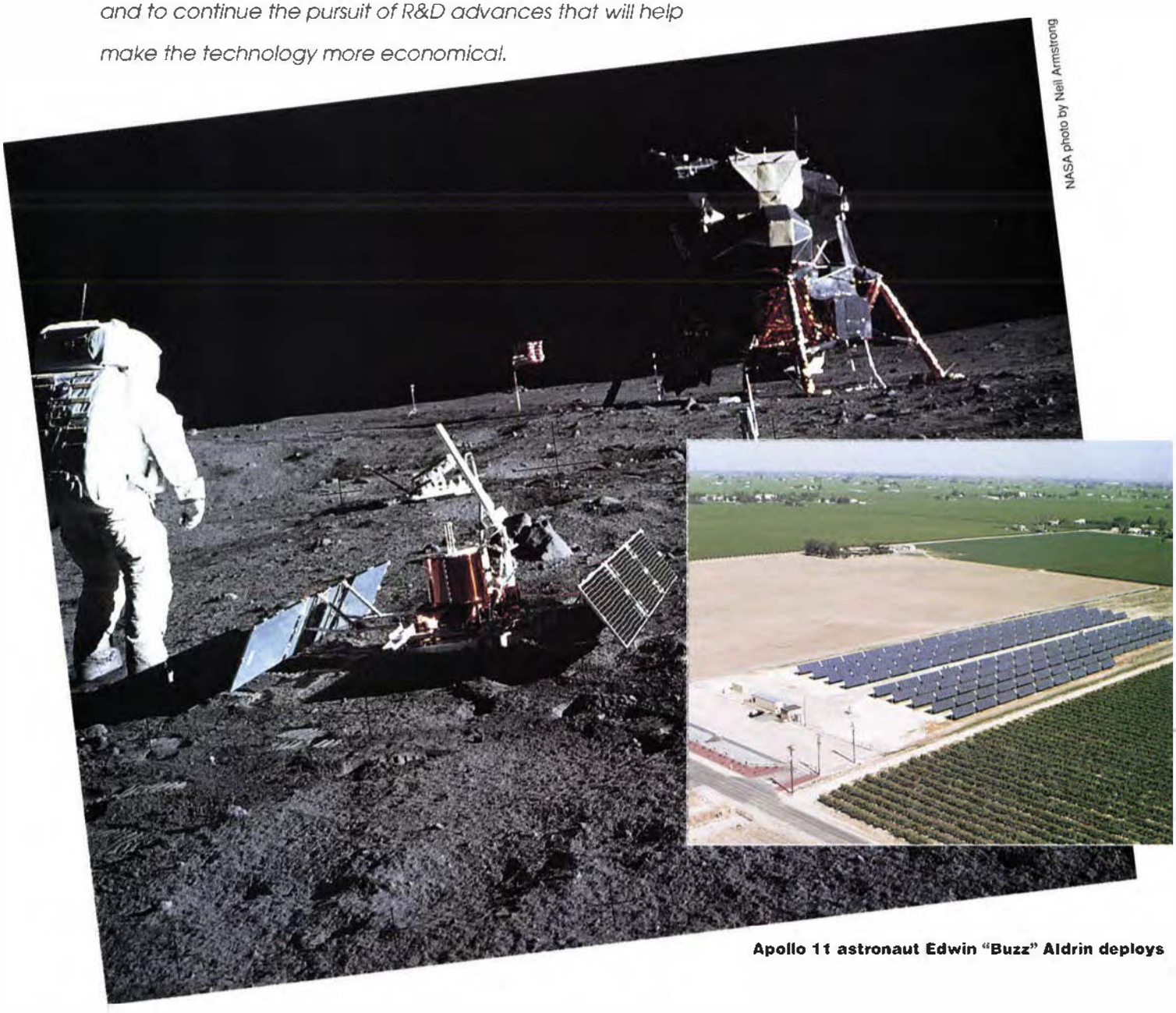
which are atypical, the coherence length is so long that the electron interactions cannot be neglected.

Rabinowitz's theory works accurately for materials ranging from superfluid ^{3}He (T_c of 0.0025 K) to neutron stars (T_c of about 10^9 K). Agreement with measured T_c values is excellent for the HTSCs at both atmospheric pressure and extremely high pressures. (First proposed in 1987, the theory has most recently been described in *International Journal of Theoretical Physics* 33, 1994, pp. 389-399, and *Chemical Physics Letters* 224, 1994, pp. 489-492.)

Looking toward the future, Rabinowitz says: "I'm very optimistic that room-temperature HTSCs will be found, since we are now less than a factor of 2 away. Hopefully they'll be put to practical use in my lifetime." He says that the search for materials with higher critical temperatures should focus on crystal structures that have a large free-electron density, small electron effective mass, and short coherence length.

■ *For more information, contact Mario Rabinowitz, (415) 855-2280.*

THE STORY IN BRIEF *Consumer items like calculators and watches were among the first commercial uses for small bits of low-performance photovoltaics, but today large, reliable, and more-efficient modules can often be spotted on streetlights, highway call boxes, microwave towers, and even building rooftops. And in developing countries as well as many developed countries, simple PV systems of just a few modules are bringing a new quality of life to remote areas that lack the basic infrastructure for electrification. While the technology remains too costly to compete directly with electricity generated by conventional power plants, PV producers and a growing number of electric utilities in this country have concluded that there are significant opportunities for distributed and remote applications of PV even at today's higher costs. Utilities are increasingly considering remote and even grid-connected PV systems within their own operations. They are also exploring the interest among some customers in rooftop solar modules to supplement their electric service. EPRI is working with utilities and the PV community both to expand the applications experience base and to continue the pursuit of R&D advances that will help make the technology more economical.*



NASA photo by Neil Armstrong

Apollo 11 astronaut Edwin "Buzz" Aldrin deploys

Emerging Markets for Photovoltaics

Pacific Gas and Electric's PVUSA Kerman site.

by Taylor Moore

In this twenty-fifth anniversary year of America's manned landing on the moon, much has been made of how the decade-and-a-half-long, $25 billion, all-out space race with the former Soviet cold war rival affected U.S. technology and economic competitiveness. In addition to giving a big boost to the then-nascent electronics and computer industries—a boost that helped fuel economic growth for many years—the space program left two energy technology legacies that have gained solid footholds in earth-bound applications.

One of these technologies is fuel cells. The other technology—solid-state solar photovoltaic (PV) cells and modules that turn sunlight directly into electricity—has already been demonstrated at multimegawatt scales and also has the potential to become a significant source of modular, distributed generating capacity. PV has successfully moved beyond its initial development as a very high cost but essential and effective space power source to become a small but diversified and enduring worldwide industry—an industry serving multiple markets and led by firms based in the United States, Japan, and Germany.

Granted, the PV industry has been largely sustained since the 1970s by a combination of government and private investment in basic R&D and manufacturing development, which in the United States alone has exceeded $3 billion over the last 20 years. No company yet claims to have recorded cumulative net profits from PV manufacturing, and most have spent much more in R&D than they have made in product sales. Several technologies and the U.S. PV manufacturing industry have also endured the oscillations of national policy interest in solar and other renewable energy resources. Internationally, the number of major oil company owners of PV manufacturers has shrunk from seven to two since the first oil price shock sparked investment interest more than 20 years ago, and only one of the two is a U.S. firm.

But along the way, as the cumulative production of PV modules has grown and manufacturers have moved further along the learning curve, the installed costs of PV systems have continued to come down from outer space. In the past decade, PV sales have climbed by a factor of 4 or more to over 60 MW annually, while installed costs have fallen by more than half.

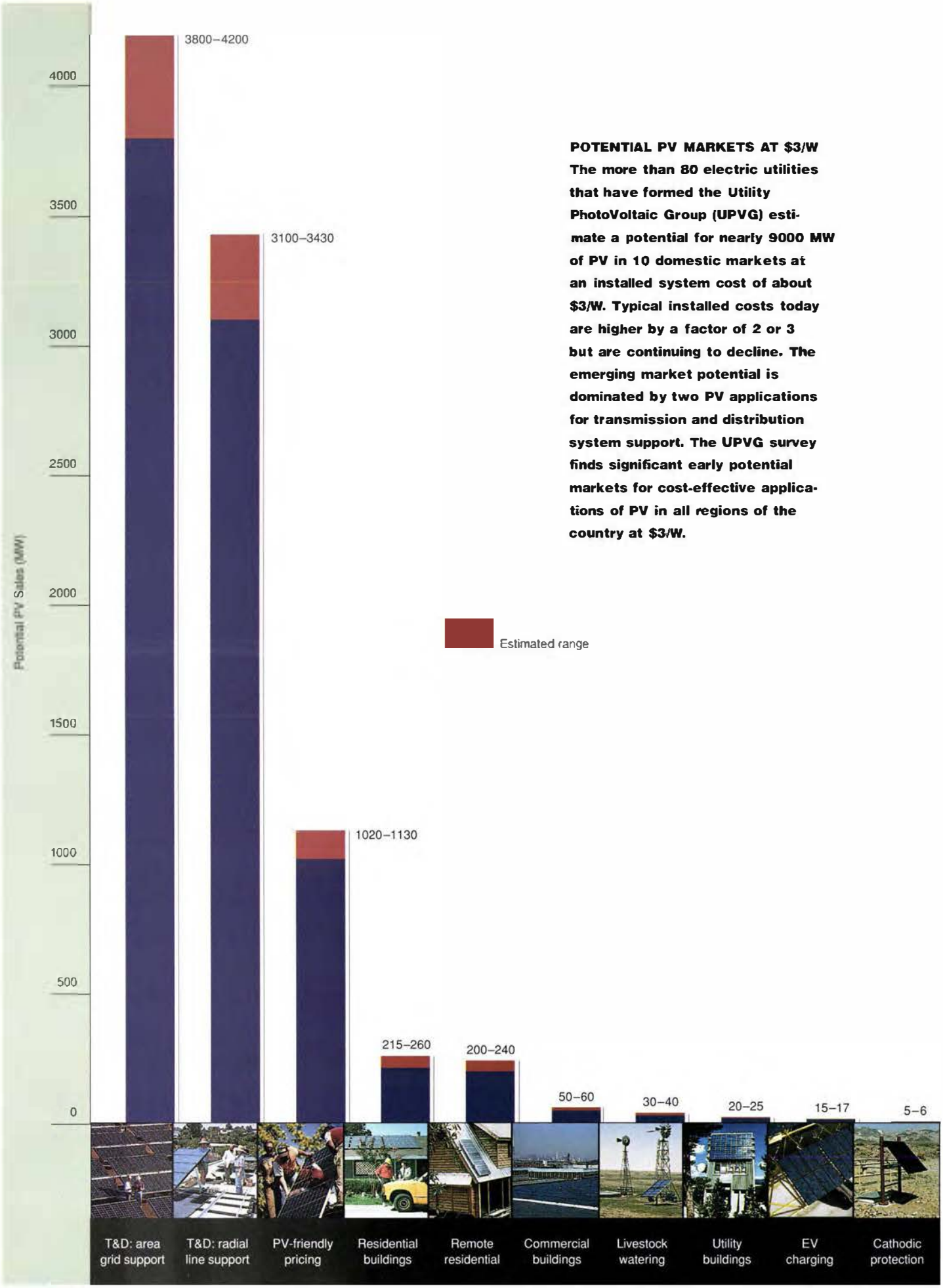
Today's lowest quoted costs for installed PV systems are around $6-$7 per watt of nameplate rating—still higher by a factor of 3 or more than the $2/W that EPRI and many utilities have long considered necessary to compete with conventional sources of bulk power generation. But many observers agree that PV is continuing to close on the target. Considering advanced PV technologies of multilayered thin films and high-efficiency concentrator systems, experts predict with increasing confidence that the twin aspects of the holy grail for PV systems capable of generating electricity at 6–8¢/kWh—a net stabilized efficiency of 15% and a cost of $60–$100/m^2—may be reached early in the next decade.

On the brink of self-sustaining momentum

According to the Utility PhotoVoltaic Group (UPVG), which was formed in 1992 by electric utilities to accelerate cost-effective PV applications and aggregate market demand and which now has more than 80 members, $3/W is the installed system cost that could represent a critical threshold for self-sustaining (nonsubsidized) PV commercialization in domestic markets. At that point, the group believes, prices would be sufficiently low to attract volume purchases, which would drive production costs still lower; this, in turn, would make PV economical in even more applications and markets.

The additional sales for new cost-effective applications would help support multiple manufacturers capable of producing 50–100 MW a year, up from today's maximum commercial factory output of 5–10 MW a year. UPVG estimates that only about another 400 MW of aggregate PV purchases may be needed to achieve the $3/W price level, assuming that R&D continues to improve performance and to lower cost. With worldwide PV sales now amounting to over 60 MW a year and growing, the price target could be reached in less than five years.

photovoltaic-powered lunar experiments package, July 20, 1969.



POTENTIAL PV MARKETS AT $3/W

The more than 80 electric utilities that have formed the Utility PhotoVoltaic Group (UPVG) estimate a potential for nearly 9000 MW of PV in 10 domestic markets at an installed system cost of about $3/W. Typical installed costs today are higher by a factor of 2 or 3 but are continuing to decline. The emerging market potential is dominated by two PV applications for transmission and distribution system support. The UPVG survey finds significant early potential markets for cost-effective applications of PV in all regions of the country at $3/W.

Shipments of cells and modules from U.S. PV factories last year jumped by 34% over 1992 levels to almost 21 MW of peak rating, marking the ninth consecutive year of growth; since 1988, the increase has averaged 17% a year. U.S. manufacturers shipped $110 million worth of PV in 1993, a value 26% greater than that for the prior year. The portion of U.S. production destined for overseas markets is growing even faster than total sales, with about three-quarters now going for export, according to the government's tally.

The leading U.S. producers are Siemens Solar Industries, Inc., a unit of the European electronics conglomerate Siemens, and Solarex, Inc., which is owned by a subsidiary of Amoco Corporation. Worldwide, the vast majority of PV production continues to be in various forms of crystalline silicon, and as evidenced by continuing price declines, producers are still wringing costs out of the manufacturing processes for this technology. Further, most manufacturers and several small startup companies are intently pursuing the development and scale-up of thin-film technologies. For now, these technologies are not as efficient as crystalline silicon PV in converting sunlight to electricity. Ultimately, however, thin films employing amorphous silicon or other semiconductor materials promise the lowest-cost PV systems by virtue of their very low materials requirements and their potentially high efficiency (due to the use of multiple films tailored to absorb a broader spectrum of sunlight).

Even for crystalline silicon, potential further cost reductions are on the horizon. Australian researchers at the University of New South Wales earlier this year outlined a new concept for making crystalline cells one-tenth as thick as ordinary cells—almost as thin as thin films—but using metallurgical-grade, impurity-laden crystalline silicon, which is very low in cost. Meanwhile, the U.S. electronics manufacturer Texas Instruments is developing for possible commercialization a spheral-cell approach that also uses low-grade silicon. Proponents of both of these approaches believe that they have the potential to bring the installed cost of PV systems to less than $3/W. And beyond those possibilities, EPRI and Oak Ridge National Laboratory are participating in a joint effort to explore new concepts for thin-layered, polycrystalline silicon PV.

Sharpening the market focus

Advanced technologies and their potential for cost breakthroughs notwithstanding, many experts within the PV manufacturing and electric utility industries are sensing that the economic threshold for significant PV market growth and expansion in demand is not far off even with today's generally 10-12%-efficient crystalline silicon modules. This is substantiated by the growth in sales of current technology, which is coming mostly from various off-grid remote or rural electrification applications. These applications have much higher thresholds at which PV (usually coupled with battery storage) is economically competitive today with such alternatives as self-generation employing fossil fuel combustion. And compared with the cost of just a short utility distribution line extension (less than a mile), PV may be the overwhelming choice.

Solarex

T&D: RADIAL LINE OR FEEDER SUPPORT
Part of 15 kW of PV modules installed by Southern California Edison on a school rooftop in Pasadena for distribution feeder support.

Even in the United States, there are substantial rural areas to which electric service does not extend because of the high cost of serving limited numbers of customers. A disproportionate share of the market potential for PV in this country, relative to current electricity sales, is ascribed to rural electric cooperatives because of the opportunities for distribution feeder support and remote PV applications (such as livestock water pumping).

UPVG's utility members have identified a potential for nearly 9000 MW of PV in 10 specific markets in the United States at an installed system cost of $3/W. An early potential for more than 100 MW was identified in each of 31 states. Every state in the union shows at least some early market potential for PV, and there is substantial potential in states beyond those typically thought to have high solar resources.

UPVG's publication earlier this year of a six-volume analysis of potential utility markets for PV, coupled with a comprehensive action plan for stimulating demand in those markets, signals the organization's emergence as an umbrella for the electric utility industry's increasing

T&D: AREA GRID SUPPORT
Sacramento Municipal Utility District's Hedge substation system.

Siemens Solar Industries

Utilities Planning More PV Projects

Beyond the PG&E, SCE, and SMUD efforts, a number of utilities are laying new plans to deploy and demonstrate PV. Many of these are being proposed under the utility- and DOE-funded TEAM-UP program; others were begun under PVUSA; and some are being initiated under EPRI's CUE program for tailored collaboration in PV projects.

Utilities have already begun to demonstrate PV for T&D support applications, which could become an important early market for the EPRI high-efficiency concentrator array using crystalline silicon cells originally developed for EPRI at Stanford University. In the past several years, Amonix, Inc., of Torrance, California, has led a team of EPRI contractors in commercializing high-performance 20-kW arrays incorporating these cells, which hold the record in sunlight-to-electricity conversion efficiency (over 28%) for a silicon PV device. Amonix's cells are averaging 25% efficiency in production, and early arrays are expected to have about 18% net efficiency.

This fall, Arizona Public Service Company is installing the first 20-kW high-concentration array from Amonix as part of the utility's STAR (Solar Test and Research) site at its Ocotillo power plant near Tempe. APS is also considering the demonstration of thin-film PV systems as well as dish-Stirling solar generation there. Amonix is in discussions with more than a dozen other utilities and hopes to deploy about 10 concentrator arrays over the next couple of years. The company reports increasing commercial interest in the technology from companies in India and Saudi Arabia. It says it is confident that at a production level of 100 MW a year, high-concentration arrays could be offered at an installed system cost of $2/W and could be expected to generate electricity for 8–10¢/kWh.

Utilities in Texas are also warming up to PV. Central and South West Corporation has established a solar test site at Fort Davis that features several types of PV technology and hardware. Two 100-kW systems, one a flat-plate type and the other a concentrator unit, were installed this year, and a third 100-kW system is expected to be operating by the middle of next year. C&SW has also installed several smaller PV systems, including some rooftop and water-pumping units. TU Electric, meanwhile, is planning to demonstrate several PV systems over the next four years, along with a dish-Stirling receiver, fuel cells, and wind turbines. The site will be an energy technology center set to open this fall near the Dallas–Fort Worth International Airport. Plans call for some PV modules to be architecturally integrated into the building.

Both C&SW's and TU Electric's PV demonstration efforts are being multiplied in effect through tailored collaboration under EPRI's CUE program. Salt River Project and Houston Lighting & Power Company are also collaborating with EPRI on planned PV projects. Other utilities that want to leverage a business investment in PV applications development are encouraged to call EPRI project manager Frank Goodman at (415) 855-2872. A key objective of the CUE program is to form an alliance for PV applications projects through which utilities and others can share results in an organized manner and can participate in the development of needed application and planning tools.

Nevada Power Company plans to install an 18-kW PV system at a commercial customer's building in Las Vegas under a program cosponsored with the EPA. The utility has proposed several other grid-connected PV projects, including the installation of a 20-kW concentrator array from Amonix. The utility also provides remote PV-powered service to four customers in a demonstration program for off-grid residences.

Reflecting a growing recognition of PV's potential for cost-effective niche applications in states north of the Sunbelt, the New York Power Authority is set to announce plans to install up to 100 PV systems over the next four years. Averaging about 40 kW each in peak rating, these systems will be sited on the rooftops of a variety of public-sector customer buildings, including schools and government buildings. □

interest in PV. The group's statement on market potential is only the latest of the positive indicators buoying optimism about the PV industry's prospects.

UPVG is supported by member utility investments and a grant from the U.S. Department of Energy and was formed with the support of the American Public Power Association, Edison Electric Institute, EPRI, and the National Rural Electric Cooperative Association. The group has outlined a compelling strategy for electric utilities to more actively purchase and deploy existing and emerging PV technology.

