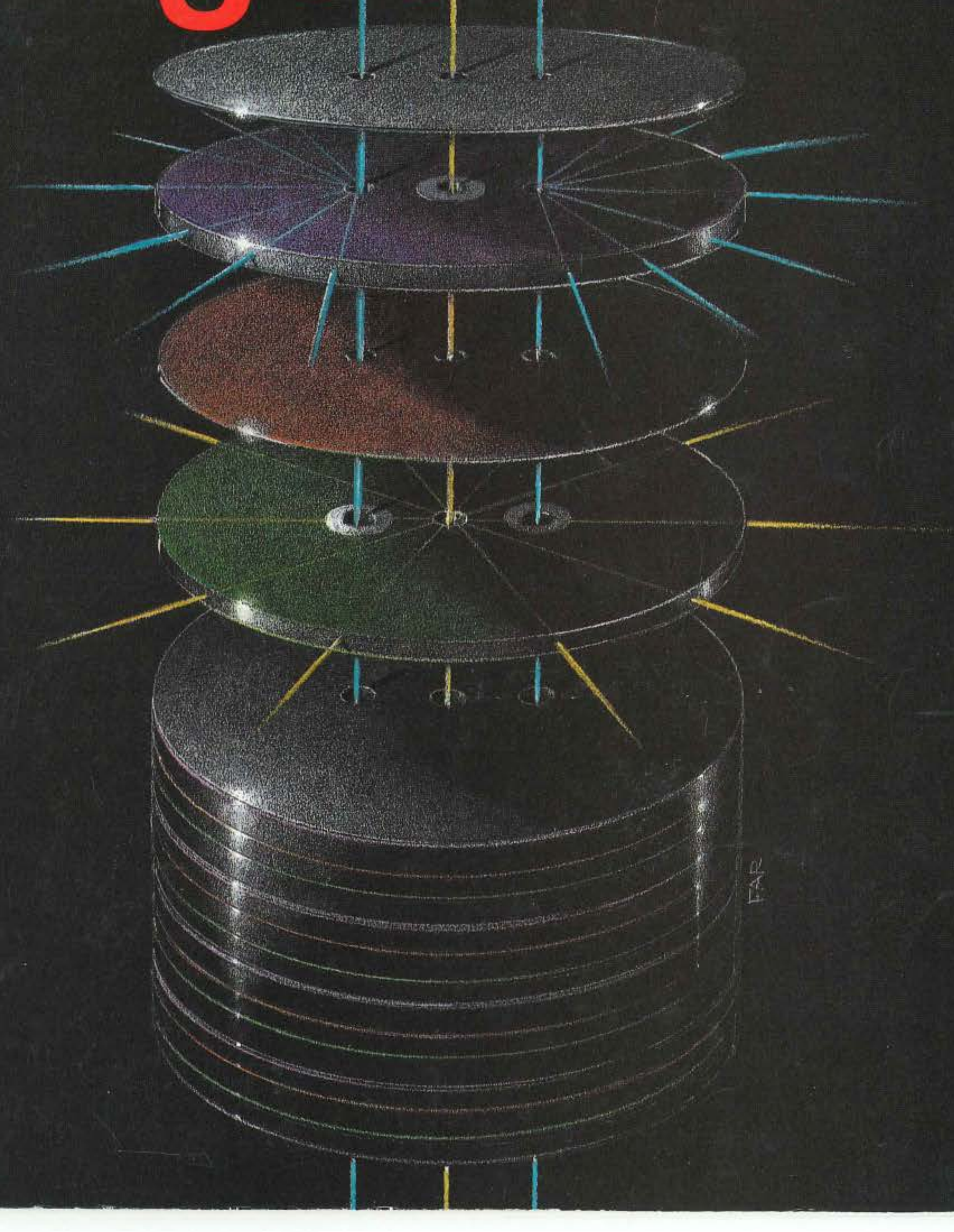
Solid-State Fuel Cells

Also in this issue • Advances in Undergrounding • Electronic Thermostats • High-Speed Rail

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

MARCH
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.

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Cover: One of several new fuel cells under development that use solid rather than liquid electrolytes, this unit from Technology Management, Inc., also features porous electrodes for fuel and air distribution.