The centerpiece of this strategy is the UPVG-designed program called TEAM-UP —Technology Experience to Accelerate Markets in Utility Photovoltaics. TEAM-UP is a $500 million, six-year, 50-MW PV hardware initiative geared toward speeding up the demonstration of prototype, precommercial, and early commercial utility-related PV applications. One-third of the funding is provided by DOE and two-thirds by utilities. TEAM-UP is cited in the Clinton administration's Climate Change Action Plan as a model for other renewable commercialization initiatives.

The initial phases of DOE funding have been authorized, and the program will begin awarding grants to utilities next year. The first projects are expected to get under way later in 1995. TEAM-UP is intended to become the principal framework for collaboration between utilities and DOE and will provide an opportunity for closer integration with much of EPRI's PV applications work in the years ahead. The program's goal of 50 MW of installed PV by

2000 is to be achieved principally through two hardware initiatives: one for larger-scale, grid-connected PV systems with high market growth potential, and one that would aggregate utility purchases for six to eight smaller-scale, off-grid applications.

A third initiative proposed by UPVG to speed the demonstration of emerging technologies and systems may ultimately become a collaborative mission for industry, the federal government (including the national laboratories), and EPRI. A principal focus for that collaboration in recent years has been PVUSA (Photovoltaics for Utility-Scale Applications), a seven-year-old cooperative research effort by a dozen utilities and federal and state government agencies that is led and managed by Pacific Gas and Electric Company (PG&E). PVUSA operates a major PV demonstration site at Davis, California, and eight other systems in several states. (As part of a broad restructuring, PG&E plans to relinquish management leadership of PVUSA, and the venture's future role as a PV systems testing resource is being evaluated by its various sponsors.)

Through volume purchasing and consistent procurement specifications, utilities hope to encourage a move toward uniform utility PV system standards. Meanwhile, the collection and analysis of solar resource data under TEAM-UP would be coordinated by DOE's National Renewable Energy Laboratory (NREL) in Colorado, which manages most of the DOE program in photovoltaics.

Indeed, UPVG credits DOE as being a key contributor to PV's current status, citing the department's nurturing of various technologies through basic research centered at NREL, its support for improved PV manufacturing processes (currently through a $54 million program called PVMat to match investments by PV producers in advanced manufacturing and engineering development), and its efforts to condition the market for PV and create market pull by underwriting a portion of the cost of early demonstration projects. TEAM-UP is now the principal focus of those market-conditioning efforts.

"The utilities that are moving ahead to put PV into their business plans instead of their R&D plans are the ones that will be successful in applying the technology," says Bud Annan, director of solar energy conversion at DOE. "I'm very encouraged by those utilities that have begun to look at PV in a business sense—for example, by working with real estate developers to incorporate PV into building designs or by using it as part of an uninterruptible power supply that becomes an added feature for tenants. Other utilities are looking at PV for communications or as part of an electric vehicle charging program. PV's modularity gives it an attractive ability to work in different business units—even for cellular phone applications, for example."

Siemens Solar Industries

PV-FRIENDLY PRICING
Residential rooftop installation for a participant in Sacramento Municipal Utility District's PV Pioneers program.

In the past 15 years, the use of demand-side management (DSM) technologies and options by utilities has grown from nothing into a business that boasts $3 billion in annual sales and that has cumulatively reduced aggregate utility peak load growth by an estimated 22,000 MW. UPVG and others in the PV community foresee a similar, potentially major role for PV in a new era of competition in the electricity industry—an era in which DSM and conservation, coupled with small, distributed generating facilities sited closer to the customers, will emerge as new planning paradigms.

If utilities are to make the most of distributed generation, they will need new planning tools and methods. It will be essential to validate the nontraditional benefits of distributed generation (such as deferral of transmission and distribution system upgrades, reactive power and voltage support, or reduced losses). Utilities that have begun to analyze these nontraditional benefits are finding that the closer distributed PV is sited to customer loads, the more fully the benefits are captured, because more utility-side operations upstream are affected.

Efforts are under way at NREL, EPRI, and elsewhere to develop new planning models that address many of the planning requirements for distributed generation. Meanwhile, UPVG is testing its own new model, called PVSCREEN, for incorporating nontraditional benefits in an evaluation of PV installations at specific sites in existing utility systems.

T&D support dominates market potential

Two transmission and distribution support applications account for 7000 MW of the nearly 9000 MW of potential PV sales at $3/W identified across 10 U.S. markets by UPVG. One application is area grid support, in which 100–500 kW or more of PV is installed at or near a substation. The other is radial line support, in which systems of perhaps 50–200 kW are sited along distribution circuits to relieve various problems involving, for example, load growth, voltage drop, or power quality. With over 200,000 distribution feeders in the country serving average loads of 1.4–4.8 MW, the potential PV market for T&D support is very large, even at low penetration levels.

According to a survey of UPVG members, there would be a potential market of

3800–4200 MW for area grid support if about 5% of all utility feeders were involved. A potential market of 3100–3430 MW was estimated for radial line support if about 4% of feeders were involved.

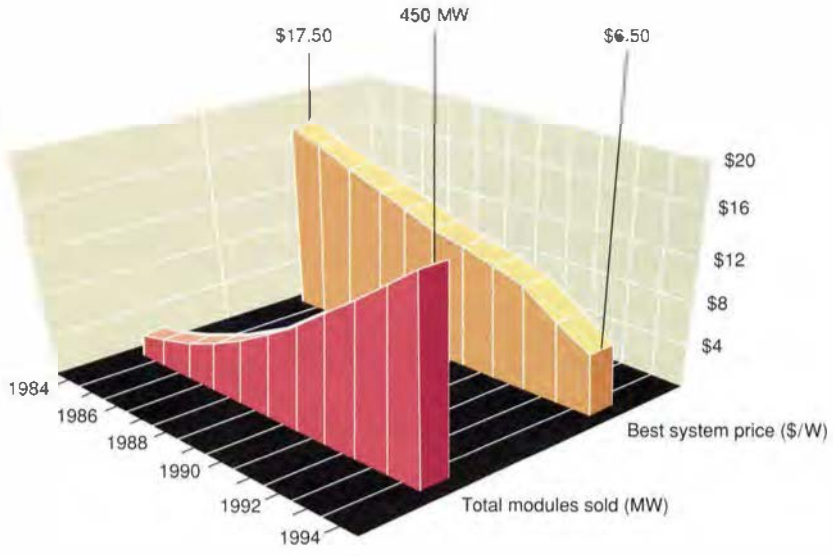
Several utility projects are already demonstrating PV for T&D support. As part of PVUSA, PG&E installed a 500-kW system with passive tracking on a feeder near its Kerman substation near Fresno; the system began operating last year. This year, the Sacramento Municipal Utility District (SMUD) began operating a 200-kW system with active tracking at its Hedge substation. And, although not specifically intended as a demonstration of the application, the almost 1 MW of PV from half a dozen manufacturers at PVUSA's Davis site operates basically in a grid-support role.

Meanwhile, to help meet growing peak demand on a 4-kV underground feeder, Southern California Edison Company (SCE) earlier this year installed the first 15 kW of what may eventually be up to 150 kW of PV on rooftops in Pasadena. Upgrading the feeder would have required removal and replacement of the underground cable conduit at considerable expense, so SCE installed PV modules on the roof of a neighborhood school instead; it may put more modules on the roofs of other cooperating customers if needed. The project is cofunded with DOE.

UPVG's utility members have identified at least 18 nontraditional benefits of distributed generation from sources like PV. In its initial Kerman case study, PG&E estimated that eight such benefits, coupled with conventional energy and capacity values, could give distributed PV or other generation a total value of over $700/kW a year. The four nontraditional benefits that have been validated since the Kerman unit began operating are at 84% of the projected values.

LIVESTOCK WATERING

More than 250 PV-powered water-pumping systems have been installed by ranchers, farmers, homeowners, and private organizations in recent years.



Source: UNISUN.

PV COSTS TREND DOWNWARD AS PRODUCTION MOUNTS In the past decade, the installed cost of PV systems has fallen by more than half while cumulative PV sales have grown by more than a factor of 4. As PV producers move further along the production learning curve and are able to lower manufacturing costs, PV becomes economical in more niche applications, triggering additional sales.

Both the PG&E and SMUD projects, which are part of PVUSA, are reportedly performing well and are generating useful data along with kilowatthours—data that will extend the experience base and help validate the industry's expectations for T&D support applications. The PG&E unit's solar output correlates well with the substation's peak load. As is characteristic of crystalline silicon PV, however, the high afternoon temperatures that drive rising peak power demand reduce the PV system's output somewhat. The utility reports some benefit from solar output in advance of peak periods that helps slow the rate of increase in temperature of the substation transformers with rising peak demand. SMUD, meanwhile, is planning to double the size of its Hedge substation system.

The UPVG member survey indicates that T&D support accounts for much of the substantial regional market potential for PV identified in the country's midsection —for example, in Texas, Ohio, and Alabama. UPVG suggests that high priority be given to utility PV demonstrations of T&D support so that data for validating the nontraditional benefits of distributed generation can be collected. The group warns, however, that until present gaps in information and experience are plugged,

T&D support markets will not be ripe for aggressive growth.

Expanding service options

After the two T&D applications, the third-largest identified early potential market for utility PV is made up of customers who may value solar or renewable energy options highly enough to respond to a strategy called PV-friendly pricing. Rather than involving residential and commercial customer installations for which the motivation is strictly economic, PV-friendly pricing involves identifying and marketing to a newly recognized segment of customers. Many utilities are developing tailored marketing strategies that help build brand identity and customer loyalty. Assuming that 70% of the more than 60 million owner-occupied residences in the country cannot use rooftop systems for technical reasons, a penetration of only 2.1% of the remaining 18 million yields a market potential of over 1000 MW for PV-friendly pricing.

SMUD is currently demonstrating PV-friendly pricing with residential customers who are hosting 4-kW rooftop PV systems through the utility's PV Pioneers program. There are already over 100 participants, and the total is expected to exceed 240. The customers not only are donating the use of their roofs but are also paying an additional $6 monthly, on average, to help defray the cost of the PV panels.

Besides the PV-friendly market, the UPVG analysis identified other potential residential and commercial rooftop applications in which PV is evaluated from the customer's side of the meter primarily for its peak-shaving value, either as part of a utility DSM strategy or by a customer to offset demand or energy charges. At a $3/W threshold, the projected potential market for PV on commercial building rooftops is 50–60 MW, with a surprisingly larger market of 215–260 MW projected for residential buildings. Counter to conventional wisdom, which postulated earlier market penetration for commercial buildings, the residential market may emerge sooner because of larger tax credits in states that offer them, generally higher electric rates than are charged commercial customers, and a greater willingness among some residential customers than among commercial customers to accept longer payback periods.

UPVG's utility members also identified a potential market of 20–25 MW for PV on the roofs of some of their own more than 16,000 buildings, ranging from generating plants to customer service centers. About 20 utilities have already installed 4- to 18-kW rooftop PV systems on customer- and company-owned buildings in a program sponsored by the utilities, the Environmental Protection Agency, Mobil Solar Energy Corporation, and EPRI.

In another subset of grid-connected markets, a potential for 15–17 MW of PV by 2001 was identified for solar-powered electric vehicle charging stations (with modules installed as part of carport shade roofs). Such stations could be used during the day while a commuter's vehicle is parked either at work or at a commercial park-and-charge lot. SCE cosponsored a 24-kW PV chargeport at the South Coast Air Quality Management District's Diamond Bar office, and SMUD has a PV-powered public charging system at one of its facilities in Sacramento.

Off the grid, more than 70 different remote PV applications have been identified that utilities believe can be cost-effective today under a wide variety of circumstances, compared with the cost of overhead distribution line extensions, which ranges from $10,000 to $60,000 per mile. Over 80 utilities already have about 2000 grid-independent installations, almost all of which are used for internal operations like powering batteries for remote switches, microwave repeaters, radio transmitters, and beacon lights. Despite the lack of adequate information to evaluate all 70 potential off-grid applications, the utility group's analysis indicates that the potential for three of the largest—remote homes, cathodic protection, and livestock water pumping—may be on the order of 350 MW.

In order to begin to pursue these rural and remote PV markets, utilities are designing special tariffs for leasing, installing, and maintaining packaged PV-power solutions for particular customer applications. Customers agree to a monthly charge that includes a percentage of the PV unit's capital cost. Idaho Power Company offered the first such remote tariff, and now SCE has begun a three-year trial, foreseeing a potential market in its territory of as much as 10 MW over the next several years. More than half a dozen other utilities also offer or plan to offer PV directly to customers under special rates.

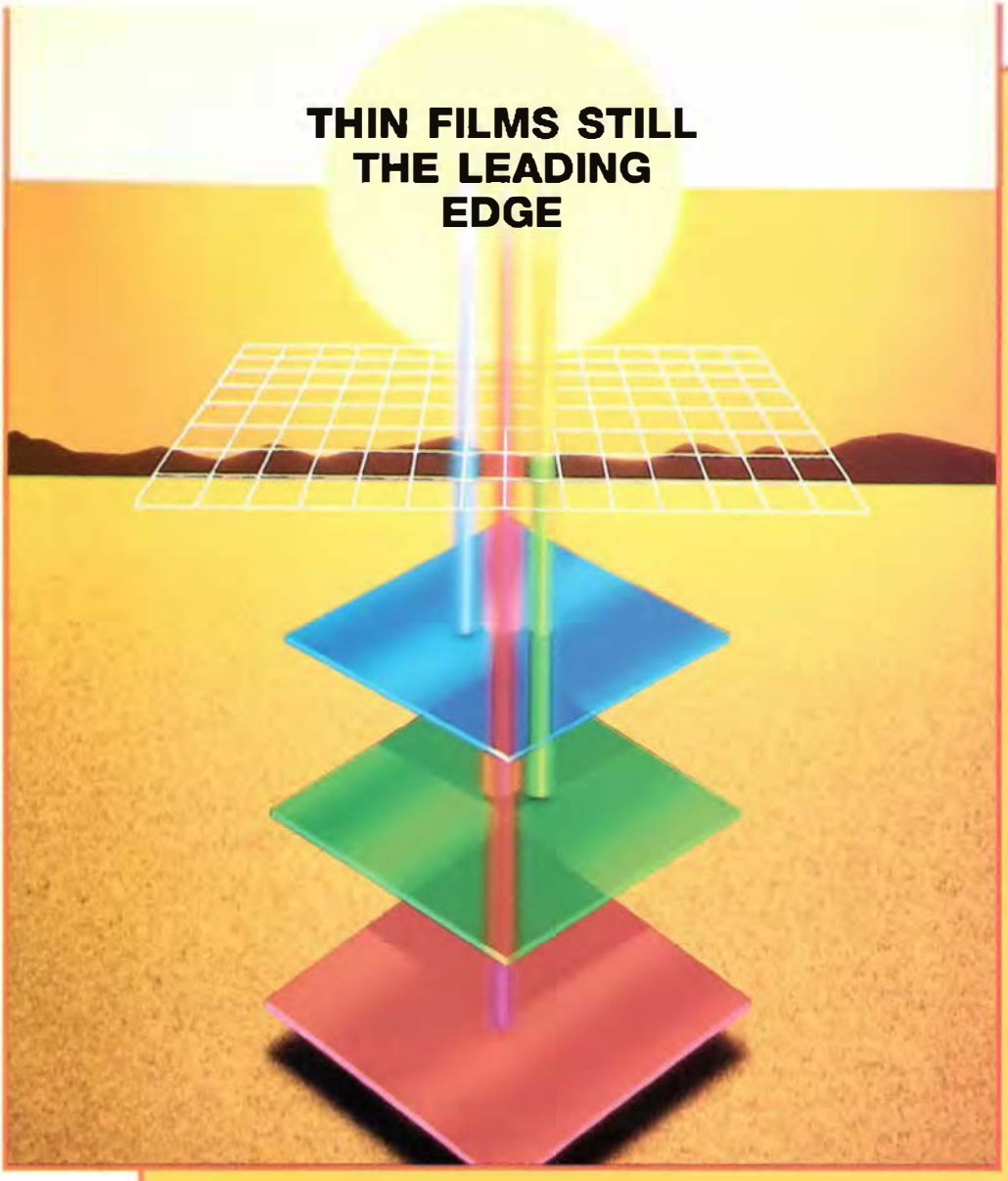
Also analyzed by UPVG—although not included in the estimated 9000 MW of early market potential for PV at $3/W—were PV markets for village electrification in 84 developing countries. Assuming sufficient funding to support PV deployment, these potentially enormous international markets could represent increasingly strong leverage for lowering domestic PV prices. About 75% of domes

NREL

COMMERCIAL BUILDINGS

New York Power Authority's 20-kW PV system atop the New York City Transit Authority central warehouse in Maspeth, Queens.

THIN FILMS STILL THE LEADING EDGE



While most of today's PV markets are being driven by the production economics of several types of crystalline-silicon-based technologies, many experts believe that if PV is to reach a $2–$3/W critical cost threshold that triggers wider use, the leading edge will be submicrometer-thin films of amorphous silicon (a-Si) alloys. The translucent, layered films can be tailored to absorb different portions of the light spectrum, making maximum use of available sunlight, both direct and diffuse.

Amenable in principle to automated, large-area deposition on simple substrates like glass or to encapsulation within flexible sheets that could be incorporated in a variety of products, including roofing materials, thin-film technologies offer some of the strongest prospects for significant further PV cost reduction. This is not only because the manufacturing technologies are more intrinsically suited to mass production, but also because thin films are at a much earlier stage of development than is crystalline silicon technology.

A major element of EPRI's PV program is focused on developing and ultimately fostering the commercial availability of multijunction a-Si thin-film modules with a net stabilized efficiency of 15% at a cost of $60–$100/m^2. The effort revolves around a coordinated university and PV industry research program in basic semiconductor materials science and fundamental device physics. EPRI is also in an alliance with a major PV manufacturer—Solarex—that is aggressively pursuing commercialization of a-Si thin-film PV.

Two years ago, EPRI adopted a team approach to focus more sharply on the rapid commercial introduction of a-Si technology. There are four teams of university and PV industry researchers. Participating are four major universities (Illinois, Iowa State, Penn State, and Princeton), thin-film manufacturers United Solar Systems Company (USSC) and Solarex, and DOE's National Renewable Energy Laboratory. USSC holds the current record in thin-film multijunction module efficiency, having achieved 10.2% with a 1-ft^2, triple-junction device in 1993.

Solarex currently produces low-wattage, single-junction a-Si thin-film battery charger modules that are about 5% efficient. With support from DOE and EPRI, the company's thin-film division in Newtown, Pennsylvania, is producing prototype double-junction modules that are about 8% efficient, and the company expects to place some 4-ft^2 prototype modules in field tests by next year. Solarex has demonstrated 9.1% efficiency in a 1-ft^2, double-junction module. The company is nearing a decision on whether to build a manufacturing facility for automated production of full-size, 8-ft^2 modules. Such products would have to be competitive with crystalline silicon PV in many remote and other niche applications to sustain commercial manufacturing.

Once large-scale production of full-size double-junction modules begins, the goal will be to increase efficiency to 10% and beyond while presumably moving down the production-cost learning curve faster than more-mature crystalline silicon PV manufacturing. As experience in manufacturing double-junction modules is gained, a third absorber layer may eventually be added, resulting in a triple-junction module. In the laboratory, Solarex has made triple-junction cells with a stabilized efficiency of just over 9%. The company acknowledges the use of results from

EPRI's university-based thin-film PV materials research in developing its double-junction technology. This technology features one layer of a-Si, which absorbs mostly medium-wavelength light, and one layer of a silicon alloy that absorbs mainly wavelengths of light in the red part of the visible spectrum.

In the longer term, copper indium diselenide (CIS) and cadmium telluride (CdTe) are promising next-generation thin-film technologies. Cells made from these materials have demonstrated conversion efficiencies of 16–17%. Prototype CdTe modules with 7% efficiency reportedly have been produced, and two companies (Golden Photon, Inc., in Colorado and Solar Cells, Inc., in Ohio) are nearing pilot production capability.

CIS may be still further away from commercial production. The technology's principal developer, Siemens Solar Industries, has produced full-size prototype modules that are 10% efficient and small cells that are 17% efficient, but the materials, electronics, and manufacturing methods of CIS technology have not yet begun to approach optimization. According to EPRI experts, current research results suggest that CIS-based PV modules are likely to eventually reach and surpass the Institute's cost and performance targets for widespread economic application of PV.

EPRI's exploratory research in PV is supporting fundamental studies of CIS at the University of South Florida, Penn State, and the University of Delaware. Topics of investigation include key materials problems that limit performance, possible use with other semiconductor combinations in multijunction modules, computer simulation of device physics, and exploration of advanced fabrication methods. EPRI research managers say that the program, as well as the efforts of PV manufacturers active in CIS technology, could lead to cost-effective, 30%-efficient modules, but probably not until after the year 2010. □

tic PV production today is sold to overseas markets, and some U.S. utilities are interested in potential business opportunities there as well.

According to UPVG, anecdotal market information suggests that village electrification projects can be economically justified at present installed costs. Calibrating the near-term potential for village electrification with market studies by other parties for some of the 84 countries (given current assumptions on economic growth and growth in electricity consumption), UPVG puts the early market over the next five years at 300–320 MW.

Illuminating a path to PV's future

In addition to identifying today's PV market opportunities that can lead the way to a self-sustaining commercial manufacturing industry, UPVG has made a number of recommendations for increased coordination and evolving relationships among the parties whose support is essential for the success of programs like TEAM-UP. EPRI, which has provided staff resources to UPVG, anticipates continued involvement as the number of new utility demonstration projects involving EPRI members climbs as a result of TEAM-UP. The program's efforts may complement those of EPRI's CUE program (Cooperative Utility Experience in PV Applications Development and Evaluation). Under CUE, tailored collaboration agreements involving some $7.5 million in cofunding have already been made with a handful of utilities, enlarging the value of their individual efforts, and others are being sought (see sidebar, p. 10).

By clarifying the outlook for near-term domestic markets and by gaining broad utility and government support for a systematic effort to encourage the development and pursuit of early market demonstrations, UPVG is showing that a self-sustaining future for the PV industry is not far off.

"We believe that PV will be a very important part of the future for utilities in general and for our company in particular," says Dick Brooks, chairman, president, and CEO of Central and South West Corporation, a holding company for several utilities in Arkansas, Louisiana, Texas, and Oklahoma. "We serve areas that are well suited to PV in terms of sunlight. In some of our sparsely populated, remote areas, PV might be cost-effective sooner than is generally anticipated."

Noting that some nonutility generating companies are considering the use of PV, Brooks says that electric utilities "should not sit back and let other companies be the ones to make use of PV. We're willing to step forward and spend some money today to make the technology happen faster than it perhaps otherwise would. We believe that the cost of PV is going to become competitive sooner in our area than perhaps in other areas. When we need additional generating capacity in a few more years, we expect to incorporate PV into our planning. We are already looking at PV, not only for T&D support and remote service applications, but also as a viable part of our future generating mix." ■

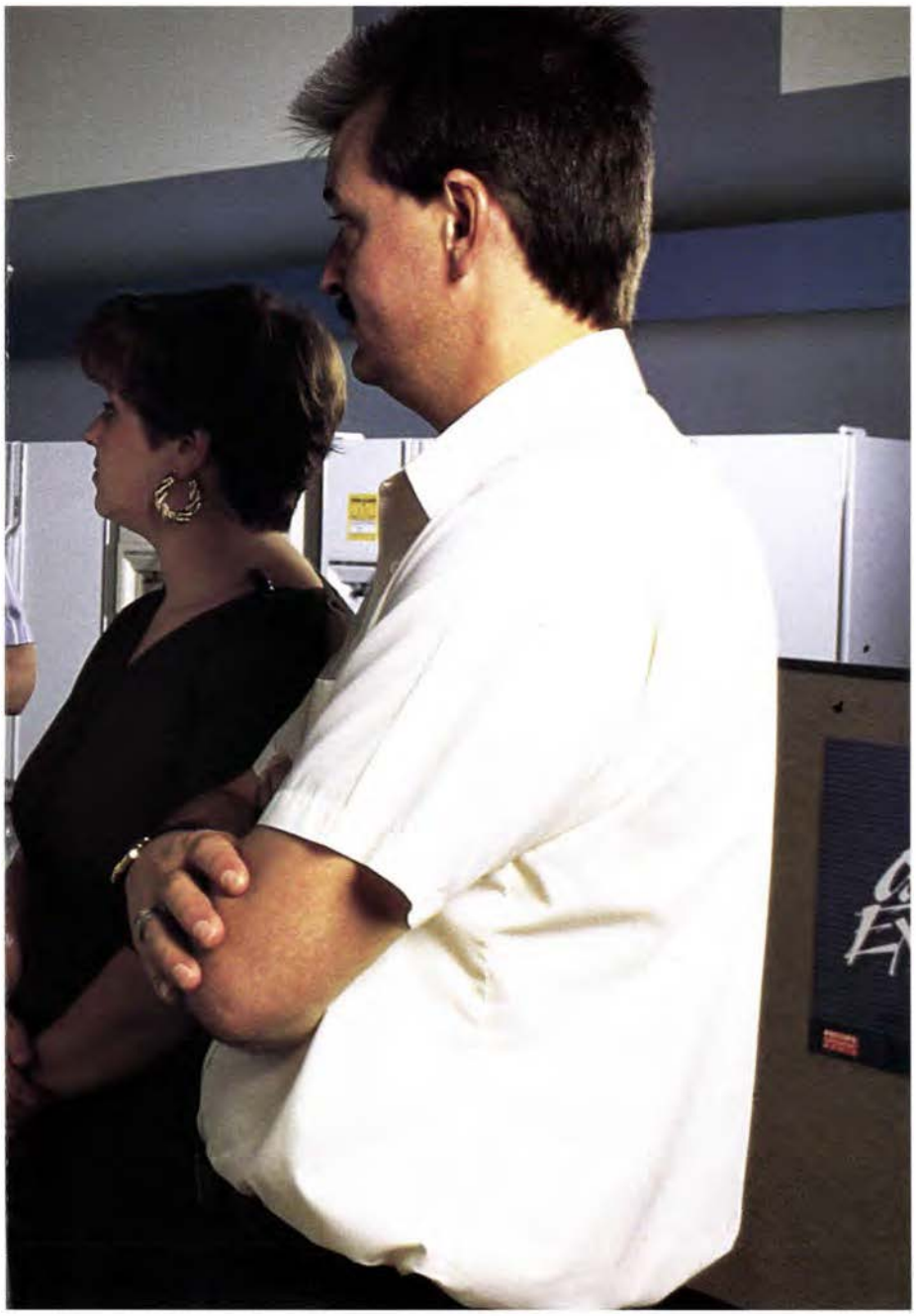
EV CHARGING

PV arrays at EV chargeports can provide cooling shade as well as help offset electricity demand during daytime charging; Southern California Edison cosponsored this PV system at the South Coast Air Quality Management District office at Diamond Bar.

Background information for this article was provided by John Bigger, Ed DeMeo, Frank Goodman, and Terry Peterson of the Generation Group's Renewables, Storage & Hydro Business Unit.

by Leslie Lamarre

Although utility programs promoting energy-efficient technologies have gotten consumers to adopt some efficient products, there's still plenty of room for improvement. Recent EPRI research examines common barriers that can hinder the adoption of energy-efficient technologies and suggests actions that utilities can take to overcome these barriers.



FFICIENCY
A Hard Sell

Two decades ago, when the United States was mired in an energy crisis that had Americans turning down their thermostats and waiting in long lines for gasoline, energy conservation was a way of life for many utility customers. Back then, energy efficiency in itself would have been sufficient to pique consumer interest in new technologies. Not anymore. After the Arab nations lifted their ban on oil exports to the United States, the cost of oil plummeted, and Americans turned their thermostats back up and filled their gas tanks to the brim. Energy efficiency took a backseat to more immediate concerns like comfort and convenience.

Despite an onslaught of technology development, promotional campaigns, and utility-sponsored rebate programs over the past 10 years, energy-efficient technologies still have not been widely adopted in the United States. "It's not that Americans have anything against saving energy," says Michael Evans of EPRI, who manages research on energy efficiency. "It's just that investing in energy-efficient technologies often requires an extra effort for them—whether it's the additional knowledge they need to gain to make an informed decision or the additional investment they may have to make to purchase the technologies."

This is not to say that energy-efficient technologies have not been adopted at all. In fact, the efforts of U.S. utilities to promote such technologies through both rebate and informational programs have succeeded in getting a number of consumers to try them. According to EPRI's estimates, by 1992 more than 24% of heat pumps and some 26% of water heaters sold were high-efficiency models. High-efficiency central air conditioning units captured 17% of the market in that year. Refrigerators and freezers have had even more success, with 1993 figures showing high-efficiency refrigerators capturing 54% of the market and freezers taking 28%. And sales of electronic fluorescent ballasts for commercial lighting have steadily increased, rising from 9.4% of the market in 1991 to 22.3% in 1993.

In compiling these statistics, EPRI de-

fined a high-efficiency technology as one having an efficiency 5% above the federal standard. The federal government has set efficiency standards for the residential sector since 1987. Today, the standards for 14

SKEPTICISM

Consumers often don't trust that new technologies will perform and save energy at the levels claimed by manufacturers.

classes of residential equipment are reviewed for potential upgrading at least every three years, offering consumers more-efficient choices all the time. Evans notes that as federal standards for efficiency become more stringent, EPRI's definition of efficient technologies becomes more selective. (At this time, the federal government does not set efficiency standards for commercial and industrial equipment.)

Although efficient technologies have made significant gains in market penetration in recent years, there is plenty of room for improvement. As suggested in a recently released EPRI report (*Overcoming Barriers to the Diffusion of Efficient Technologies*, TR-103527), the most successful technologies typically take off because of their general merit, not because of an efficiency advantage. Often, what these technologies have in common is their ability to meet consumer needs better than existing technologies do. Take, for example, the microwave oven, now used in 79% of U.S. homes. The microwave succeeded because it met an emerging need, providing fast-paced cooking to accommodate the hectic schedules of today's dual-income families. As Evans points out, no other technology provided an in-home solution to this problem. "Practically the only other alternatives were McDonald's and bologna sandwiches," he says. The fact that the microwave happened to save energy was an added benefit—a benefit that many consumers did not even consider when they purchased their units.

However, many of the efficient products sold today, such as compact fluorescent lamps (CFLs), are promoted solely on the basis of their energy-saving attributes. And as EPRI's John Kesselring, manager for residential technologies, notes, "You don't have to have a degree in marketing to understand that advertising a product as energy-efficient is not exactly a good way to sell it. There's nothing wrong with telling consumers a product is energy-efficient, as long as the focus is on other strengths as well."

In the case of CFLs, market penetration has suffered from other problems too. As revealed by a series of EPRI-sponsored surveys, consumers have had a number of technical concerns about CFLs, including the quality of light they provide, their size, and the fact that they cannot be

FIRST COST

A relatively high purchase price can discourage consumers from buying an energy-efficient technology, although first-cost concerns often take a backseat to other interests, such as performance benefits and reliable brand names.

dimmed. By contrast, halogen lamps—more efficient than incandescents but less efficient than CFLs—are becoming a big hit among consumers. And it's no wonder, since they produce a bright, white light, they're dimmable, and their small size has enabled their incorporation into an assortment of high-tech fixtures that sometimes border on art pieces.

According to EPRI researchers, utilities can learn much from their past efforts to promote energy-efficient technologies and services—knowledge that could help new technologies and services become more widely used. In fact, the researchers say, utilities will face similar difficulties in trying to sell their customers differentiated products and services in a deregulated industry environment. The first step in addressing these difficulties is to understand the barriers preventing consumers from buying new products and services. Only then, the researchers conclude, can the barriers be overcome.

To help in this effort, EPRI and the Edison Electric Institute are setting up a fund for research geared toward increasing opportunities for, and removing barriers to, the deployment of electrotechnologies. The first two projects identified for the fund are a market assessment of heat pump water heaters and an analysis of natural gas cooling issues. The intent of the heat pump water heater project is to develop accurate information on installation costs, market barriers, and customer acceptance issues in response to a U.S. Department of Energy proposal that would effectively eliminate the manufacture and sale of electric resistance water heaters. The second project will focus on a set of studies, sponsored by the gas cooling industry, that highlight the benefits of gas cooling equipment. Researchers for this project will develop a response strategy for the electric utility industry.

Big customers

Because utility customers in the commercial and industrial sectors have a vested interest in the bottom line, they are generally more interested in cost-saving, energy-efficient technologies than are residential customers. High-efficiency fluorescent lamps, motors, heat pumps, and special-application technologies like induction heating are just some of the many energy-saving technologies commonly employed in these sectors.

MEETING CONSUMER NEEDS **Often, efficient technologies are successful because of strengths unrelated to their capacity for energy savings. Such was the case with the microwave oven, now used in 79% of U.S. homes. Few consumers purchased the microwave because it saves energy over conventional cooking methods. Rather, the technology's appeal lay in its rapid cooking capabilities, which met the pressing need of a burgeoning number of dual-income families. EPRI researchers are hoping for similar success with the microwave clothes dryer, which is expected to be as much as 65% faster than conventional dryers when it hits the market in three years.**

"Industrial and commercial customers are far more likely to make calculations of payback periods than are residential customers," Evans says. "They also have the knowledge and resources necessary for making accurate technology comparisons." In most cases, commercial and industrial customers seek a payback period of three years or less. Residential customers, however, are not likely to invest the effort to calculate payback periods.

By the year 2000, EPRI researchers predict, as much as one-quarter of the energy used in the commercial sector and over two-thirds of the energy used in industry will power efficient technologies. But the researchers note that there are still major opportunities for efficiency gains, through both existing and new technologies.

One big potential source of energy savings is the advancement of electric motors, which account for some 67% of the electricity consumed in the United States. EPRI is working on a series of advanced motors that take advantage of progress made in both power electronic converters, which enable control of speed and torque, and permanent magnet materials, which can now provide up to 10 times the energy density of conventional materials. Products expected to be commercialized in the next two years include the converter-optimized, five-phase permanent magnet synchronous motor. Developed in collaboration with McCleer Power Company and the University of Tennessee at Knoxville, this advanced motor can be used in applications ranging from heating, ventilating, and air conditioning systems to machine tools and even off-road electric vehicles.

Even though commercial and industrial customers may be relatively receptive to efficiency, they still have unique concerns that can hinder their adoption of efficient technologies. For instance, investments that improve the corporate image may be highest on the priority list. As a result, a company may opt to upgrade a piece of machinery or invest in an advertising campaign rather than upgrade its lighting system, even if the new lighting system offers a faster payback. For manufacturing processes, a common concern is the risk a new technology might pose to the quality of the product, particularly during the early stages of the technology's use.

First cost—in perspective

In all sectors, the consumers most resistant to energy-efficient technologies are

those who own but do not live in or use the buildings that will house the technologies. In many cases, these consumers are also not responsible for the resulting energy bills. This category includes absentee landlords and developers. Mainly interested in maximizing profits and minimizing expenses, these customers have a good incentive for choosing the least expensive equipment allowed by local and state regulations.

Although first cost may be a primary concern for absentee landlords and developers, EPRI researchers say, it is—surprisingly—not the main issue for most customers. "We've become obsessed with the first-cost issue," Evans says. "First cost is not the be-all and end-all for most consumers." In fact, he says, many consumers put factors such as brand name ahead of cost in considering the purchase of new technologies. In all, EPRI researchers have identified some 22 factors that commercial and industrial customers typically consider in making their purchase decisions. Residential customers typically weigh more than a dozen factors. "We're not saying that first cost doesn't matter at all—it certainly does," says Evans. "We're just saying that utilities should view it in relation to other, very important customer needs and wants."

A recent success story in the residential sector is the EPRI-sponsored LTnSTAT thermostat, manufactured by PSG Industries. During its first year on the market, consumers bought more than 350,000 units, even though the units cost almost twice as much as conventional line-voltage thermostats. Aside from being more energy-efficient than conventional thermostats for electric heating systems, this thermostat provides greater comfort, maintaining temperature to within 2°F of its setting. Its digital liquid crystal display not only provides a precise readout but also gives the device the contemporary look many consumers desire. But perhaps most important, this thermostat solves a problem pervasive among the electromechanical thermostats on the market—the problem of temperature fluctuation, which can make a space uncomfortably warm or cool. LTnSTAT's frequent cycling enables a near-constant temperature by preventing the heater from overshooting the thermostat's set point. "People don't buy heat," says Kesselring. "They buy comfort."

One significant customer desire in the residential sector is aesthetic appeal. Even consumers who are informed about and interested in efficiency may opt for a less efficient appliance if it looks significantly better than an efficient model. For instance, a buyer might select a dishwasher with an electronic keypad over a more efficient and higher-performance model with buttons and dials on the panel. "We're talking about a 15-year investment. Selecting the most modern-looking appliance is a high priority for many homeowners," says Kesselring. "Some anticipate selling their home at some point in the future, and they don't want their appliances to look outdated."

SAVINGS DIFFICULT TO MEASURE

It's often difficult for utility customers to pinpoint the appliance-specific source of their energy savings from the more general information typically offered on an electric bill.

Really?

A concern that spans all market sectors is consumer skepticism about technology performance. According to EPRI's report on overcoming barriers to technology adoption, "The commercial and industrial marketplace for energy-efficient devices is replete with stories of installations which did not work, of promised savings which did not materialize, and of reversion to old systems because new ones were too complicated or cumbersome to operate." For businesses, there's an additional concern about liability, given the potential legal problems associated with using "unproved" technologies.

Residential users have experienced similar frustrations. For instance, the radiant barrier, an aluminum foil product designed to keep heat out of a house during warm months and to keep it in during cold months, was overpromoted in the late 1980s. One company claimed that the product could save more than 40% of a household's energy bill. Alert consumers immediately recognized this as an exaggeration, since heating costs alone do not often represent such a significant portion of the energy bill. Other companies marketing the same product were reluctant to contradict the inflated claims, fearing that they would sacrifice their own business.

POOR AESTHETICS

Energy efficiency is not necessarily synonymous with good looks when it comes to appliances. And given a choice between the two characteristics, consumers will often opt for the latter.

"This was a case in which the product was so overpromoted that the commercializers eventually killed their own market," says Kesselring. "No one trusted it." He notes that a similar mistrust hindered the heat pump market. The early heat pumps of the 1950s and 1960s hit the market with some technical problems that consumers did not discover until after they had purchased their units. Since that era, a number of technical improvements have breathed new life into the heat pump market. But the market struggled for years to gain the consumer confidence it has today.

Closely related to the skepticism issue is customer concern about reliability. "Particularly when it comes to the more significant purchases--water heaters, refrigerators, air conditioners, and the like--consumers, builders, and installers want to know that the equipment will last for 15 years without any problems," says Evans. But energy-efficient products often do not have an extensive track record because they are so new.

Getting to market

Another set of potential barriers involves market infrastructure. Some of the barriers in this category—for example, turnover rate--are virtually impossible to control. The turnover rate for a given product helps determine the annual market for that product. In the case of refrigerators, which will typically last for 12 years, this means that the maximum potential market penetration for a new refrigerator technology is only 8% in any year. And given other factors, such as the alternative technologies available, it is virtually impossible for high-efficiency refrigerators to achieve the entire 8% penetration.

More-controllable market infrastructure issues include the ability of the product distribution system to make the product available and to get it to the customer who wants it. If supply cannot keep up with demand, there's a potential for losing consumer interest to a competing product or products. Customers also want to know that a reliable service organization will be available in the event of a problem with their new technology. And any service organization would like to be assured that it can get the parts its workers need to repair the technology.

Market experts say that if a product is to succeed, its use should not force a significant change in consumer behavior. But there have been some exceptions to this rule. Electronic mail, fax machines, and overnight delivery services are all products that required changes in behavior yet still experienced phenomenal success. Another classic example is the microwave oven, which was introduced with the understanding that the technology required special dishes. Nevertheless, the time savings and convenience offered by the oven were overriding strengths. Soon microwave-proof dishes were available on store shelves across the country, and consumers eagerly snatched them up. Today, a wide assortment of foods, including soups, dinners, desserts, and snacks, are available in microwave-proof packaging, complete with directions for microwave preparation.

Kesselring anticipates similar success for the microwave clothes dryer now being developed for EPRI by Thermo Energy Corporation and ASTeX/Gerling Laboratories. Like the microwave oven, the microwave clothes dryer meets an existing need. "One problem with conventional dryers is that the drying takes so much longer than the washing that you've always got the wash load backed up and waiting," Kesselring notes. The microwave dryer is expected to be as much as 65% faster than conventional dryers. It works by evaporating water molecules rather than by heating the cloth itself, as is the case with conventional dryers. This means that the drying process occurs at cooler temperatures, which is good news for delicate fabrics. In fact, the microwave dryer is expected to save money on dry cleaning. The lower temperatures are also expected to help durable materials last longer.