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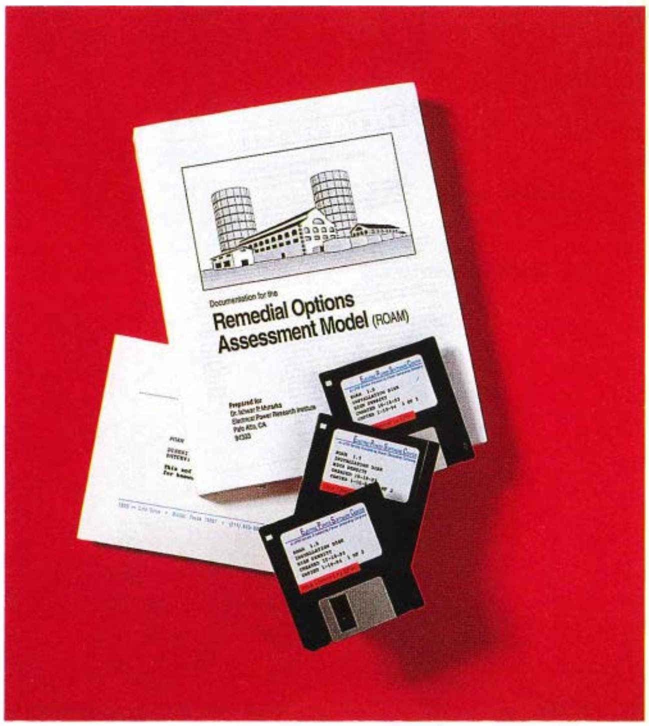
ROAM for Swift and Effective Cleanup

With the Remedial Options Assessment Model (ROAM), utilities can efficiently evaluate feasible remedial actions to determine the most effective approach to use at a given contaminated site. The model predicts the migration of organic contaminants in soils and groundwater and deter-



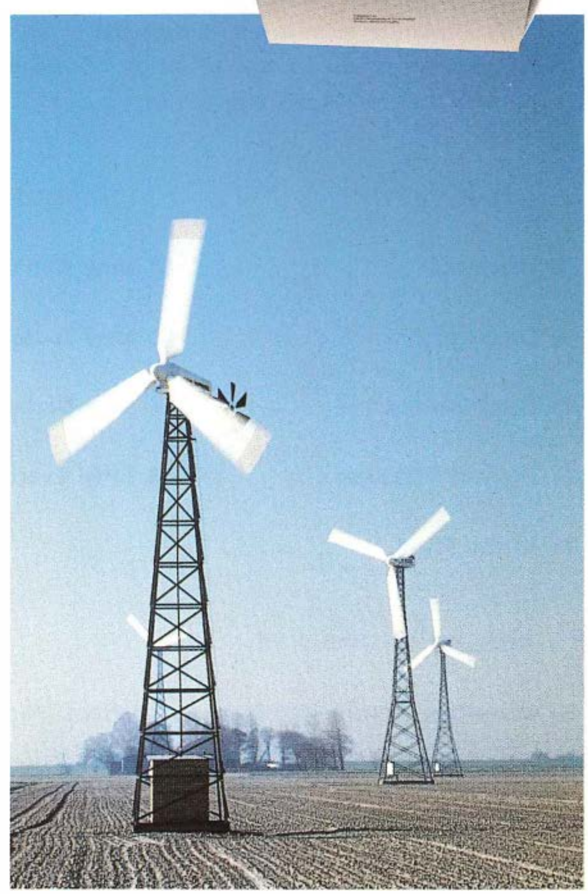
mines the effectiveness of remedial actions in reducing concentrations of dissolved chemicals, heavy coal tar, or petroleum products. Specifically designed for manufactured gas plant sites, ROAM Version 1.0 can also be used to assess sites housing either aboveground or underground storage tanks. A Windows-based software application, ROAM is user-friendly and displays contour plots of contaminated areas.

For more information, contact Ishwar Murarka, (415) 855-2150. To order, call the Electric Power Software Center, (214) 655-8883.