CHANGE IN BEHAVIOR REQUIRED

New products that require consumers to change the way they behave will often meet with rejection in the marketplace.

Researchers are working to eliminate the dryer's remaining technical bugs before its commercial introduction, which is expected within three years. The researchers have already overcome the obstacles posed by zippers and buttons. Now they are addressing the scorching problem that can be caused by objects such as hairpins and paper clips.

Utility action

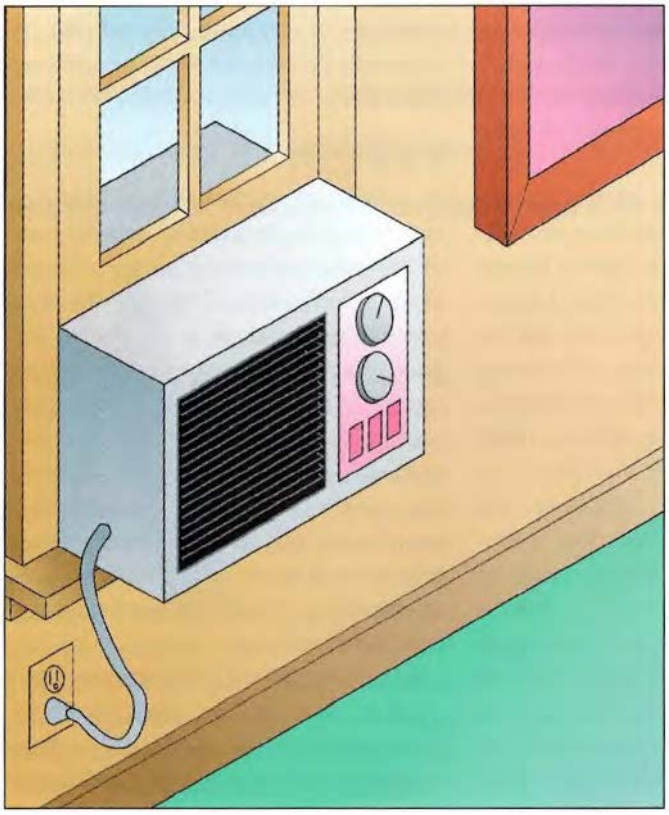
A number of utilities already offer special programs designed to address some of the common barriers to the adoption of new technologies. Perhaps the most popular among them is the rebate program. Through rebates on products ranging from CFLs to high-efficiency refrigerators, utilities have convinced some consumers to opt for more efficient technologies. As is the case with the free samples of cereal, soap, and other products consumers receive in the mail, the idea is to get the consumers to try the new product and then become hooked.

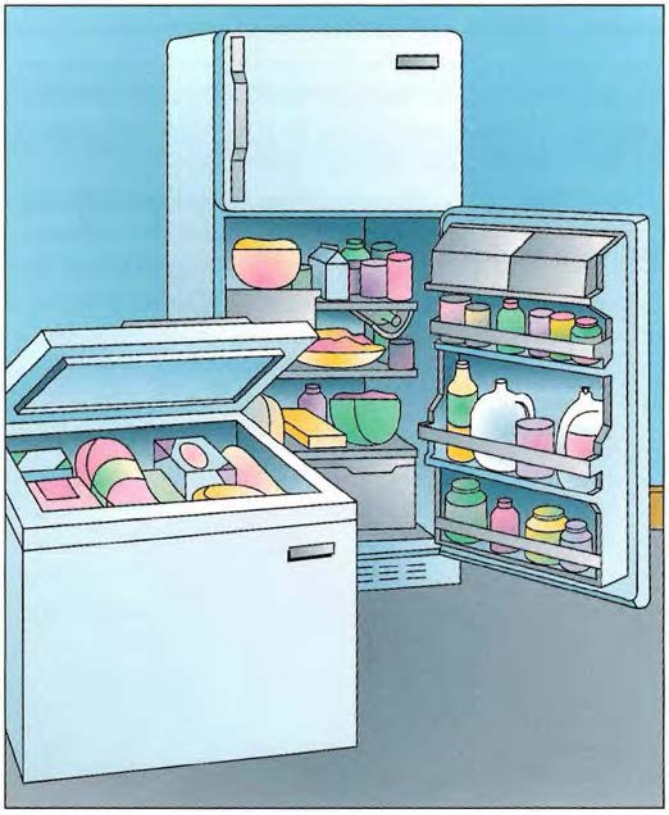
But rebates should not be the only factor keeping a market afloat. Many market experts believe, for example, that without the current utility subsidies, the CFL market would eventually evaporate. "That is not how a rebate program should work," Evans says. "The idea is to help manufacturers and sellers develop self-supporting markets for these technologies. After a few years, once there are enough units in the field and savings and performance have been documented, the market should be able to sustain itself."

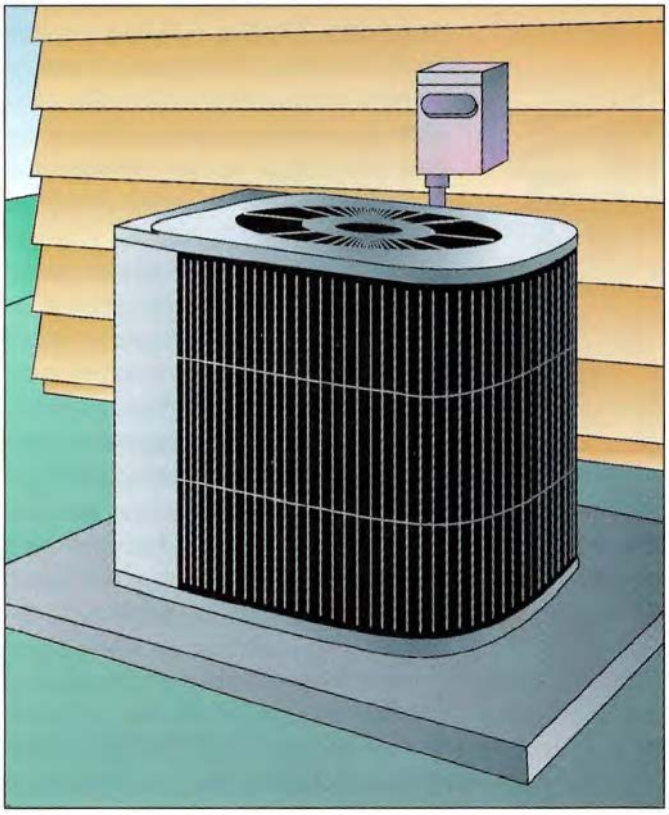
Indeed, subsidies are not usually enough to ensure that new products succeed. As EPRI's research suggests, information and education are also critical. Evans notes that gathering data on relatively new technologies is particularly important, since the information can be used to develop a case for reliability. He recommends that utilities take advantage of their marketing and information infrastructures to disseminate such valuable information to consumers.

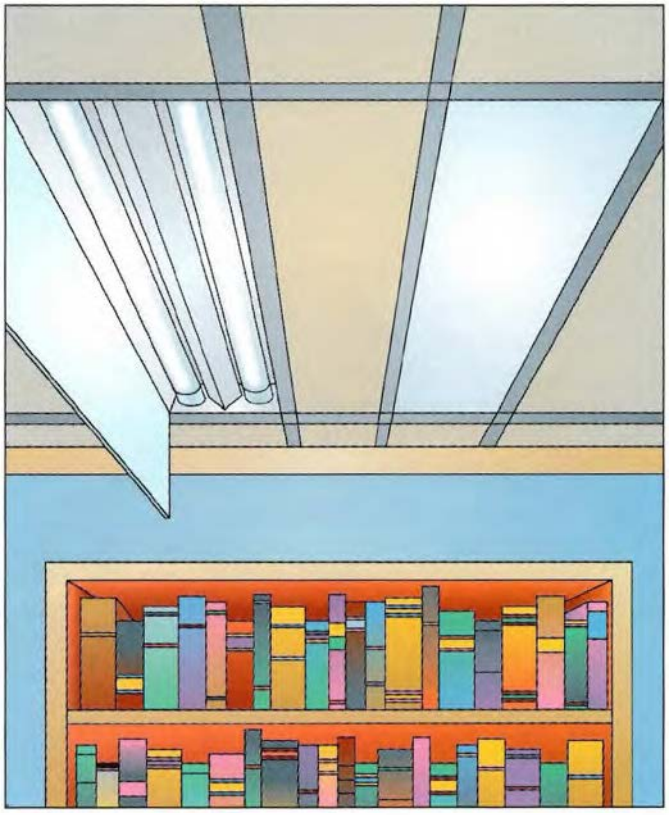
Utility influence can go well beyond the dissemination of information, however. Because of their direct link to so many consumers, utilities often have the clout to encourage manufacturers to improve the

SETTING THE STANDARD **To help improve the nation's energy use, the federal government sets efficiency standards for residential appliances and regularly reviews them to determine whether they should be upgraded. At this time, no such standards exist for commercial and industrial equipment.**









performance and energy efficiency of certain products. As Kesselring notes, "Utility customers represent a significant potential market for these manufacturers. The chances are that if a utility wants to promote a specific product through a special program, the manufacturer is going to listen to utility suggestions about how to improve that product."

A number of utilities have already taken advantage of their influence by joining together in consortiums geared toward improving specific technologies. For instance, the Office Technology Efficiency Consortium—established by electric utilities, government agencies, and research organizations, including EPRI—works with equipment manufacturers and large commercial customers to improve the energy performance of automated office technologies. Specifically, the group is interested in making those technologies more energy-efficient and in solving associated power quality problems.

Similarly, the Consortium for Energy Efficiency (CEE)—consisting of utilities, the U.S. Environmental Protection Agency, and advocacy groups like the Natural Resources Defense Council and Greenpeace—works to promote the energy efficiency of a number of appliances. The group's first major project was the well-publicized Super Efficient Refrigerator Program, which promised $30 million to the manufacturer that produced a model 25% more efficient than the federal standard. The winning model also could not contain chlorofluorocarbons. Whirlpool won the competition, and its refrigerator is now on the market in selected regions of the United States. CEE is now sponsoring projects on CFLs, laundry technologies, and ground-source heat pumps.

It is critical that utilities carefully analyze the needs of their customers before selecting or designing new products or services. EPRI researchers point out that by grouping customers according to similar requirements and needs, utilities can more effectively market products and services to them. The CLASSIFY system—an EPRI-developed collection of methodologies, reports, software, and other tools—is designed specifically to help utilities analyze customer needs. CLASSIFY helps utilities group end users into behavioral segments based on their attitudes toward a wide range of energy-related topics.

In addition, the researchers recommend that utilities employ techniques, such as the customer value deployment (CVD) process, that will help them ensure market success. Introduced in Japan in 1973, the CVD process has helped deliver a number of products to the market in one-third the time it takes through conventional processes and for half the cost. Among the more than 100 U.S. firms that have relied on this technique are Xerox and Ford. Examining customer needs is integral to the CVD process, also known as quality function deployment. "It's all about getting it right at the beginning," Evans says. "The problems become more expensive and more difficult to solve as time goes on. If barriers related to infrastructure and customer preferences are addressed early in a product's development, that product will have a much better chance for success."

PROBLEMS WITH INFRASTRUCTURE

Market-related issues—as simple as ensuring that retailers can stock an adequate supply of a new product—can also affect a product's success.

The current environment of increasing competition in the utility industry could have a significant impact on future efficiency programs. Since such programs are typically written into a utility's rate base—a practice that allows utilities to recover program costs through electric rates—they could be perceived as making utilities less competitive. For example, if a utility faces stiff competition and a cessation of efficiency programs would result in a corresponding reduction in electric rates, the programs' existence could be threatened.

The other possibility, Evans points out, is that utilities may begin to market these programs for a fee charged only to customers who participate in the programs. In fact, some utilities are already selling customers such services as power quality consultation and in-depth energy audits. "It's similar to the transition that the telephone companies went through," Evans says. "Customers used to get one type of phone service for which they paid a flat fee. Now they've got a choice of additional features like voice mail, call waiting, and even voice recognition, which are helping distinguish competitors from one another."

Regardless of how things shake out in the utility industry, it is clear that the problems utilities currently face in getting customers to buy energy-efficient technologies will recur in the future as utilities begin to offer other innovative products and services, such as power quality diagnoses, real-time pricing, and advanced load management. Opportunities to tap new markets will increase as the industry moves toward deregulation. By understanding the barriers that hinder the widespread acceptance of new products and services, utilities can position themselves for success in the competitive markets of the future. ■

Further reading

Development of a Microwave Clothes Dryer. Interim report for RP3417-1, prepared by Thermo Energy Corporation and JG Microwave. July 1994. EPRI TR-103899.

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Improving the Marketing Infrastructure of Efficient Technologies: A Case Study Approach. Final report for RP2788-42, prepared by Barakat & Chamberlin, Inc. December 1992. EPRI TR-101454.

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Background information for this article was provided by Michael Evans of the Customer Systems Group's Marketing Tools & DSM Business Unit and John Kesselring of the group's Residential & Small Commercial Business Unit.

THE STORY IN BRIEF *Air quality regulations are encouraging the use of electric vehicles at urban airports across the United States. In many ways, airports offer an ideal application for EVs, given the short distances and predictable routes that airport vehicles typically travel. Even considering the emissions from power plants supplying electricity to an airport, the replacement of internal combustion vehicles with comparable electric-powered vehicles significantly reduces pollutants that contribute to such environmental problems as smog, haze, and global warming. Through EPRI's Airport Electrification Project, utilities in urban areas are working in partnership with their airport customers to devise strategies for the cost-effective implementation of EVs.*

A quiet revolution has gained a foothold on the tarmac of urban airports across the United States. Slowly but surely, airports and their tenants, including air carriers and the companies that service their aircraft, are taking steps to electrify the multitude of gasoline and diesel-powered vehicles that swarm airport grounds 24 hours a day. The movement to replace or convert internal combustion vehicles ranging from baggage carriers to shuttle buses is being propelled largely by air quality concerns.

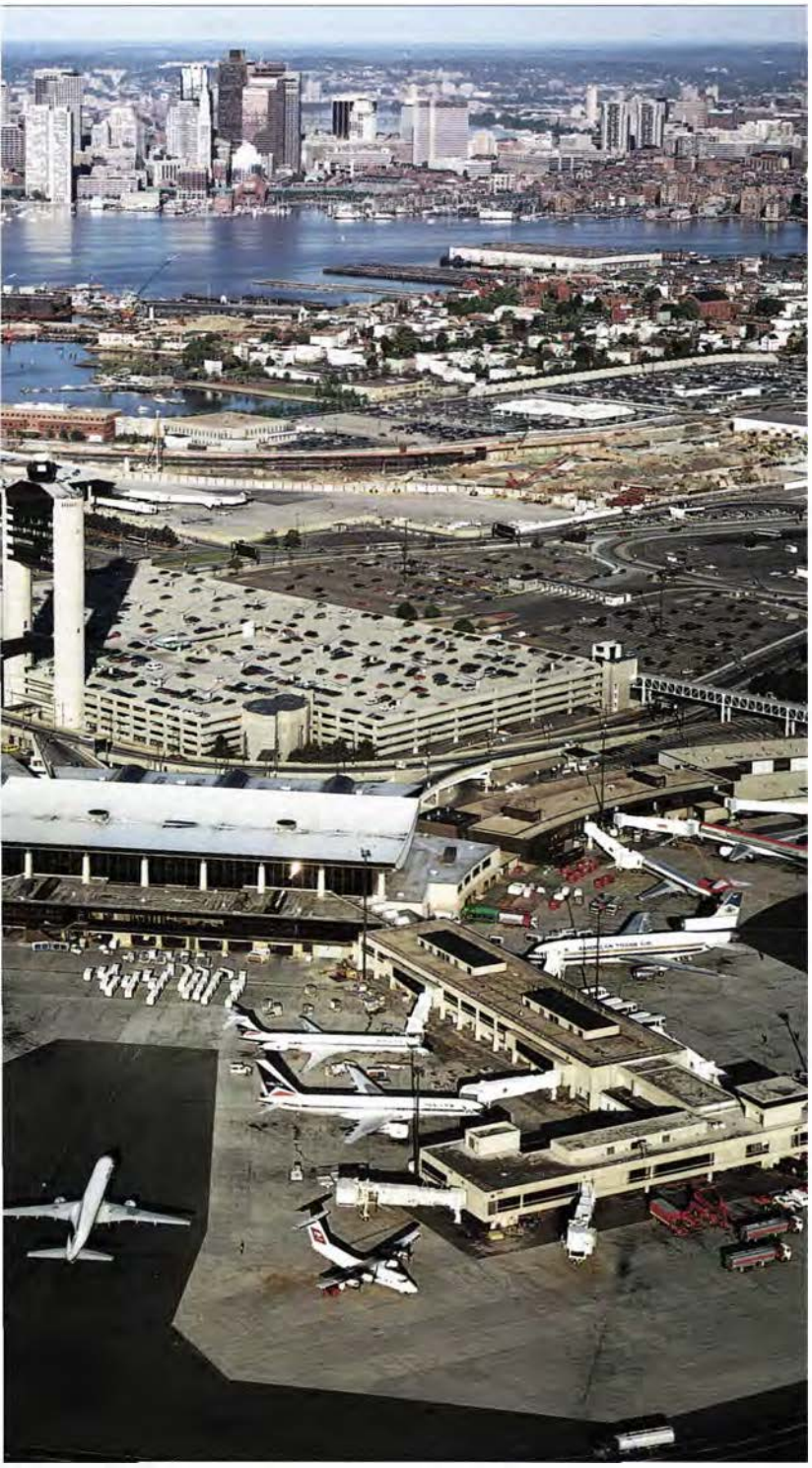
Airports can be a significant source of air pollution in urban areas. And while electrification can't do much for the emissions coming from the airplanes themselves, it can dramatically reduce vehicle-generated pollutants, which contribute to such environmental problems as urban smog, global warming, and haze. Indeed, electric vehicles (EVs) release no on-site emissions. And even when the emissions from power plants supplying electricity to the EVs are taken into account, the pollution reduction advantage of EVs is significant. Two recent EPRI-sponsored studies show that—power plant emissions and all—the electrification of vehicles at urban airports can reduce three key vehicular pollutants by more than 70%.

Ideal application

In many ways, airports are an ideal application for electric vehicle technology. The

by Leslie Lamarre

airport rEVolution



EV's relatively short mileage range between charges (compared with gasoline-powered vehicles)—a source of concern in highway applications—is generally not an issue at an airport, since vehicles used there tend to travel short distances. Furthermore, airport vehicles typically follow predictable routes, which facilitates the location of EV charging stations. But perhaps even more significant, most of the vehicles used at airports spend a lot of time idling and accelerating. For gasoline- and diesel-powered vehicles, this means fuel is used inefficiently and, given the short distances traveled, a high level of pollutants is released.

Since EVs use energy only when they are moving, they are much cleaner and more efficient than their internal combustion counterparts. The efficiency advantage can also make them cheaper to operate. Because EVs have few moving parts, their maintenance costs are considerably lower than those of conventional vehicles. Other benefits include a reduction in noise and vibration. For utilities the advantages are obvious: EVs provide a source of additional income while making productive use of off-peak power generating capacity that might otherwise be underutilized.

These advantages have already convinced some airports and their tenants to adopt a certain number of EVs. Boston's Logan International Airport recently ordered eight EVs as a first step toward replacing its entire fleet of conventional vehicles with alternative-fuel vehicles. Los Angeles International Airport is operating a new 31-foot electric shuttle bus and plans to replace 80% of its 677 vehicles

BOTH SIDES OF THE TERMINAL **Electric-powered vehicles and equipment are available to meet needs on both the passenger-entry side of the terminal (referred to as the ground side) and the aircraft side of the terminal (the air side). EPRI's studies have shown that many of the economically attractive options for electrification are on the air side, through technologies like push-back tractors, baggage carriers, and ground-power units. Ground-side opportunities include shuttles, sedans, pickup trucks, and vans.**

with alternative-fuel models. And since 1993, international baggage at Chicago's O'Hare International Airport has been sorted in a 210,000-square-foot, all-electric baggage room complete with battery-operated baggage tractors, electric conveyors, and other electrotechnologies.

Still, though, most airports today employ few EVs. Hoping to change this scenario, a group of EPRI member utilities has joined the Institute's International Airport Electrification Project, which got under way last year. As part of this project, researchers are developing site-specific strategies for the cost-effective implementation of EVs at participating airports. So far, nine EPRI member utilities, in locations ranging from Boston to Houston to Los Angeles, have joined the project with their urban airport customers. "Electric utilities are just beginning to realize the kind of influence they can have in encouraging airports to explore the advantages offered by EV technology," says Gary Purcell of EPRI, who manages the project. "And airports are just beginning to understand the breadth of information and other forms of assistance that utilities can provide."