European Wind Technology

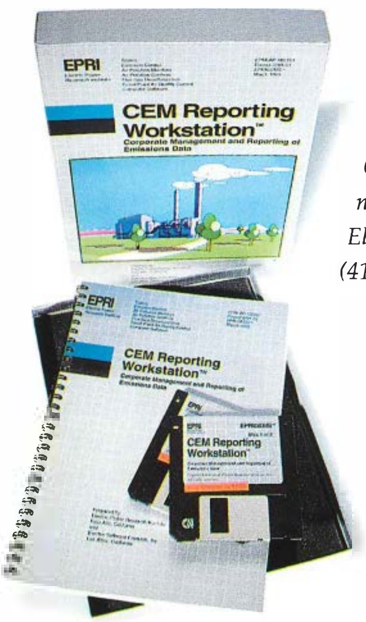
European countries learned much from the U.S. experience with wind power technologies in the 1980s. Now, with indications that Europe may be the next world leader in the implementation of wind power technologies, it appears to be time for us to learn from them. This EPRI report (TR-101391) offers a good start in that direction, explaining the reasons for the increased interest in wind power generation among European countries. Based on interviews with many European organizations active in wind power, findings presented at key European wind technology meetings over the past several years, and a survey of recently published literature, the report provides useful information to all utilities interested in wind power generation.

For more information, contact Edgar DeMeo, (415) 855-2159. To order, call the EPRI Distribution Center, (510) 934-4212.



CEM Reporting Workstation

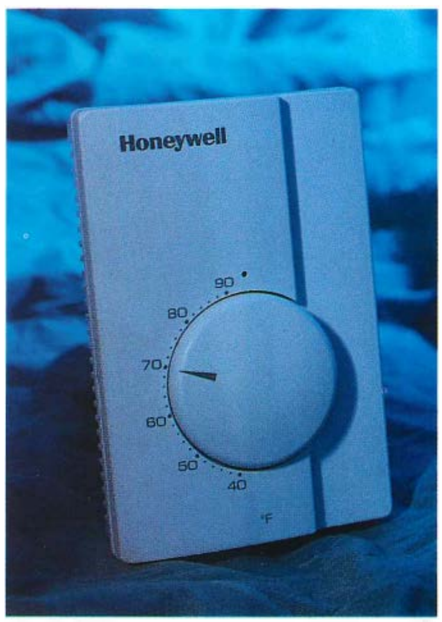
The 1990 Clean Air Act Amendments require utilities to file quarterly reports on their emissions of sulfur dioxide, nitrogen oxides, and particulates. This workstation makes the job of reporting continuous emissions monitoring data a lot easier, preparing electronic files for utilities to submit to the Environmental Protection Agency. The Windows-based software interfaces with Microsoft Excel, offering all the user-friendly capabilities of that program. The workstation can be used to create custom companywide reports that include pie charts, bar graphs, and other visual aids.



For more information, contact Chuck Dene, (415) 855-2425. To order, EPRI members should call the Electric Power Software Center, (214) 655-8883; nonmembers should call Electric Software Products, (415) 949-5900.