Incentives

According to the Energy Research Group (ERG), the contractor overseeing EPRI's Airport Electrification Project, only 5% of the approximately 41,000 service vehicles now operating at the major U.S. airports are electric powered. By contrast, EVs are more commonly used in Europe. David Owen, an EV project manager for PowerGen, an English utility and EPRI affiliate, reports that about 30% of the vehicles servicing airplanes in the United Kingdom run on electricity and that airports in other European countries employ a similarly large number of EVs. "Petrol is more than three times as expensive in Europe as it is in the United States," says Owen. "This makes the business case for investing in EVs more attractive in Europe."

Rik Bleijs, technical coordinator for EV research at Electricité de France (EDF), notes that Europe's more extensive use of EVs at airports reflects the region's greater reliance on EVs in general. Among other applications, EVs have traditionally been

BIG IMPACT **As this chart shows, the use of electric vehicles at two urban airports offers the potential for substantial reductions in vehicular emissions. In calculating these reductions, researchers considered only EV technologies identical or similar to the internal combustion (IC) vehicles already being used at the airports. The resulting figures assume that all IC vehicles with identical or similar EV counterparts are converted. The figures also incorporate power plant emissions that would result from generating electricity for the EVs. Some airports will show an increase in SO_2 emissions, since popular power plant feedstocks like coal have a relatively high sulfur content while gasoline-fired engines release only trace amounts of SO_2.**

AIRPORT VEHICULAR EMISSIONS SUMMARY: AVERAGE RESULTS TO DATE (Pounds per Year)

	Particulates	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	Carbon Dioxide	Sulfur Dioxide
Current level	93,136	453,294	10,667,824	652,710	47,624,816	40,485
Level with EVs	25,640	116,740	2,717,631	197,644	33,265,679	51,685
Potential reduction	67,496	336,554	7,950,193	455,066	14,359,137	(11,200)
Percent reduction	72%	74%	75%	70%	30%	−28%

used for milk delivery in the United Kingdom. "European towns are smaller and the distances traveled are much shorter, so the EV makes good sense," says Bleijs, noting that EDF has 350 electric fleet vehicles of its own and plans to increase the number to 650 by the end of the year. He adds that the greater population density of European cities and a growing concern for protecting historic architecture from degradation by automobile exhaust have also encouraged the use of EVs.

In the United States, a combination of habit, higher capital costs, and lower gasoline prices have prevented the electric vehicle from penetrating the airport market. "Airports and their tenants have been buying gasoline- and diesel-fueled vehicles for years," notes Stephen Allen, a project manager at ERG. "Until now, they haven't had much incentive to purchase electric vehicles, which are largely unfamiliar to them and tend to carry higher capital costs. What they're starting to realize is that in many cases the other advantages of EVs can far outweigh the initial expense."

The EV advantage currently drawing the most interest is that of air quality enhancement. Increasingly stringent environmental regulations are encouraging U.S. airports and their tenants—including air carriers, car rental companies, catering businesses, and the firms that run the vehicles servicing the aircraft—to evaluate EVs more closely. For instance, regulations resulting from the 1990 Clean Air Act Amendments mandate that by 1998 all companies with 10 or more light- and medium-duty vehicles (such as cars, small trucks, and vans) must replace these vehicles with low-emission vehicles as the conventional vehicles are retired. Low-emission vehicles can include cleaner gasoline-powered vehicles as well as alternative-fuel vehicles, such as those powered by electricity or compressed natural gas.

Typically, car rental companies at major urban airports fall into this category. So do airport owners. Some, like the Massachusetts Port Authority (Massport), which owns and operates Logan, are making an effort to stay one step ahead of the regulations. According to Tom Champion, Massport's assistant to the director of aviation, Massport is developing a plan to replace virtually all of the 194 vehicles in its airport-based fleet with alternative-fuel vehicles; exceptions are fire-rescue, police, and other emergency vehicles. Massport aims to devise its vehicle replacement plan by 1996, two years ahead of the Environmental Protection Agency's schedule. "Essentially, we've established our own requirement," says Champion. "We're trying to get a head start on the Clean Air Act."

Getting tougher

Even more significant in terms of environmental regulation is the federal implementation plan (FIP) that the EPA recently proposed for three ozone-heavy nonattainment areas of California. Nonattainment areas are geographic regions in which the air quality does not meet National Ambient Air Quality Standards (NAAQS). Currently, 93 metropolitan areas in the United States fall into this category for ozone pollution.

Under the Clean Air Act, states are required to file state implementation plans (SIPs) indicating how they will comply with the NAAQS. In California, local environmental groups argued that the SIP was not stringent enough and successfully sued the EPA, which was then required to issue a more demanding FIP. The proposed FIP sets strategies for attaining the NAAQS for ozone by either 1999 or 2005 in Sacramento, by 2005 in Ventura, and by 2010 in the South Coast region. To meet these standards, urban airports in these regions—just one type of establishment affected—would have to reduce relevant emissions anywhere from 20% to 45% below the 1990 levels. Those exceeding their limits would be fined according to the level of their excess emissions. The EPA has held hearings on the proposal and will issue its final FIP in February 1995. In the meantime, local air boards for the affected regions are developing their own SIPs, which must be submitted to the EPA in November. If the EPA approves these local plans, they could replace the proposed federal controls.

The California FIP represents a new approach for the EPA in controlling emissions at airports. While the EPA sets emissions standards for specific equipment like aircraft engines and the various fossil-fueled vehicles employed at airports, it has never before proposed the so-called bubble approach at airports; this approach sets overall emissions limits and lets business operators decide the precise actions they will take to reduce those emissions. Some observers have raised questions about the government's right to impose such regulation at airports. Nevertheless, airports in other states are bracing themselves for more-stringent requirements. Airport owners note that California has been known to set trends in environmental law. They point to the state's landmark legislation of 1990 mandating that, by 1998, 2% of the vehicles sold be zero-emission vehicles. Five other states have since adopted similar requirements.

Initiative from Boston

Some airports, such as Logan, are preparing for upcoming regulations by studying and planning for the use of alternative-fuel vehicles. In devising its plan, Logan is working closely with Boston Edison Company and other utilities. In fact, says Purcell of EPRI, Boston Edison gave EPRI the idea for the Airport Electrification Project. "They provided the spark," he recalls. "They were right on top of this issue and alerted EPRI to it. And when we looked around, we found there were a lot of other airports in urban areas with similar needs."

As part of its plan for acquiring alternative-fuel vehicles, Logan has already ordered eight electric vehicles—three buses, two sedans, two pickups, and a van. According to Champion of Massport, Logan's upcoming $1.5 billion, 10-year modernization project offers an ideal opportunity for EV acquisitions. "This project has brought us under tremendous scrutiny by environmental regulatory agencies and community groups," says Champion. "We therefore have a very powerful incentive to develop aggressive environmental mitigation programs. An alternative-fuels program helps demonstrate our commitment to holding adverse environmental impacts at current levels—or rolling them back—even as we move to accommodate significantly more passengers."

Construction for the modernization project, which includes an aboveground electric people-mover system, will get under way next spring. Concurrently, Massport will pursue its introduction of additional alternative-fuel vehicles. In most cases, Champion says, the airport will replace its gasoline- and diesel-powered vehicles with either electric or compressed-natural-gas vehicles as the conventional vehicles are retired. However, federal grants may allow for the early replacement of some vehicles. Plans also call for five quick-charge EV kiosks, the first of which is scheduled to be installed next year. In the meantime, the eight EVs Logan has ordered can be charged through standard 120- and 240-volt outlets. The other vehicles to be acquired can be plugged in and charged in a similar fashion. During the initial evaluation and testing, says Champion, some vehicles will be taken home by employees and charged overnight.

Like other airport proprietors, Massport owns only a small portion of the vehicles operating on-site—about 17% of the 1108 vehicles inventoried for EPRI's Airport Electrification Project. Eighty-two percent of Logan's tenants—including national and regional air carriers, freight forwarders, car rental companies, aviation service firms, and catering businesses—participated in EPRI's study. Champion notes that while the airport cannot force its tenants to convert to alternative-fuel vehicles, it can certainly serve as an example. He says that part of Logan's vehicle replacement plan specifies that the airport intends to work with its airlines and other major tenants to help them develop voluntary plans for adopting alternative-fuel vehicles.

Study results

So far, EPRI's Airport Electrification Project has produced studies for Logan and for San Diego International Airport. At this writing, a draft of a study for La Guardia Airport in New York is near completion. Studies of other participating airports are under way. The Boston and San Diego assessments had similar results, showing that about 70% of the inventoried internal combustion (IC) vehicles and equipment at Logan and 74% of those at San Diego can be replaced with existing EV technologies either identical to or similar to their IC counterparts. When the IC vehicles that could be converted to electric models are included, the totals increase to nearly 96% for Logan and 98% for San Diego.

Since data pertaining to converted vehicles are generally insufficient, detailed comparisons were performed only for the replacement EVs. Environmental assessments showed that at both airports the replacement electrotechnologies would result in reductions of more than 70% in vehicle-related particulate, hydrocarbon, and carbon monoxide emissions. The reduction of nitrogen oxide emissions could be as great as 70%, depending on the type and number of vehicles converted. Carbon dioxide emissions could fall by around 30%.

Sulfur dioxide emissions could increase or decrease, depending on the local utility's fuel mix and on the type of vehicles currently employed at the airport. For instance, SO_2 is normally produced by coal- and oil-fired power plants but is emitted in only trace amounts by gasoline-fueled vehicles. Purcell notes that an SO_2 increase is not a cause for alarm, since the Clean Air Act Amendments have set a cap on the overall SO_2 emissions a utility is allowed to produce. In other words, if an EV load increases SO_2 emissions, the utility will reduce emissions elsewhere.

Economic comparisons indicated that such advantages as lower maintenance costs outweighed the higher purchase price of EVs in many cases. The study showed that about half of the replacement EV options for Logan and 75% of those for San Diego have lower life-cycle costs than their IC counterparts. The life-cycle calculations incorporated costs for fuel, maintenance, and infrastructure (such as charging facilities). While federal tax credits and deductions for the use of EVs were included, potential cofunding from federal and state governments was not, since such financing is determined on a case-by-case basis.

ALREADY IN USE While only 5% of the roughly 41,000 service vehicles now operating at major U.S. airports are electric powered, an assortment of EVs are making inroads in specific airport-related applications. Here are just a few examples.

Shuttle bus, cargo van, shop cart, Los Angeles International Airport

Baggage carrier, San Diego International Airport

All-electric baggage room, O'Hare International Airport

Aircraft tug, Logan International Airport

Allen of ERG notes that most of the economically attractive options fell into the category of air-side vehicles and equipment. EPRI's study defines air-side vehicles as those operating the majority of the time on the aircraft side of the terminal. By contrast, land-side vehicles are those that operate most frequently on the passenger entry side of the terminal. Air-side equipment includes such technologies as belt loaders for conveying baggage onto aircraft; tractors for pushing planes away from the terminal; baggage carriers; and ground-power units, which provide power for air conditioning, heating, and other needs to airplanes sitting at the terminal. Ground-side equipment includes shuttles for conveying passengers from parking lots to airport terminals; utility trucks for snow removal, road repairs, and other duties; and sedans, wagons, pickup trucks, and vans for conducting airport security activities, transporting materials, and running errands.

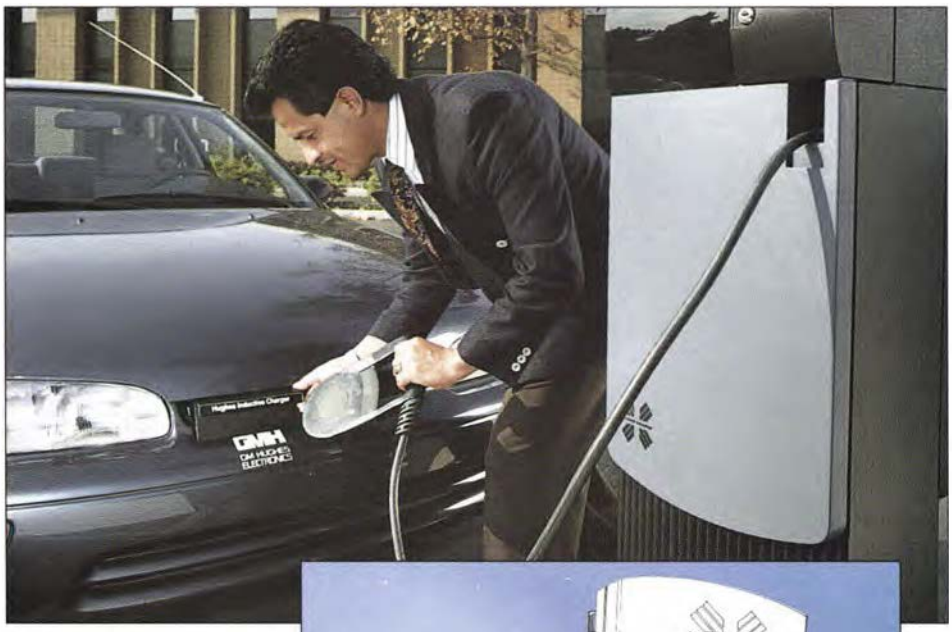
Equipment available

According to ERG, electric-powered forklifts, tugs, sweepers, and belt loaders are just some of the currently available technologies that can directly replace IC equipment. Electric-powered technologies that can be considered similar to their IC counterparts, or indirect replacements, include pickup trucks, container loaders, and mobile stair units. Technologies that would require a conversion include fuel trucks and flatbed trucks. Among the vehicles with no viable electrification potential at this time are deicer trucks and wreckers.

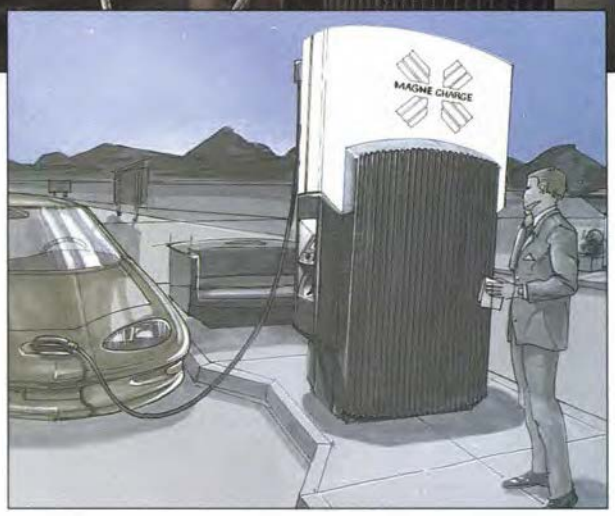
Electric vehicles have been used to a limited extent at U.S. airports for years. However, only a few of the electrotechnologies ERG cites as currently available are actually assembled and waiting to be purchased. As Bob Garzee, a vice president with U.S. Electricar, explains, manufacturers typically produce most of these vehicles on demand from an array of available components. Over the years, his company has manufactured electric-powered baggage loaders, conveyers, tow vehicles for small aircraft, catering trucks, and other equipment at the request of its customers. "Within the past five years, there

CHARGING TECHNOLOGIES **Electric vehicle users can opt for on-board or off-board charging systems. On-board chargers, which are contained within the vehicle, are made to be plugged into standard 120- or 240-volt outlets. Off-board chargers are located outside the vehicle. Charging through either on-board or off-board systems can take as little as 3–5 hours. Quick chargers, which will achieve a 50% charge in less than 10 minutes, are expected to become available within the next two years.**

On-board charger (integrated into power electronics box)



Off-board charger



Quick-charging station

Nonroad EV Consortium

To help increase the market share of off-road electric vehicles, such as those found at airports, EPRI established the Nonroad Electric Vehicle Applications Consortium early this year. So far, seven EPRI member utilities are participating in the consortium, which aims to improve the performance of off-road electric vehicles and equipment and to promote the use of such technologies in a wide variety of applications.

The consortium members have identified a number of technologies and are currently pursuing projects to develop two of them: an improved electric baggage tractor and a large-capacity electric lift truck. Tug Manufacturing Corporation has been selected to develop the baggage tractor, which will employ new high-performance motors and advanced batteries. Field tests of the baggage tractor are expected to begin at U.S. airports sometime in 1995.

The intent of the lift truck project is to introduce a truck with a lifting capacity of 2000–7000 pounds that will show a dramatic performance improvement over existing electric models in this size category. The most popular electric lift trucks currently on the market are smaller-capacity models. For the most part, the electric models with lifting capacities greater than 2000 pounds cannot compete with their gasoline-powered counterparts. But given the increasing demand for emission-free industrial vehicles, consortium members anticipate a growing market for larger-capacity electric lift trucks. The consortium is now in the process of selecting a manufacturer to develop the lift truck and expects to begin testing the technology in 1995.

Other technologies the Nonroad EV Consortium is interested in include electric lawn mowers, golf cars, and agricultural machinery. In addition to pursuing its vehicle development projects, the consortium is working to address customer concerns about off-road EV applications, to assess the value of this market to electric utilities, and to identify demand-side management opportunities related to off-road EVs.

Utilities that are interested in joining the Nonroad EV Applications Consortium should contact Gary Purcell, (415) 855-2168. □

hasn't been a big demand for these kinds of vehicles," Garzee says. "But we're starting to see an increase in interest now with the new air quality regulations."

Alan Clark, vice president of operations for Tug Manufacturing Corporation, notes that increased demand has prompted his company to pursue an enhanced version of an electric-powered baggage tractor it has sold for 15 years. The new model will offer improved efficiency and reliability, he says. (EPRI is supporting the development of this tractor. See the sidebar for more information.) Tug is also developing an electric version of its mobile belt conveyor.

EV chargers—devices that convert utility power into a form an EV can store and use—are also evolving. Chargers available today include both on-board technologies, which are contained within the vehicle, and off-board technologies, which are stationed at fixed locations outside the vehicle. Most of today's on-board charging systems are built into the electronics of EV propulsion systems. These chargers enable EVs to use the 120- or 240-volt outlets common in homes and businesses. Charging through a 240-volt outlet typically takes between 3 and 5 hours for an electric car; use of a 120-volt outlet takes twice as long. Charging time increases with the size of a vehicle's battery.

Off-board charging systems employ both conductive and inductive technology. Whereas conductive systems conduct electricity directly, inductive systems generate a magnetic field, which induces an electric current to charge the battery. Inductive systems, which only recently arrived on the market, involve no metal-to-metal contact. Instead users insert a plastic paddle into a plastic receptacle, or charge port, on the vehicle. Charging an electric car with off-board chargers currently takes as little as 3–4 hours. And quick-charging systems are being developed that will offer a 50% charge in less than 10 minutes. Such systems are expected to reach the market in the next two years.

Some electric-powered technologies, including catenary bus systems and ground-power units, do not require chargers because they tie directly into the airport's electric power system. Marc Goldsmith, president of ERG, envisions airports taking this concept one step further by connecting aircraft to their air conditioning, heating, and possibly even fuel and sewage systems. Some airports in the Southwest have already replaced their portable fossil-fueled air conditioning units with hoses similar to those used for venting household dryers. Retrieved from beneath the tarmac, the hoses provide a link to the terminal's indoor air conditioning system, supplying cold air directly to the aircraft. "I think this is the wave of the future," Goldsmith says. "I suspect that instead of seeing trucks bringing water to the planes and hauling sewage away, we'll see piping systems embedded in the ground."

Making it happen

Although the life-cycle costs of EVs are often lower than those of IC vehicles, the initial cost of acquiring EVs and making related infrastructure changes, such as installing charging stations, can be a significant capital investment.

A variety of funding sources are available to help airports implement EV programs. Generally, these sources fall into four categories: federal government programs, state government programs, special arrangements with EV vendors and manufacturers, and grants from private foundations and other nonprofit groups. By far the largest single source of funding is the federal government. The reports produced through EPRI's Airport Electrification Project offer more-detailed infor-

An EPRI Collaboration

AIRPORT ELECTRIFICATION PROJECT: UTILITY-AIRPORT PARTNERSHIPS

Utility	Airport
Boston Edison Company	Logan International
San Diego Gas & Electric Company	San Diego International
Los Angeles Department of Water & Power	Los Angeles International
Georgia Power Company	Hartsfield
New York Power Authority	La Guardia
Houston Lighting & Power Company	Houston Intercontinental
PECO Energy Company	Philadelphia International
New England Power Service	T. F. Green (Providence, Rhode Island)
Northeast Utilities	Bradley International (Hartford, Connecticut)

mation on these funding sources and the tax benefits currently available to airports pursuing the use of EVs.

The degree of assistance airports receive from electric utilities can vary dramatically, but it is clear that an increasing number of utilities are eager to help their airport customers with this issue. "In our case, we knew that Logan was environmentally proactive and was concerned about air quality," says Mark Warren, division manager of customer technical support for Boston Edison. "Given our knowledge of the electric vehicle industry, we knew that we could provide a valuable service. There's a lot of synergy between EV makers and electric utilities, and we felt we could offer an information conduit." He adds that a Boston Edison subsidiary, Boston Energy Technology Group, is a distributor for the GM Hughes Electronics line of charging equipment and is a great information resource. And what will Boston Edison get out of the collaboration? "Strategic load growth and an even stronger relationship with one of our biggest customers," says Warren. "This is the kind of value-added customer service that pays off in a competitive business environment."

Often utilities will participate in a team of organizations interested in the advancement of EV technologies. This is the case at Los Angeles International Airport (LAX). The airport joined forces with the Los Angeles Department of Water & Power (LADWP), GM Hughes Electronics, and Specialty Vehicle Manufacturing Corporation to try out a new 31-foot electric bus produced by Specialty. The South Coast Air Quality Management District also helped sponsor the project.

Specialty's 32-passenger bus features an innovative battery changeout system. The vehicle's battery pack is contained in a third axle designed for easy removal; vehicle attendants can simply slide the axle out and replace it with a new axle holding a freshly charged battery pack. According to Specialty, the changeout process takes only 10 minutes.

Since February of this year, the electric bus has been transporting LAX passengers between an airport parking lot and a central terminal area, a 4.8-mile loop. A replacement for a diesel bus that ran the same loop, the electric bus will eliminate some 5000 pounds of smog-forming emissions by the end of its first year in use, LAX reports—including 3640 pounds of nitrogen oxides, 860 pounds of carbon monoxide, and 165 pounds of particulates. In February 1995, the project team will evaluate the bus's performance and determine whether to continue its operation.

The electric bus is just one element of LAX's overall plan to convert 80% of its 677 diesel- and gasoline-fueled fleet vehicles to alternative-fuel vehicles. LADWP has been collaborating with LAX to develop this plan over the past three years. As part of the plan, more than 17% of the 700 stalls in a new parking structure will be wired for EV chargers that will be available to the public. Construction on this parking structure will begin late in 1995.

"Our objective is to attract enough interest in these technologies to create the market pull needed to bring their costs down," says Tom Doughty, LADWP's director of electric transportation. "We envision LAX as a showcase—a place where we can demonstrate a wide range of transportation alternatives." Noting that LAX is the world's third busiest airport, serving 45 million passengers a year, Doughty says he'd like the 31-foot electric bus to serve as a model for car rental companies, hotels, and other businesses that could employ similar technologies in their fleets. "Really," he says, "when it comes to demonstrating the advantages of electric vehicles, airports are one of the best venues around." ■

Background information for this article was provided by Gary Purcell of the Customer Systems Group's Electric Transportation Business Unit.

CONTRIBUTORS

Technical sources for Journal feature articles

BIGGER

DEMEO

GOODMAN

PETERSON

EVANS

KESSELRING

PURCELL

Emerging Markets for Photovoltaics (page 6) was written by Taylor Moore, *Journal* senior feature writer, with assistance from four members of the Generation Group's Renewables, Storage & Hydro Business Unit.

John Bigger manages projects in utility applications of photovoltaics. Since last spring, he has provided staff support as an EPRI loaned employee to the Utility PhotoVoltaic Group in Washington, D.C. Bigger joined EPRI in 1976 after 10 years as an engineer with the Los Angeles Department of Water & Power. He received a BS degree in electrical engineering from Iowa State University and an MS degree, also in electrical engineering, from the University of Southern California.

Edgar DeMeo manages EPRI's solar power program. He joined the Institute in 1976 after several years as a research associate professor of engineering at Brown University. DeMeo served as a lieutenant in the U.S. Naval Reserve from 1967 to 1969 and taught in the Science Department at the U.S. Naval Academy. He received a BS degree in electrical engineering from Rensselaer Polytechnic Institute and MS and PhD degrees in engineering from Brown.

Frank Goodman manages projects in utility applications of photovoltaics, including those under EPRI's CUE (Cooperative Utility Experience) program for tailored collaboration. He came to EPRI in 1979 from the Los Angeles Department of Water & Power. Goodman earned BS, MS, and PhD degrees in electrical engineering from the University of California at Santa Barbara and has taught electrical engineering at UCSB, the University of Southern California, and Loyola Marymount University.

Terry Peterson manages work in thin-film photovoltaics and in superconducting magnetic energy storage. He joined EPRI in 1986 after eight years at Chevron Research Company, where he was involved in catalyst and solar cell research. Peterson received a BS degree in physics from the University of California at San Diego and an MA in physics and a PhD in materials science and engineering from the University of California at Berkeley. ■

Efficiency: A Hard Sell (page 16) was written by Leslie Lamarre, *Journal* senior feature writer, with technical information from two members of the Customer Systems Group.

Michael Evans, CSG's manager for the Center for Demand-Side Excellence, came to EPRI in 1990 after six years with the electronics manufacturing firm X-Cyte, where he ultimately served as vice president of engineering. Before that, he was vice president of operations at a combustion technology R&D company. Evans has BA and BS degrees in mechanical engineering from Rice University and MS and PhD degrees in high-temperature gas dynamics from Stanford University.

John Kesselring, a manager for CSG's Residential & Small Commercial Business Unit, joined EPRI in 1986 after four years as a vice president with Alzeta Corporation. Before that, he was associate manager of the Combustion Technology Department at Acurex Corporation. Earlier he served for five years as an assistant professor of mechanical and aerospace engineering at the University of Tennessee. Kesselring holds a BS degree in aeronautical engineering from the University of Michigan and MS and PhD degrees in aeronautics and astronautics from Stanford University. ■

Airport REVolution (page 24) was written by Leslie Lamarre, *Journal* senior feature writer, with assistance from **Gary Purcell,** a manager with the Customer Systems Group's Electric Transportation Business Unit. Purcell joined EPRI in 1977 after 15 years with Lockheed Missiles & Space Company, specializing in aerospace vehicle temperature controls. A mechanical engineer, Purcell received an MBA from Pepperdine University. ■

Operator Training

Interactive Technology to Emulate Hard-Panel Controls

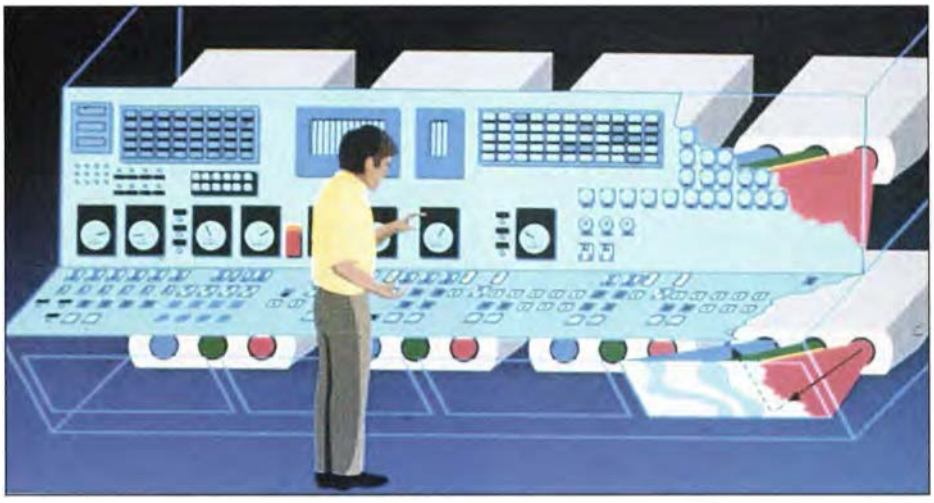
Training operators to run fossil power plants that have hard-panel controls is an expensive task. Traditionally utilities have constructed replica control panels out of sheet metal and equipped them with all the buttons, dials, meters, and switches that exist on actual control room panels. Today utilities are more likely to rely on a cluster of computer screens, which together depict only part of a given control panel at any one time.

EPRI-sponsored researchers are developing an advanced display technology that will offer a more effective and significantly less costly method of operator training. The researchers, at MITRE Corporation and TRAX Corporation, are creating a system that will project a full-scale, touch-controllable image of a hard panel onto an array of large screens.

To create the projected image for their prototype system, the researchers photographed individual sections of the control panel at Unit 6 of Boston Edison Company's Mystic plant. With the help of a special computer graphics program (EPRI's Graphic Screen Editor), they made relevant features of the panel interactive, such as meters, lights, and alarms. The final image is projected onto a series of 42-inch screens; each screen's interactive capabilities are controlled by a personal computer. To avoid the problem of shadows, the image is projected from behind the screens.

Simulation of one hard-panel section

Full-panel simulation



At a utility conference last spring, EPRI's researchers demonstrated the technology by using three 42-inch screens to represent one section of the panel at the Mystic plant. The next goal, set for December, is to employ 21 screens to represent the entire panel. By comparison, it would take 112 computer screens to show the same image.

Boston Edison plans to begin using the new system for training early next year. By that time, says Roy Fray, EPRI's manager for the project, the technology will become available for other utilities to customize. "The project at Mystic is just the start," says Fray. "We want to make this facility our laboratory for future research." Ultimately, he says, the large-screen technology could become the next-generation interface for actual power plant control rooms.

■ *For more information, contact Roy Fray, (415) 855-2441.*

Pest Control

Waging War on the Fire Ant

In the name of productivity and worker safety, not to mention the health of electrical equipment, EPRI researchers have launched a full-scale offensive on the fire ant. Pesky inhabitants of the warm southern states, fire ants migrated from South America 20 years ago and are best known for their painful sting. They also happen to build large dirt mounds. And as southern utilities well know, these mounds have a tendency to crop up on electrical equipment.

"Fire ants seem to have an affinity for electrical equipment, and they are very territorial," says Paul Lyons, a research manager in EPRI's Power Delivery Group. According to Lyons, the ants have built their mounds in and atop everything from

underground transformer boxes to above-ground substation components, causing fires, outages, and equipment corrosion. Lyons estimates that the ants inflict many millions of dollars' worth of damage annually.

Generally utilities rely on chemical methods for controlling the pests, but these methods are not equally effective. Also, workers must evacuate the treated areas for 1–2 hours after the chemicals are applied. "That's time workers lose on the job," Lyons notes.

Through a three-year project initiated in August, EPRI researchers aim to determine precisely what attracts fire ants to electrical equipment. Current theories include the insects' fondness for equipment vibrations, warmth, and even electric and magnetic fields.

The researchers plan to assess existing control methods and to develop new approaches that are more environmentally acceptable. TU Electric, Houston Lighting & Power Company, and Entergy Services are participating in the study. Additional participants are welcome.

■ *For more information, contact Paul Lyons, (214) 556-6523.*

Resource Assessment

Testing the Winds

Seven utilities in North Dakota have joined forces with EPRI, the University of North Dakota, and the state's Office of Intergovernmental Assistance to establish one of the most extensive wind-monitoring systems in the United States. Data retrieved through this system are expected to be critical to the assessment of cost-effective wind power plant deployment not just in North Dakota but in other areas too.

Researchers believe that North Dakota has the largest wind resource of any state in the country—five times greater than the western and southwestern states combined, by today's estimates. At this time, however, the only wind turbines in the state are small machines, typically owned and operated by farmers and ranchers.

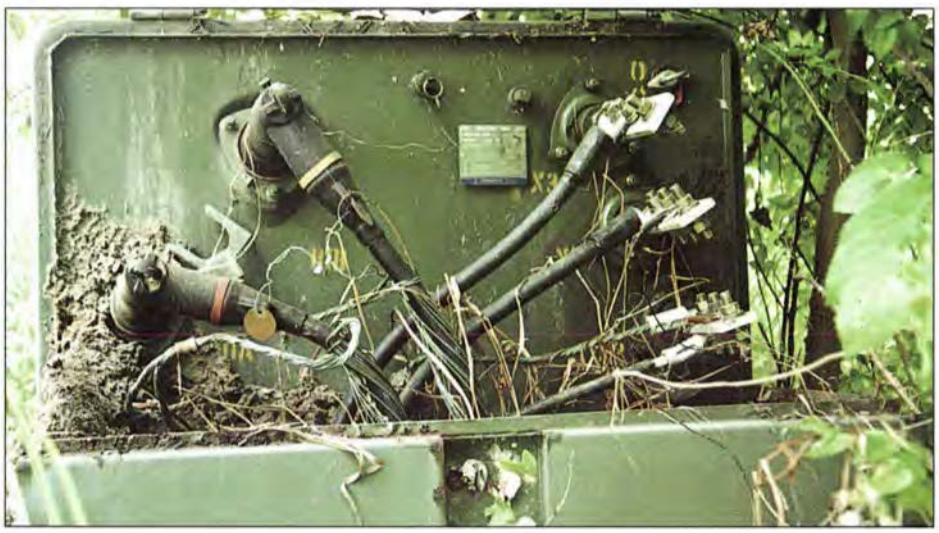
The available wind information for North Dakota is based on government data recorded from two state sites in the late 1970s and current data retrieved from agricultural and aviation stations. The wind-monitoring project will provide a more comprehensive view. Researchers have established a 130-foot wind measurement tower at each of eight sites across the state. One of these sites has five additional 33-foot towers for obtaining more detailed data. The University of North Dakota will record wind data from the eight sites for at least two years.

According to Earl Davis, EPRI's manager for the wind-monitoring project, North Dakota's new system is already serving as a model for other states. Davis says that, in addition to being used by utilities for resource assessment, the more extensive data will help EPRI researchers better simulate the output of one or many wind plants in a given region, develop and test models for wind forecasting, and devise numerical methods for more cost-effective and efficient turbine siting.

EPRI member participants in the wind-monitoring project include Basin Electric Power Cooperative, Northern States Power Company, Otter Tail Power Company, and United Power Association.

■ *For more information, contact Earl Davis, (415) 855-2256.*

A fire ant mound clogs the interior of a residential transformer.



Infrared Ink Curing Boosts Productivity for Indianapolis Apparel Decorator

Some 10,000 companies nationwide operate more than 30,000 silk-screening machines to decorate garments such as T-shirts and sweatshirts. The plastisol inks that are used must be cured on the garments to provide the desired results. Most of the energy for ink curing is supplied by gas convection ovens that use from 350,000 Btu to 1.5 million Btu per hour.

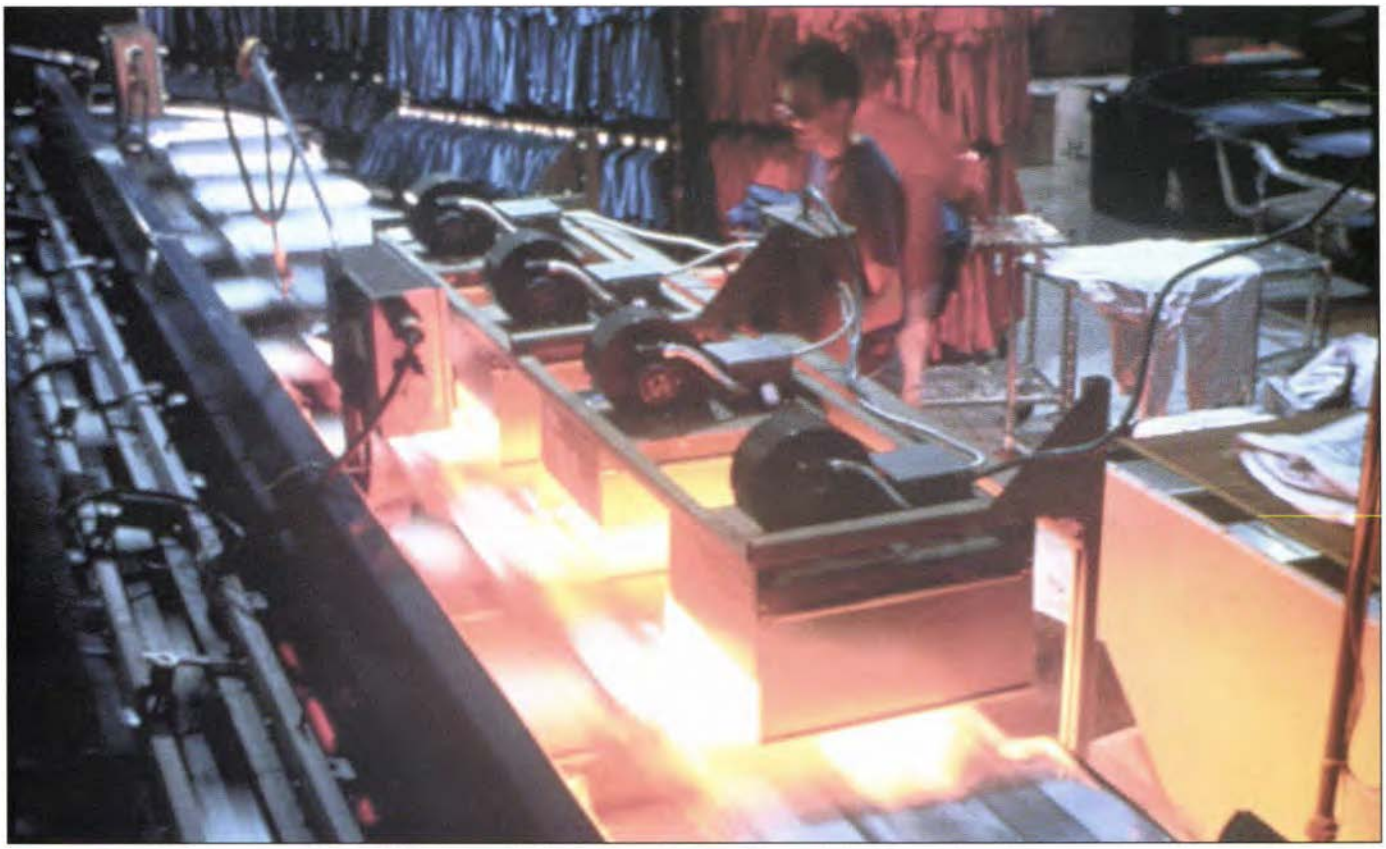
Even with air recirculation, the ovens waste a lot of energy through the stack, and they also lose some to the indoor atmosphere, even if they are well insulated. Additional energy costs are incurred if use of the ovens makes air conditioning necessary.

In collaboration with Indianapolis Power & Light Company (IP&L), EPRI's Center for Materials Fabrication recently evaluated the energy savings potential of on-line infrared (IR) ink-curing ovens at Logo 7, Inc., a major Indianapolis apparel decorator. Four IR panels, each rated at 4.8 kW, were installed on a 12-stage silk-screening machine and were evaluated through a series of tests. The tests demonstrated that inks could be fully cured while still on the machine, eliminating the need for a convection oven. Energy consumption was reduced 23% compared with convection oven curing—a reduction that translates to annual energy cost savings of nearly $900 per silk-screening machine.

According to Gene Eckhart, a project manager in EPRI's Customer Systems Group, the implementation of IR ink curing by just 10% of the apparel decorators that now use silk screening could save these customers more than $72 million a year in energy costs and could lead to additional electricity sales of 183 million kWh a year.

While IR curing saves energy and labor, the most valuable benefit identified in Logo 7's case was that, compared with bulky convection ovens, IR panels will enable additional floor space to be used for future production equipment. "IR curing will allow Logo 7 to continue its capacity expansion plans without the need for new buildings," says IP&L's Buck Hatcher.

■ *For more information, contact Gene Eckhart, (202) 293-7517.*



Advanced Dehumidification Systems Under Development

Eight utilities are collaborating with EPRI in a $2 million effort to develop and evaluate several advanced electric dehumidification technologies that potentially could compete cost-effectively against gas-powered desiccant systems in commercial building applications. Both kinds of technologies help cool indoor air by removing moisture.

Eventually, the electric dehumidification technologies may offer the potential to offset increased energy use resulting from the adoption of higher ventilation standards for commercial buildings. Compared with the ventilation standards applied in many buildings in the 1970s and 1980s in the interest of energy conservation, the new standards call for three times the flow of air from outside. They are expected to increase energy use for heating, ventilating, and air conditioning (HVAC).