Honeywell Thermostat

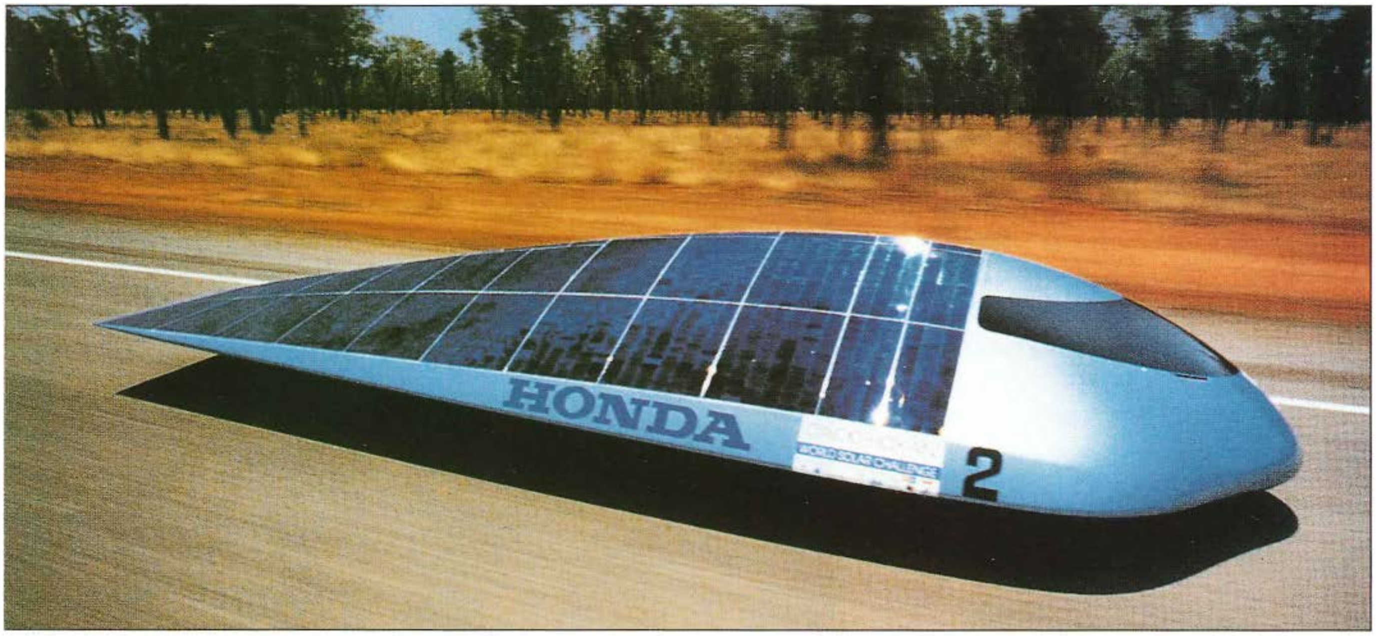
Honeywell's latest thermostat for electric heating systems (the T4800) lets residential and small commercial users enjoy greater comfort while saving on their electricity bills. The thermostat's patented CoolSwitch technology delivers precise, highly accurate control that virtually eliminates the temperature swings common with conventional line-voltage thermostats. Because the Honeywell thermostat operates on electricity drawn by the heating-system load, the unit features simple, two-wire installation. The thermostat's sleek white casing is large enough to cover faded paint and other defects that may be left from previous thermostat installations, yet it is small enough to be mounted just about anywhere. A light-emitting diode indicates that the unit is functioning.



For more information, contact John Kesselring, (415) 855-2902. To order, call Nancy Jansen at Honeywell, (612) 954-6865.

EPRI-Developed PV Cells Power World-Record Solar Car

The World Solar Challenge race across Australia for cars powered exclusively by photovoltaic (PV) cells was won in November 1993 by a vehicle using cells developed with EPRI and U.S. Department of Energy funding. The car was built by Honda R&D Company of Japan and used PV cells manufactured by SunPower Corporation of Sunnyvale, California, an EPRI licensee.



The annual 1865-mile race, which has become an international showcase for solar-powered electric car technology, last year attracted 50 entries from 17 countries. Honda's winning car, named *Dream*, averaged 53.1 miles per hour and shattered the previous record for the course by more than 9 hours—finishing in an elapsed time of 35.5 hours. The course bisected the Australian continent, running from Darwin in the north to Adelaide in the south. The cars raced only from 8:00 in the morning until 5:00 in the afternoon.

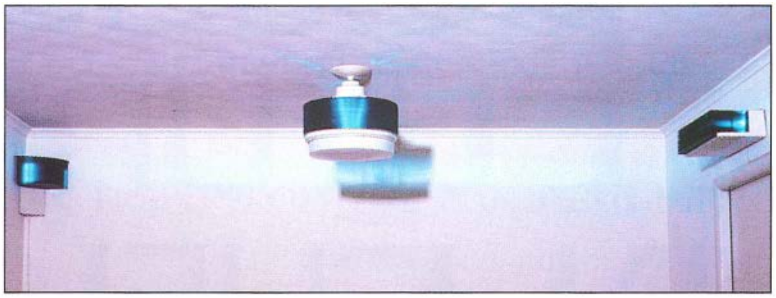
The primary development of the solar cells took place over a 15-year period at Stanford University, with principal funding from EPRI and additional sponsorship by DOE through Sandia National Laboratories and the National Renewable Energy Laboratory. The final stages of cell development took place at SunPower, which was formed by the principal investigators from Stanford. The resulting single-crystal silicon PV cells hold the world record for conversion efficiency in commercially available cells, both in concentrator applications (at an intensity of 250 suns) and in the 1-sun design used for the solar car.