EPRI has identified several innovative approaches to dehumidification that promise to save energy even with higher inflows of outside air. They do this by removing much of the moisture that is commonly present in air in warm months throughout the eastern United States and that impairs the efficiency of such equipment as HVAC systems and supermarket refrigerated cases. Moist air inside commercial buildings is also a common culprit behind occupant discomfort, possible health hazards, and compromised product quality.

Innovative new electric cooling techniques use commercially available technology in unconventional combinations and configurations to control humidity while greatly reducing electricity use and peak demand. They include applications of heat pipe heat exchangers, coil bypass control, high-differential-temperature evaporator coils, thermal storage, improved defrost control, and low-temperature air distribution.

To demonstrate a range of advanced dehumidification systems in a variety of building types, eight commercial buildings (six supermarkets, a retail store, and a public library) are each hosting a project sponsored by the local utility and EPRI. Data collection has been completed at most sites, and researchers report favorable results. EPRI expects to publish initial analyses later this year. Application guidelines are expected to eventually be developed.

Additional utilities interested in demonstrating advanced dehumidification with a commercial customer in a building that would expand the study's comprehensiveness are invited to join the collaboration. The initial group of sponsoring utilities consists of Alabama Power Company, Gulf Power Company, Illinois Power Company, Jersey Central Power & Light Company, Mississippi Power Company, New England Power Company, Northern States Power Company, and PSI Energy.

■ *For more information, contact Mukesh Khattar, (415) 855-2699.*

Applied Science and Technology

Cavitation and Liquid Droplet Erosion Protection

by John Stringer, Strategic Development Group

The damage of materials by erosion reduces equipment performance and leads to maintenance expense in many industrial activities, including electricity generation, coal gasification, and chemical processing. For steam turbines, hydroelectric generators, pumps, and other fluid-handling systems, erosion damage is in large part the result of fluid cavitation and liquid droplet impingement processes.

These damage mechanisms are similar. Erosion by cavitation takes place when flowing liquid enters a region of lower pressure—as occurs in certain flow patterns associated with pump impellers or hydroturbine blades—and cavitates; that is, small pockets of vapor form. These vapor pockets collapse violently in regions of higher pressure, resulting in localized fluid jets that cause material deformation and, eventually, damage. Droplet erosion occurs when liquid droplets carried in fast-flowing vapor collide with equipment, as in the last stages of a steam turbine. Recurrent deformation from the impacts can produce erosion damage.

On the basis of this empirical understanding, theory has indicated (and some experts have agreed) that degradation in cavitation, liquid droplet, and similar erosion processes is the result of low-cycle fatigue—that is, damage accumulated over thousands, not millions, of impact cycles. Despite years of research in this area, however, the materials property or properties that provide erosion resistance have remained unidentified. Protective construction materials have been discovered only through experience, and the potential of advanced materials fabrication for improving erosion resistance has gone unrealized.

To identify a cost-effective means of mitigating cavitation and liquid droplet erosion in utility equipment, EPRI is funding a long-term effort by scientists at Daedalus Associates of Mountain View, California. The exploratory phase—begun in 1987 and completed in 1991—was aimed at investigating the fundamental relationships between materials properties and erosion resistance (RP2426-13). The applied phase—now in progress—targets the development and demonstration of practical erosion protection claddings (RP8042-2).

Exploring erosion

The EPRI-sponsored research began with the compilation of a database incorporating the extensive tabulations of materials properties and erosion resistance that had been reported in decades of investigation. The database, which includes information on almost every commercial alloy, most unalloyed metals, and many nonmetallic substances, was then used by the Daedalus scientists to conduct extensive multivariate analysis of all factors considered important in fluid-erosion resistance.

By seeking correlations between damage susceptibility or material removal rates and strain-based fatigue properties, the researchers confirmed the suspected connection between repeated deformation (fatigue) and cavitation erosion. Specifically, they found that the main determinant of erosion behavior is the fatigue strength coefficient, a measure of resistance to repeated stress. However, because fatigue strength is strongly controlled by cyclic strain hardening (a measure of resistance to repeated deformation), a material's erosion resistance is related to its response to both stress and strain. The complication introduced by the cofactor relation had prevented earlier workers—who considered either stress response or strain response alone—from discovering a correlation with erosivity.

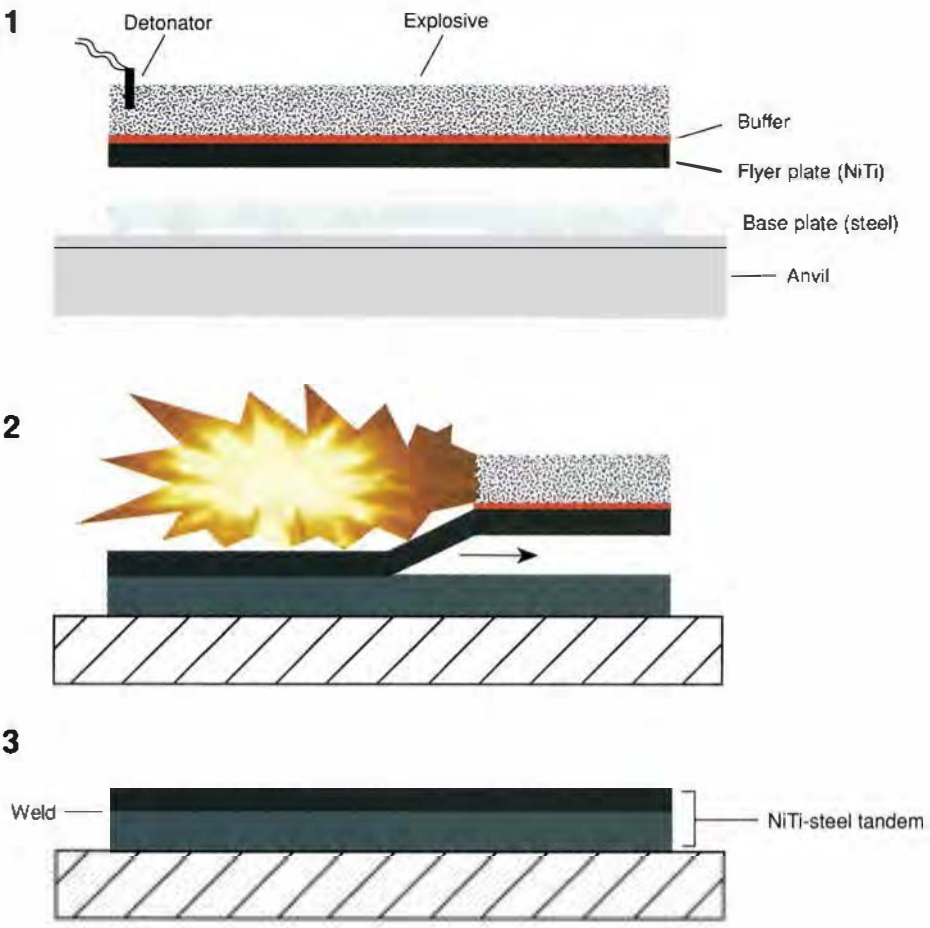
Armed with the knowledge that specific low-cycle fatigue properties are correlated with erosion resistance, researchers were for the first time able to rationally judge a material's potential for protecting power

ABSTRACT *Cavitation erosion and liquid droplet erosion can degrade fluid-handling equipment such as power turbines, pumps, and valves. Protective materials have been discovered primarily through experience, the property or properties conferring erosion resistance remaining unknown despite years of investigation. In recent exploratory research, however, EPRI-funded scientists established a correlation between erosion resistance and materials fatigue properties. On the basis of this finding, two promising protective nickel-titanium alloys were identified; laboratory tests confirmed that they are indeed highly resistant to cavitation and liquid droplet erosion. EPRI work now in progress is aimed at refining bonding techniques to facilitate the practical application of these materials.*

plant components against erosion. Two near-equiatomic nickel-titanium (NiTi) Nitinol alloys were identified as promising candidates on the basis of tabulated data indicating their anomalously high resistance to low-cycle fatigue. One is superelastic; that is, if deformed, it spontaneously returns to its original configuration when the stress causing deformation is removed. The other, a martensitic structural variant of the first, is known as a shape-memory alloy because, if deformed, it returns to its original shape once its temperature is raised above a characteristic threshold.

Laboratory experiments on vibratory cavitation confirmed the newly established correlation: both NiTi alloys were found to be extremely resistant to erosion, the superelastic form being very slightly superior. In fact, the cavitation experiments had to be extended from a standard duration of 12 hours to 38 hours to obtain measurable degradation. Analysis of the test results also suggested that both NiTi alloys are able to resist the effects of repeated impacts because they deform primarily by crystal-twinning-like shears that produce little residual damage in the affected grains. Such behavior is an important basis of both superelasticity and shape memory.

Figure 1 Researchers are adapting explosive bonding techniques to attach EPRI-developed erosion-resistant NiTi claddings to turbines and other fluid-handling equipment. Initially devised in the 1960s and used to produce clad materials of nearly all shapes, explosive bonding is based on the high-velocity impact between a mobile "flyer" plate and a fixed "base" plate. A controlled explosion creates a metallic jet that strips the plates of surface contaminants and progressively forces them together at high pressure to form a tight weld. Ultimately, researchers hope to develop capabilities for welding NiTi patches to large components in situ.



Practical protection

In the second, applied phase of this effort, Daedalus researchers are collaborating with New Mexico Institute of Mining and Technology scientists to develop practical means of employing NiTi in hydraulic pumps, turbines, and other fluid-handling machinery.

The use of NiTi to construct—or at least fully coat—equipment components would maximize erosion protection, but materials considerations make this approach impractical: NiTi is both costly and, in thick sections, brittle. The current research is thus focused on a more practical approach—cladding ordinary construction materials with NiTi in specific locations where erosion by cavitation or liquid droplets is a particular threat. Areas where protection may be needed include hydroturbine blades and vanes, valve seats, pump impellers, and last-stage steam turbines.

Surface overlays of austenitic stainless steel are already employed to protect or repair components of hydroturbines and pumps; they are commonly applied by fusion welding. Unfortunately, fusion welding cannot be used with NiTi claddings because the associated heating and melting locally alters their composition and crystal structure, causing embrittlement and loss of erosion resistance. And, to date, thermal spraying of NiTi has been unsuccessful. However, a third approach, explosive bonding (or welding), can produce excellent NiTi-metal coupling.

Since the 1960s, explosive bonding has been employed cost-effectively to produce clad materials for the chemical-processing industry. Large welded plates, curved sheets, and asymmetrical components have been successfully produced from titanium-covered steel and other clad materials. The explosive bonding technique is based on the high-velocity, oblique impact between two (or more) metal pieces, one a mobile "flyer" plate and the other a fixed "base" plate. A conventional explosive such as ANFO-6 (ammonium nitrate with 6% fuel oil) is used to generate, by controlled detonation, a metallic jet between the plates that strips the metal surfaces of contaminants; high pressure then forces them together to form a tight weld (Figure 1). Because the materials remain essentially solid throughout the process, deleterious metal-metal and metal-environment reactions are avoided and microstructural changes are minimized.

The Daedalus and New Mexico scientists are working to develop explosive

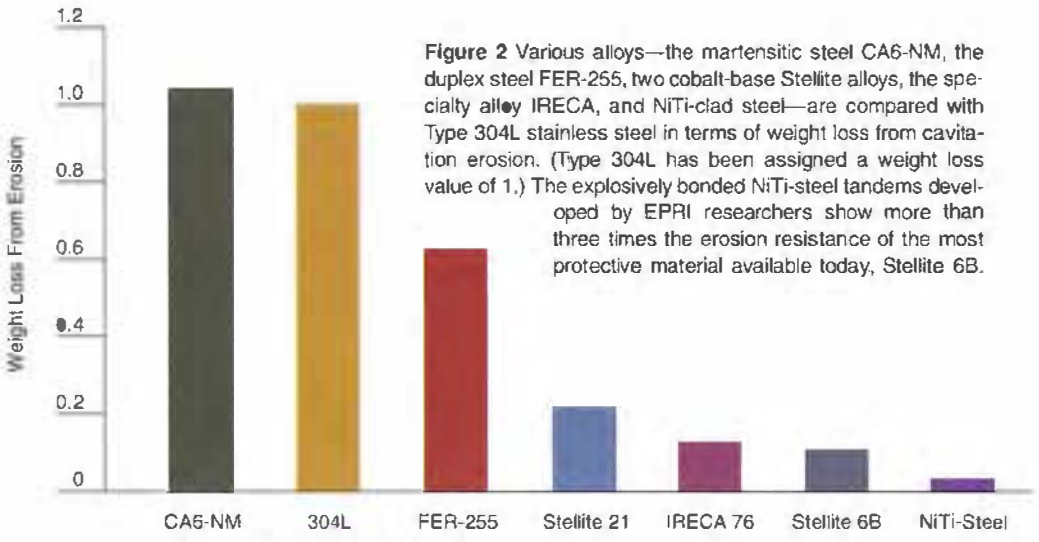


Figure 2 Various alloys—the martensitic steel CA6-NM, the duplex steel FER-255, two cobalt-base Stellite alloys, the specialty alloy IRECA, and NiTi-clad steel—are compared with Type 304L stainless steel in terms of weight loss from cavitation erosion. (Type 304L has been assigned a weight loss value of 1.) The explosively bonded NiTi-steel tandems developed by EPRI researchers show more than three times the erosion resistance of the most protective material available today, Stellite 6B.

bonding methods for joining thin NiTi plates (1 mm or less) to construction materials for power generation equipment. In shop tests, high-quality explosive welds have been obtained between flat NiTi plates and the low-carbon steel commonly used in hydraulic machinery. Although the erosion resistance of superelastic NiTi is somewhat decreased by the process (martensitic NiTi is unaffected), postweld heating of NiTi-clad steel at 500°C for 15 minutes restores almost all of the loss. The resultant tandem is the most cavitation-resistant material known, as illustrated in Figure 2.

In upcoming work, the researchers plan to refine methods for explosively bonding NiTi with the martensitic stainless steels commonly employed in turbine blades and vanes. Research will also be conducted to develop the shaped explosion frames and flyer plates necessary to clad curved or asymmetrical equipment surfaces. These efforts are aimed at shop fabrication of NiTi-clad prototype components for long-term demonstration in utility environments. The first field test, which will probably evaluate NiTi-clad materials for the protection of last-stage turbine blades against liquid droplet erosion, is expected to begin in late 1994. In the future, the researchers hope to develop capabilities for explosively welding NiTi patches to large components in situ.

The NiTi work is being coordinated with independent EPRI-sponsored work on the nitrogen-stabilized steel NOREM—a cobalt-free, wear-resistant alloy developed for use in nuclear plants. Currently, researchers are exploring possible nonnuclear applications of NOREM. The NiTi and NOREM efforts are using the same test procedures in order to facilitate comparison and evaluation.

Nuclear Power

Case Study in Full-System Chemical Decontamination

by John O. Parry and Stephen A. Trovato, Consolidated Edison Company of New York, and Christopher J. Wood, EPRI Nuclear Power Group

Consolidated Edison Company of New York is planning the first full primary system chemical decontamination at an operating U.S. commercial nuclear power plant. Scheduled for next March at the utility's Indian Point 2 plant—a pressurized water reactor (PWR) located about 40 miles north of New York City—the full-system decontamination will be conducted during a refueling outage, with the fuel removed. It will be a milestone in an industrywide effort to enhance nuclear plant productivity and reduce operating and maintenance costs through aggressive radiation management programs. These programs have helped reduce the average total personnel exposure attributable to certain plant components. The scheduled full-system decontamination is expected to lead to a major plantwide reduction of radiation fields, thereby reducing existing exposure levels by half.

The full-system decontamination will build upon the extensive research on the decontamination of components and subsystems. This research has shown that a variety of components and systems can be chemically decontaminated without adverse impact on the equipment's long-term reliability. The research has been conducted over two decades by numerous organizations, including EPRI, the Empire State Electric Energy Research Corporation (ESEERCO), and Con Edison.

However, the step from component decontamination to full primary system decontamination is technologically a large one. The systems involved, the technical issues to be addressed, and the logistics of performing such a large-scale chemical decontamination are complex. Indeed, full-system decontamination constitutes a major challenge for the nuclear industry.

Need for full-system decontamination

Corrosion and wear products are found throughout the reactor coolant system

ABSTRACT *Preparations for the first full primary system chemical decontamination at an operating U.S. commercial nuclear power plant are progressing on or ahead of schedule. Nearing completion are the engineering and fabrication stages of the demonstration phase of a program begun in 1987 to reduce general plant radiation levels without threatening long-term plant reliability and operability. Next March's full-system decontamination at Con Edison's Indian Point 2 plant will culminate an industrywide effort to enhance nuclear plant productivity and reduce operating and maintenance costs through aggressive radiation management programs.*

(RCS) of any PWR power plant. These products circulate with the primary coolant through the reactor, where some may become activated. A variety of radioisotopes are formed in this way, but for the most part, they are removed by filtration and demineralization in the chemical and volume control system (CVCS).

An oxide layer containing such activated products does form, however, on the surfaces of the RCS, including the fuel elements, the CVCS, and other primary support systems. Two radioisotopes of cobalt (58 and 60) are the main contributors to the radiation fields in a PWR. The amount of radioactive material deposited on the different surfaces varies and depends primarily on the corrosion rate of the various plant materials, the chemistry of the water used as coolant, and the number of sources of cobalt.

As maintenance is performed on plant systems, personnel are exposed to radiation, primarily gamma, emitted from the radioactive oxide layer. Radiation fields from the steam generators (up to 40 R/h) are usually the largest contributor to PWR personnel exposure because of the extensive maintenance the generators require.

The International Committee on Radiation Protection and the National Council on Radiation Protection have recommended personnel exposure limits that are, on average, less than half the current limit of 5 rem (total internal and external exposure). In addition to these lower exposure limits, federal regulations have been revised to require that personnel exposure to radiation be kept "as low as reasonably achievable" (ALARA). The revision enables the Nuclear Regulatory Commission to set strict rules to ensure that utilities apply the ALARA concept to personnel exposure. (Previously, this was framed as a recommendation.)

Moreover, radiation exposure contributes to lost productivity. In a radioactive environment, more and larger crews are needed and work is less productive. "Stay times" for crews are shorter, and setup and cleanup requirements are much greater than they would be for the same work in a clean environment.

Thus, although the component and subsystem decontaminations already performed have helped, the nuclear industry will benefit from a more substantial reduction in radiation fields to comply with regulatory requirements, enhance worker productivity, and keep nuclear power operating costs competitive.

Qualifying candidate processes

In 1987, a program was initiated to determine the technical acceptability of dilute chemical solvent processes for primary system decontamination. EPRI, ESEERCO, Con Edison, and 10 other utilities that own PWRs participated in the effort, along with Westinghouse Electric Corporation. Two processes, AP/CAN-DEREM and AP/LOMI, were selected to go through the qualification testing. Each had been used many times for component decontamination.

Studies of Westinghouse PWR primary systems and laboratory tests were then conducted to establish the conditions, pa-

Figure 1 Decontamination equipment for the Indian Point 2 application.

rameters, and criteria for a test program to qualify the two processes for the full RCS. Extensive surveys were conducted to establish a complete list of materials that would be exposed to the chemical solvents, and a series of tests was designed to address all possible issues for each material at the flow and chemistry conditions expected in the RCS. Over 250 specimens of over 80 different materials were tested for wear and corrosion effects. Tests were also performed under more corrosive conditions (i.e., with slightly higher chemical concentrations and temperatures); the results demonstrated that the processes could still be applied with a margin of safety under a hypothetical fault scenario.

The tests were designed to establish a technical basis for performing at least three full-system decontaminations during the remaining life of the plant. They were conducted in two test loops constructed at the Westinghouse R&D Center. Engineers at Westinghouse, the original supplier of the reactor system at Indian Point 2, evaluated the test results in cooperation with a utility steering committee. These evaluations were compiled, recommendations for application in the field were made, and a safety assessment was performed. Westinghouse submitted reports on the successful qualification to the NRC for the program sponsors. The NRC has approved use of the reports, which concluded that the decontamination could be safely performed, provided that certain guidelines are followed.

Although both of the candidate processes were approved by the NRC, Con Edison selected the AP/CAN-DEREM process on the basis of application considerations. The process can be controlled on-line, is chemically stable, and offers reduced waste generation because of its regenerative nature.