"The high efficiency of SunPower's cells was a key factor in winning the Solar Challenge," says EPRI's Frank Goodman, who manages solar power research. "We are currently developing alliances with industrial and utility organizations to commercialize these cells in arrays and complete systems for near-term utility use, primarily in concentrator applications."

Although PV power is not likely to become the sole energy source for ordinary automobiles, some utilities are experimenting with solar cells to help charge batteries for electric vehicles. Solar cells made with low-cost amorphous silicon are already being used in commercial automotive applications, mainly to power fans that ventilate a vehicle while it is parked in the hot sun. In nonconcentrator applications, the much more expensive high-efficiency cells like those from SunPower will probably be used where space and weight are at a premium, as in earth-orbiting satellites.

■ *For more information, contact Frank Goodman, (415) 855-2872.*

Ultraviolet Light—An Answer to Tuberculosis?



For half a century the health care industry has sporadically relied on ultraviolet (UV) light to kill bacteria. Now some members of the medical community are advocating the widespread use of this technique to control tuberculosis, which is making a particularly dangerous comeback in major U.S. cities.

Medical experts who have used UV lamps to prevent the spread of various illnesses say that UV light can wipe out many airborne viruses and bacteria, including measles and chicken pox, by destroying their DNA so that they can no longer reproduce. Although sunlight provides the UV-A and UV-B wavelengths, only the UV-C wavelength, which cannot penetrate the ozone layer in the upper atmosphere, has the capacity to sterilize. UV lamps provide the UV-C wavelength and have been used on an informal basis by a small number of health care facilities over the decades.

With the hope of making UV techniques for bacteria control more widespread, the recently formed National Tuberculosis Coalition is launching a controlled study of the use of UV lamps to prevent the spread of tuberculosis. With support from EPRI, Consolidated Edison Company of New York, the Lighting Research Institute, and other sources, the coalition plans to study the use of UV lamps in six urban areas across the United States.

The plan is to install UV lamps in homeless shelters, where tuberculosis is commonly transmitted. Over a five-year period, researchers will study the spread of the disease among workers and homeless people at the shelters. The results will be compared with data obtained over the same period from homeless shelters with no UV lamps. The study will be directed by doctors from St. Vincent's Hospital in New York City and from Harvard Medical School. The final results are expected late in 1999.

Unlike the situation in the 1940s, today some tuberculosis bacteria are resistant to the antibiotics developed to wipe them out. According to the federal government, there were 26,700 new cases of tuberculosis in 1992, 20% more than at the lowest point for new cases, reported seven years earlier. Urban areas in this country have been hit particularly hard by the recent resurgence of the disease.

"Tuberculosis could become a real health crisis in the next 5 to 10 years," says Myron Jones, who is managing EPRI's involvement with the coalition. "By supporting this research, electric utilities may ultimately help hold down health care costs in their service territories. And by reducing these costs, utilities are also helping to keep their commercial customers more competitive."

■ *For more information, contact Myron Jones, (415) 855-2993.*

Alfalfa May Provide Fuel As Well As Feed

Alfalfa has long been used as a high-protein animal feed and cultivated as a rotation crop for adding nitrogen to the soil. Now this versatile plant may find another important use in regions where it is commonly grown—as a fuel for electricity generation. This possibility is being explored in a project cosponsored by EPRI and the National Renewable Energy Laboratory and conducted by Northern States Power Company (NSP), with assistance from the University of Minnesota, the Institute of Gas Technology, Tampella Power Corporation, and Westinghouse Electric Corporation. The study will determine the feasibility of using alfalfa as an energy source for a highly efficient power plant that would consume 500–1000 tons of biomass per day.

The first step in preparing alfalfa for use as a biofuel is to separate the stems from the leaves, which are fed to animals. The stems are then gasified by reaction with steam in a heated, pressurized vessel. After particulate removal, the hot gases fuel a combustion turbine to generate electricity; extra heat is recovered for additional power generation in a combined-cycle process.

The study, which began last December, will conclude in August. If it shows that alfalfa makes an attractive biofuel, the sponsors will then consider a large-scale demonstration at NSP's Granite Falls power plant in southwestern Minnesota.

■ *For more information, contact Evan Hughes, (415) 855-2179.*

SOLID FUTURES IN FUEL CELLS

Ceramic tubes used in the Westinghouse solid-oxide fuel cell are dipped in a slurry to coat them with a conductive layer.

by John Douglas

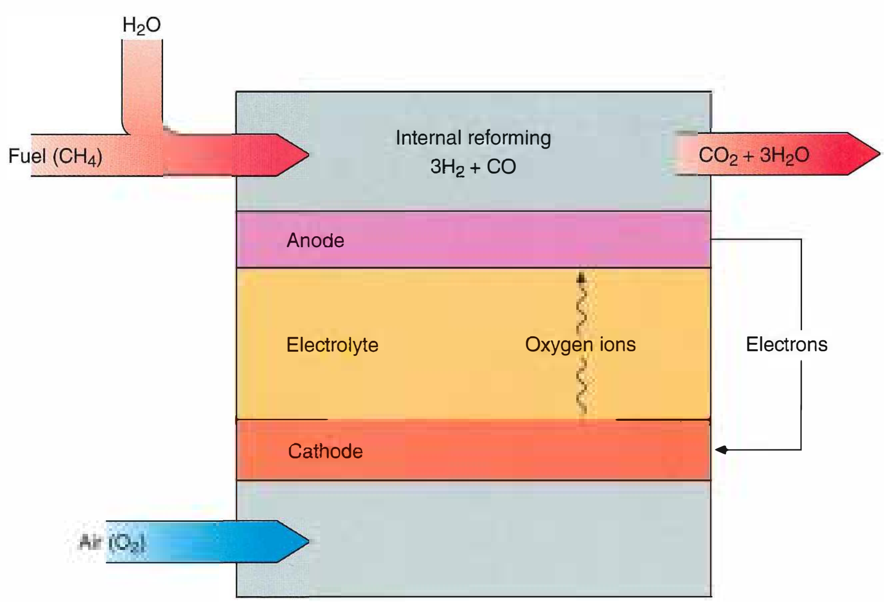
THE STORY IN BRIEF SOLID-OXIDE FUEL CELLS, WHICH FEATURE SOLID RATHER THAN LIQUID ELECTROLYTES, REPRESENT THE NEXT BIG OPPORTUNITY IN FUEL CELL DEVELOPMENT. FREED FROM THE HANDLING DIFFICULTIES OF CORROSIVE LIQUIDS, THESE SOLID-STATE CELLS HAVE THE POTENTIAL TO BE MANUFACTURED INEXPENSIVELY AND TO OPERATE COST-COMPETITIVELY IN VERY SMALL UNIT SIZES. AND BECAUSE THEY OPERATE AT HIGH TEMPERATURES, SOFCS OFFER BOTH INTERNAL FUEL REFORMING AND THE POSSIBILITY OF COPRODUCING STEAM HOT ENOUGH TO USE IN INDUSTRIAL PROCESSES. THE FIRST AMERICAN UTILITY DEMONSTRATION OF AN SOFC—A 20-KW UNIT BASED ON A TUBULAR DESIGN—IS SCHEDULED TO BEGIN THIS YEAR IN SOUTHERN CALIFORNIA. SEVERAL OTHER CONFIGURATIONS WITH POTENTIAL ADVANTAGES FOR EFFICIENCY AND MANUFACTURABILITY ARE NOW IN THE PROOF-OF-CONCEPT STAGE OF DEVELOPMENT.