Status and benefits

Preparations for the full-system decontamination are progressing on or ahead of schedule, and the project costs are within budget. In particular, checkout tests of the equipment fabricated for the project have been satisfactorily completed ahead of schedule at the facilities of VECTRA Technologies, which will conduct the decontamination. Figure 1 shows the decontamination equipment.

Most of the process system will be located in a small room (33 × 27 × 15 feet) in the Indian Point 2 primary auxiliary building normally used for temporary waste storage. The process system will be controlled remotely from outside the building, with coordination with plant operation through the central control room.

Although the benefits of full-system decontamination will be plant specific and will depend on age, radiation fields, and maintenance and equipment-replacement activities, potential savings to the industry may be several hundred million dollars. For example, more than 200 person-rem could be avoided at a PWR with a cycle exposure of 290 person-rem; over five operating cycles, net savings of about $3.5 million could be achieved.

The national demonstration in progress includes steps to ensure that the broadest benefit is achieved by the entire industry. A consortium of utilities and other organizations has been formed to participate in next year's demonstration and to facilitate technology transfer to other utilities. It is still possible to join this consortium; interested organizations should call Chris Wood at EPRI, (415) 855-2379.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Persistence of Demand-Side Management Impacts (RP3269-30)	$60,000 8 months	Synergic Resources Corp./*P. Meagher*
SAE-JEVA Conductive Coupler Contact Testing (RP3304-21)	$123,400 5 months	Underwriters Laboratories/ *G. Purcell*
Performance Evaluation of Genlyte Energy-Smart/Vision-Smart Luminaires (RP3366-3)	$81,400 8 months	Rensselaer Polytechnic Institute/*K. Johnson*
Solar Heat Pump Engineering Support (RP3647-6)	$231,700 29 months	AiL Research/*T. Stati*
System Compatibility Research (RP3729-1)	$399,300 12 months	Tennessee Center for Research & Development/ *D. Rector*
Demonstration of Synthetica Detoxifier Applied to Medical Waste Disposal (RP3742-4)	$600,000 26 months	Synthetica Technologies/ *M. Jones*
Software Development for the Economic Analysis of Medical Waste Disposal Options (RP3742-5)	$155,000 27 months	Wenatchi Group/ *M. Jones*
Active Power Line Conditioners With Ride-Through Capability (RP3780-1)	$3,000,000 35 months	Westinghouse Electric Corp./*B. Banerjee*
Power Quality Standards and Specifications Workbook (RP3810-2)	$100,000 6 months	Electrotek Concepts/ *M. Samotyj*
Southeast Data Exchange Program (RP3819-19)	$325,400 12 months	Analytic Sciences Corp./ *R. Gillman*
EPRI Partnership for Industrial Competitiveness: Plant Surveys for Metals and Plastics Fabrication (RP3829-13)	$250,200 12 months	Arlex Group/ *W. Smith*
Environment & Vital Issues		
Relation Between Residential Magnetic Fields, Light at Night, and Nocturnal Urine Melatonin Levels in Women (RP2964-24)	$350,100 24 months	Fred Hutchinson Cancer Research Foundation/ *L. Kheifets*
Relation Between Residential Magnetic Fields, Light at Night, and Nocturnal Urine Melatonin Levels in Women (RP2964-25)	$360,600 24 months	EM Factors/*L. Kheifets*
Gap-Junction Intercellular Communication in Bone Cells Exposed to Extremely Low Frequency EMF (RP2965-32)	$188,900 23 months	University of California, Los Angeles/*C. Rafferty*
Review of Environmental Externality Estimation Methodologies for Particulate (PM10) and Ozone Health Effects (RP3231-8)	$60,000 6 months	State University of New York Research Foundation/ *V. Niemeyer*
Coal Tar Mixture Test Burn Management (RP9015-14)	$153,400 8 months	Groundwater Technology/ *I. Murarka*
Utilization of Coal Combustion By-Products in Agriculture and Land Reclamation in the Tennessee Valley (RP9023-2)	$266,000 58 months	Tennessee Valley Authority/ *J. Goodrich-Mahoney*
Coal Ash Utilization for Soil Amendment to Enhance Water Relations and Turf Growth (RP9023-3)	$59,900 10 months	University of Georgia Research Foundation/ *J. Goodrich-Mahoney*
Automated Intelligent Monitoring System for the Terrestrial Environment (RP9051-1)	$500,100 22 months	Ontario Hydro/ *J. Huckabee*
Generation		
Addition of NO_x Control to Clean Air Technology Workstation (RP2154-19)	$97,000 11 months	Sargent & Lundy/ *A. Facchiano*
O&M Workstation Development (RP2817-39)	$416,400 10 months	Sargent & Lundy/ *R. Colsher*
Analysis, Design, and Demonstration of Low-NO_x Oil and Gas Burner Technology (RP2869-22)	$151,300 6 months	Electric Power Technologies/*A. Facchiano*
PISCES Toxics Sampling and Analytical Tests at Ratcliffe Station (RP3177-23)	$244,600 10 months	PowerGen/*P. Chu*
Resource Allocation Tool Development (RP3288-6)	$65,000 10 months	Decision Focus/ *R. Goldberg*
Fleet Deployment Tool Development and Delivery (RP3288-8)	$75,600 6 months	Automation Technology/ *R. Goldberg*
Fabrication of Alloy 28 Waterwalls for Syngas Coolers (RP3439-2)	$137,700 8 months	NV KEMA/*W. Bakker*
Formal Evaluation of Flue Gas Chemical Measurement Methods (RP3471-8)	$447,900 15 months	University of North Dakota/ *B. Nott*
Compact Simulator Technology Development (RP3606-3)	$75,000 20 months	Automation Technology/ *J. Weiss*
DMEC-1 Gas Turbine Material Evaluation (RP3639-2)	$60,000 8 months	Ahlstrom Pyropower/ *R. Brown*
GNOCIS: Generic NO_x Control Intelligent System (RP3715-2)	$277,200 18 months	PowerGen/*R. Squires*
Environmentally Assisted Crack Growth in Low-Energy Fossil Boiler Components (RP3721-1)	$65,000 12 months	Babcock & Wilcox Co./ *R. Tilley*
In Situ Bioremediation Options for Soils and Groundwater Contaminated With Non-PCB-Containing Transformer Oils (RP3734-4)	$163,000 23 months	New England Power Service/*S. Yunker*
Photovoltaic Systems at Fort Davis, Texas (RP3779-1)	$3,900,000 44 months	Central and South West Services/*F. Goodman*
Nuclear Power		
Development of Methodologies and a Generic Process for Extending Equipment Qualification Replacement Intervals (RP3186-32)	$53,600 12 months	Ogden Environmental and Energy Services/*F. Rosch*
Primary Water Stress Corrosion Cracking in Alloy 600 and Weld Metals in PWR Environments (RP3223-9)	$200,000 30 months	Electricité de France/ *R. Pathania*
Integrated Feedwater Control Algorithms (RP3332-5)	$214,000 19 months	Science Applications International Corp./*R. Torok*
Failure Analysis of Steam Generator Tubing From Crystal River Unit 3 (RPS413-12)	$324,800 6 months	B&W Nuclear Service Co./ *P. Paine*
Power Delivery		
EMPT (Electromagnetic Transients Program) Restructuring, Phase 1 (RP2149-9)	$100,000 5 months	Canadian Electrical Association/*R. Adapa*
Power Transformer Expert System (RP2445-5)	$270,000 26 months	Rensselaer Polytechnic Institute/*S. Lindgren*
Substation Design Workstation (RP3193-2)	$1,643,400 47 months	Power Technologies/ *B. Damsky*
Advanced Artificial Neural Net Short-Term Load Forecaster (RP3555-7)	$342,100 24 months	Stone & Webster/ *D. Maratukulam*
Assessment of On-Line Application of Voltage Stability Analysis (RP3573-15)	$117,300 9 months	ESCA Corp./ *D. Maratukulam*
FACTS Requirements Study With Pacific Gas and Electric: Evaluation of Statcon Versus Synchronous Condenser (RP3789-5)	$149,000 18 months	General Electric Co./ *R. Adapa*
Strategic R&D		
Intelligent Control of Systems With Set-Partitioned Dynamics (RP8030-19)	$100,000 17 months	University of California, Santa Barbara/*J. Weiss*
Monotone Control of Discrete Event Systems (RP8030-22)	$100,000 16 months	Columbia University/ *J. Bloom*
Catalytic Reduction of NO_x (RP8032-1)	$140,000 36 months	University of Kansas Center for Research/*J. Maulbetsch*
Theoretical Models for Nucleation of Droplets in Flowing Steam Containing Dissolved Impurities (RP8034-8)	$52,700 12 months	Stress Technology/ *B. Dooley*
Non-Newtonian Slurry Flows (RP8034-9)	$106,900 12 months	Southwest Research Institute/*J. Maulbetsch*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities. Reports will be provided to others in the United States for the price listed or, in some cases, under the terms of a license agreement. Those outside the United States should contact the Distribution Center for price information.

CUSTOMER SYSTEMS

Fuzzy Logic Controls for Microwave Clothes Dryers
TR-104336 Final Report (RP3417-3); $200
Contractor: Honeywell, Inc., Sensor and System Development Center
EPRI Project Manager: J. Kesselring

ENVIRONMENT & VITAL ISSUES

Applicability of the CompMech Trout Model to Hydropower Impact Assessment: A Case Study of High-Priority Environmental Issues at Pacific Gas and Electric
TR-103028 Final Report (RP9046-1); $200
Contractor: Pacific Gas and Electric Co.
EPRI Project Manager: J. Mattice

Assuring Compliance Under the 1990 Clean Air Act Amendments: A Study of Emission Allowance Reserves
TR-104017 Final Report (RP3306-4); $200
Contractor: RCG/Hagler, Bailly, Inc.
EPRI Project Managers: R. Patrick, V. Niemeyer

Chemical Translator Guidance Manual
TR-104047 Final Report (RP2377-7), $200
Contractor: EA Engineering, Science, and Technology, Inc.
EPRI Project Manager: R. Brocksen

GENERATION

Roxboro Automation Project
TR-102083 Interim Report (RP2922, RP3487-12); $10,000
Contractor: Carolina Power & Light Co.
EPRI Project Manager: R. Colsher

Behavior of Sodium Phosphates Under Boiler Conditions
TR-102431 Final Report (RP2712-12); $1000
Contractor: ABB Combustion Engineering
EPRI Project Manager: B. Dooley

Guideline for Selection of Power Plant Insulation
TR-102752 Final Report (RP1030-46), $10,000
Contractor: Science Applications International Corp., Inc.
EPRI Project Managers: M. Blanco, R. Tilley

Proceedings: Condenser Technology Conference
TR-103475 Final Report (RP2504-13); $1000
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Tsou

Proceedings: Simulators, Modeling, and Training (1993 EPRI International Conference)
TR-103826 Proceedings (RP3152); $1000
EPRI Project Managers: R. Fray, G. Cauley

Use of FGD Gypsum and Bottom Ash in Roadway and Building Construction
TR-103856 Interim Report (RP3176-11); $200
Contractor: Texas Transportation Institute/Texas A&M University
EPRI Project Manager: D. Golden

Proceedings: 1993 Fuel Oil Utilization Workshop
TR-103990 Proceedings (RP2778-8); $400
Contractor: Carnot
EPRI Project Manager: W. Rovesti

Erosion and Corrosion of Refractories in Circulating-Fluidized-Bed Combustors
TR-104039 Final Report (RP979-30); $200
Contractor: Lawrence Berkeley Laboratory
EPRI Project Manager: W. Bakker

Distributed Generation Assessment for Azienda Energetica Municipale of the City of Milan, Phase 1: Siting and Technology Screening for High-Value Applications
TR-104108 Interim Report (RP1677-28), $200
Contractor: Rumia, Inc.
EPRI Project Manager: D. Rastler

Health Effects Review of Asbestos Substitutes
TR-104320 Final Report (RP1030-47); $10,000
Contractor: Dynamac Corp.
EPRI Project Manager: R. Tilley

NUCLEAR POWER

Effects of Resistance Temperature Detector Aging on Cross-Calibration Techniques
TR-103099 Final Report (RP2409-15); $1000
Contractor: ERIN Engineering and Research, Inc.
EPRI Project Manager: R. James

Hot Cell Examination of Extended Burnup Fuel From Calvert Cliffs-1
TR-103302-V2 Final Report (RP2905-2), license required
Contractor: ABB Combustion Engineering—Nuclear Fuel
EPRI Project Manager: O. Ozer

Evaluation of the Toughness Properties and ASME Service Level A and B Upper Shelf Toughness Criteria for A 302-B Vessel Steel
TR-103434 Final Report (RP2455-22); $2000
Contractor: Sartrex Corp.
EPRI Project Manager: R. Carter

PWSCC of Alloy 600 Materials in PWR Primary System Penetrations
TR-103696 Final Report (RP3223-1), $1000
Contractor: Dominion Engineering, Inc.
EPRI Project Manager: R. Pathania

Examination of Kewaunee Cold Leg Steam Generator Tubes
TR-103901 Final Report (RPS413-9); $500
Contractor: Westinghouse Science and Technology Center
EPRI Project Managers: A. McIlree, P. Paine

PWSCC Prediction Guidelines
TR-104030 Final Report (RP2812-15); $2000
Contractor: Dominion Engineering, Inc.
EPRI Project Manager: A. McIlree

A Model of Caustic Stress Corrosion Crack Initiation and Growth in Alloy 600
TR-104073 Final Report (RPS407-38); $200
Contractor: Modeling and Computing Services
EPRI Project Manager: P. Paine

Industry Experience With Discrete Radioactive Particles
TR-104125 Final Report (RP3099-6); $200
Contractor: CENTEC-21, Inc.
EPRI Project Manager: C. Hornbrook

Development of Advanced Concepts for Nuclear Processes in Deuterated Metals
TR-104195 Final Report (RP3170-1); $200
Contractors: SRI International; Lockheed Missiles & Space Co., Inc.
EPRI Project Managers: T. Passell, J. Santucci

Nuclear Power Plant License Renewal Environmental Compliance Program Plan Manual
TR-104291 Final Report (RP3343); $5000
Contractors: Baltimore Gas and Electric Co.; Halliburton NUS Corp.
EPRI Project Managers: M. Lapides, W. Bilanin

POWER DELIVERY

Upgrade Design for Wood H-Frame Structures Using the EPRI TLWorkstation
TR-102914 Final Report (RP2016); $200
Contractor: Sverdrup Technology, Inc.
EPRI Project Manager: P. Lyons

Dispersed System Impacts: Survey and Requirements Study
TR-103337 Final Report (RP3357-1); $5000
Contractors: EPIC Engineering, Inc.; Electrotek Concepts, Inc.
EPRI Project Manager: D. Maratukulam

Considerations for Obtaining Mean Drag Coefficients for Overhead Transmission Line Conductors in Wind Tunnels
TR-103430 Final Report (RP1717); $5000
Contractor: Sverdrup Technology, Inc.
EPRI Project Manager: P. Lyons

Hybrid Tower Study, Vol. 3: Phase 3—Scale-Model Development and Full-Scale Tests
TR-103598 Final Report (RP2472-6); $5000
Contractors: General Electric Co.; Ohio State University
EPRI Project Manager: J. Hall

Possible Application of Static Phase Shifter in ENEL Network
TR-103701 Final Report (RP3022-12); $5000
Contractors: ENEL; CESI; Ansaldo Ricerche
EPRI Project Manager: D. Maratukulam

Feasibility Assessment: Simulation of Electromagnetic Transients in Real Time
TR-103808 Final Report (RP4000-15); $5000
Contractors: University of Alabama; ENEL; CESI
EPRI Project Manager: D. Maratukulam

Technical and Economic Study of PPP- and Paper-Insulated SCFF Cables Rated 138, 230, and 345 kV
TR-103905 Final Report (RP7898-30); $5000
Contractor: David A. Silver and Associates
EPRI Project Manager: J. Shimshock

FACTS Devices Applications and Modeling: Reference Manual
TR-103906 Final Report (RP3022-12; RP1208-11, -12, -13; RP3144-1); $5000
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

Field Evaluation of Ammoniacal Copper Fatty Acids as a Utility Pole Preservative
TR-103907 Final Report (RP1528-1); $5000
Contractor: Michigan Technological University Institute of Wood Research
EPRI Project Manager: H. Ng

Effect of the Volatile By-Products of the Cross-Linking Reaction on the Dielectric Strength of Cross-Linked Polyethylene Cables
TR-103908 Final Report (RP2713-5); $5000
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

SUNBURST GIC Network
TR-104167 Final Report (RP3211-1); $5000
Contractor: Energy Research and Management, Inc.
EPRI Project Managers: B. Damsky, J. Porter

GIS Fault Locater
TR-104232 Final Report (RP1360-12); $5000
Contractor: XEDAR Corp.
EPRI Project Manager: S. Nilsson

Transmission Services Costing Framework, Vol. 1: Interim Report on Technical and Economic Fundamentals
TR-104266 Interim Report (RP3216-1); $5000
Contractor: CSA Energy Consultants
EPRI Project Manager: A. Vojdani

Power System Control Practices and Outlook for New or Revised Control Concepts
TR-104275 Final Report (RP3555-3); $5000
Contractor: Zadeh Meyer Engineering, Inc.
EPRI Project Manager: G. Cauley

STRATEGIC R&D

H_∞ Controller Design for Boilers
TR-103944 Final Report (RP8010-19); $200
Contractor: University of Illinois, Mechanical and Industrial Engineering Department
EPRI Project Manager: S. Bhatt

Proceedings: EPRI Workshop on In Situ Electrochemical Soil and Water Remediation
TR-104170 Proceedings (RP8060); $200
Sponsors: Southern California Edison Company; EPRI
EPRI Project Managers: F. Will, A. Amarnath, I. Murarka

EPRI Events

JANUARY 1995

31–February 2
Infrared Thermography
Charlotte, North Carolina
Contact: Linda Suddreth, (704) 547-6141

FEBRUARY

8–9
Energy Efficiency and the Global Environment
Newport Beach, California
Contact: June Appel, (610) 667-2160

MARCH

2–3
EPRI Partnership for Industrial Competitiveness
Phoenix, Arizona
Contact: Bill Smith, (415) 855-2415

13–16
5th NMAC Annual Conference
Amelia Island, Florida
Contact: Linda Suddreth, (704) 547-6141

19–22
EMF Science and Communication Seminar
Santa Clara, California
Contact: Banks & Associates, (612) 623-4600

22–24
Verification and Validation of Digital Systems
Nashville, Tennessee
Contact: Linda Nelson, (415) 855-2127

28–31
1995 SO_2 Control Symposium
Miami, Florida
Contact: Pam Turner, (415) 855-2010

APRIL

10–13
1995 International Fossil Simulator Users Group Meeting
Phoenix, Arizona
Contact: Ron Griebenow, (704) 547-6168

MAY

3–5
Continuous Emissions Monitoring Users Group Meeting
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

8–10
13th International Conference on Fluidized-Bed Combustion
Orlando, Florida
Contact: Rich Brown, (415) 855-2216

8–11
4th International Conference on Power Quality: Applications and Perspectives—PQA '95
New York, New York
Contact: Lori Adams, (415) 855-8763

15–19
Joint Symposium on Stationary Combustion NO_x Control
Kansas City, Missouri
Contact: Susan Bisetti, (415) 855-7919

JUNE

19–21
ISA POWID/EPRI Controls and Instrumentation Conference
San Diego, California
Contact: Lori Adams, (415) 855-8763

22–23
EPRI Partnership for Industrial Competitiveness
San Francisco, California
Contact: Bill Smith, (415) 855-2415

28–30
7th National Demand-Side Management Conference
Dallas, Texas
Contact: Pam Turner, (415) 855-8900

JULY

10–12
Low-Level-Waste Conference
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

12–14
EPRI/ASME Radwaste Workshop
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

AUGUST

15–18
Particulate Control/Managing Hazardous Air Pollutants
Toronto, Canada
Contact: Lori Adams, (415) 855-8763

29–31
PCB Seminar
Boston, Massachusetts
Contact: Linda Nelson, (415) 855-2127

SEPTEMBER

13–15
1995 Heat Rate Improvement Conference
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

OCTOBER

4–6
Biodiversity and Ecosystem Health
Jackson Hole, Wyoming
Contact: Pam Turner, (415) 855-2010

18–20
1995 Fuel Supply Seminar
New Orleans, Louisiana
Contact: Susan Bisetti, (415) 855-7919

25–27
Gasification Power Plants Conference
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

NOVEMBER

28–30
Predictive Maintenance and Refurbishment
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

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October/November 1994

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EJ-104551