Fuel cells offer advantages that would seem to make them ideal for meeting future generation needs. By converting fuel energy directly into electricity without the need for combustion, they can achieve higher efficiency with virtually no emissions. In addition, they are inherently modular, quiet, and quickly responsive to changing load. Current-generation fuel cells are relatively expensive to build, however, and the corrosive liquid electrolytes used in today's largest cells are difficult to manage and tend to reduce expected unit service life.

Good progress continues to be made on these liquid-electrolyte cells, which are likely to be an important option for large-capacity installations. But a new generation of fuel cells, containing only solid components, is now also beginning to become available for utility demonstration. These units have the potential to avoid some of the technical and economic drawbacks that have hindered wider commercial application of fuel cell technology. Freed from the nuisance of liquid electrolytes, these new units may have much simpler designs involving relatively inexpensive ceramic or metallic materials, which should eventually lead to mass production and low manufacturing costs. Laboratory tests have also indicated that if their development is successful, solid-electrolyte fuel cells could have service lives of more than 10 years—nearly twice the service life currently projected for cells with liquid electrolytes.

Still, several technical challenges remain unresolved—particularly the need for materials with appropriately matched thermal expansion properties and for seals capable of withstanding high-temperature operation. It is also still too early to predict which of several alternative designs for solid-state fuel cells might ultimately achieve commercial success. By far the most highly developed today is the solid-oxide fuel cell (SOFC) with a tubular design developed by Westinghouse Electric Corporation; it is currently being tested at two utility installations in 25-kW units. Other SOFC designs are expected to reach utility demonstration at similar power levels in a couple of years. Meanwhile, laboratory work is under way to explore additional innovative concepts, including thin-film fabrication and proton-conducting solid electrolytes. EPRI is actively supporting work in each of these areas and anticipates bringing solid-state fuel cells to commercial viability for dispersed generation utility use by the end of the decade.

GENERATION WITHOUT COMBUSTION
Fuel cells are like batteries that run on fuel. Oxidation of hydrogen and carbon monoxide at the anode releases electrons to an external circuit, which conducts them to the cathode, where they combine with oxygen atoms in a reduction reaction. The negatively charged oxygen ions thus produced are transported through an electrolyte to the anode. Solid-oxide fuel cells have a ceramic electrolyte and operate at temperatures high enough for internal reforming of methane fuel into the hydrogen and carbon monoxide needed for the oxidation reaction.



Like a battery

Fuel cells are like batteries that don't run down, because they are continuously supplied with fuel. They convert fuel energy to electricity through flameless oxidation, which takes place in two stages at electrodes separated by an electrolyte. At the anode, electrons are released to an external circuit when hydrogen from the fuel combines with oxygen ions that have been transported through the electrolyte—which, in an SOFC, is usually composed of yttria-stabilized zirconia (YSZ). At the cathode, electrons from the external circuit combine with oxygen from the air to produce the negatively charged oxygen ions. The only by-products of this electrochemical process are water and carbon dioxide, and, because of the higher efficiency of fuel use, the amount of CO_2 produced is less per kilowatthour than that produced by a combustion-based system.

Invented more than a century ago, fuel cells have been used in a variety of applications since the late 1950s. The fuel cell that today has the greatest commercial penetration utilizes a phosphoric acid electrolyte and operates at around 200°C. An 11-MW phosphoric acid fuel cell (PAFC)—by far the world's largest—is operating at Tokyo Electric Power Company with a 42% power-generating efficiency. A molten carbonate fuel cell (MCFC) is currently being commercialized at 2-MW scale with EPRI participation. By operating at a higher temperature, 650°C, with improved system integration, the MCFC promises to achieve higher generating efficiency (55–

60%) by internally reforming hydrocarbon fuel (such as natural gas) to produce hydrogen. The PAFC requires an energy-consuming external reformer.

Solid-oxide fuel cells represent the next generation of development. Operating at temperatures of around 1000°C, they feature internal fuel reforming and can produce steam hot enough for use in almost any industrial process. The generating efficiency of an SOFC is expected to be about 50–55%, and total system efficiency may exceed 80% if the available waste heat is fully utilized. The solid electrolyte eliminates the materials-stability problems associated with highly corrosive phosphoric acid and molten carbonate and allows SOFCs to have simple designs based on raw materials that cost as little as $7–$15/kW (according to cost studies by Combustion Engineering). SOFC systems also have the potential to be manufactured inexpensively and to operate competitively in units ranging from 5 kW to 5 MW.

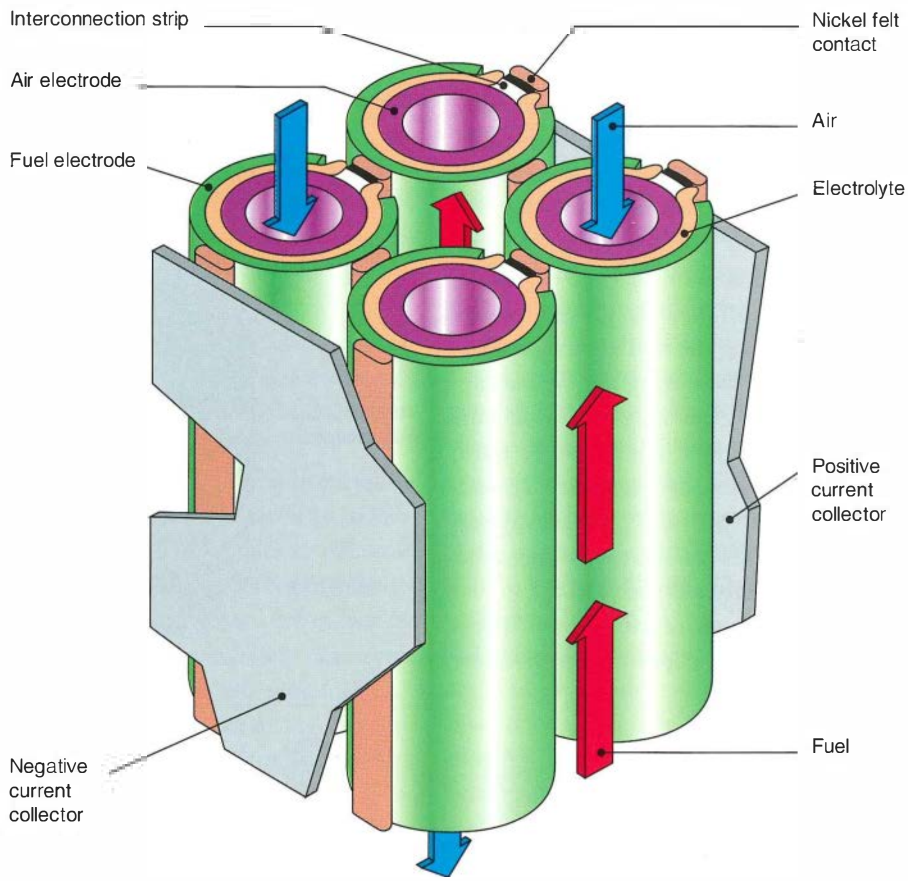
"SOFCs should be ideal for distributed generation," says EPRI research manager Rocky Goldstein. "They could be installed, for example, at utility substations or on the premises of commercial or industrial customers. In either case, utilities could benefit by avoiding the capital costs of building large generating plants and transmission facilities to meet load growth. Clearly the market is there for SOFCs—utilities would buy them today if the technology were mature. But first we have to overcome some significant technical barriers."

Initial utility demonstrations

Two of the main technical barriers that have hindered SOFC development are the mismatches between the expansion characteristics of various cell components, which can lead to cracking, and the difficulty of separating and manifolding fuel and oxidant gas streams with seals that can withstand high operating temperatures. The tubular SOFC developed by Westinghouse is the first design to have surmounted these barriers sufficiently to begin utility demonstrations.

In the Westinghouse design, the need for high-temperature seals has been elim-

WESTINGHOUSE TUBULAR DESIGN The Westinghouse SOFC units, now undergoing utility testing, are made up of bundles of long, closed tubular cells composed of concentric electrodes separated by a layer of solid electrolyte. Fuel for the reaction rises between the tube exteriors, while air enters the tube interiors from above. Unreacted fuel is burned above the bundles of tubes to preheat the air. Nickel felt contacts provide flexible electrical connections between the cells.



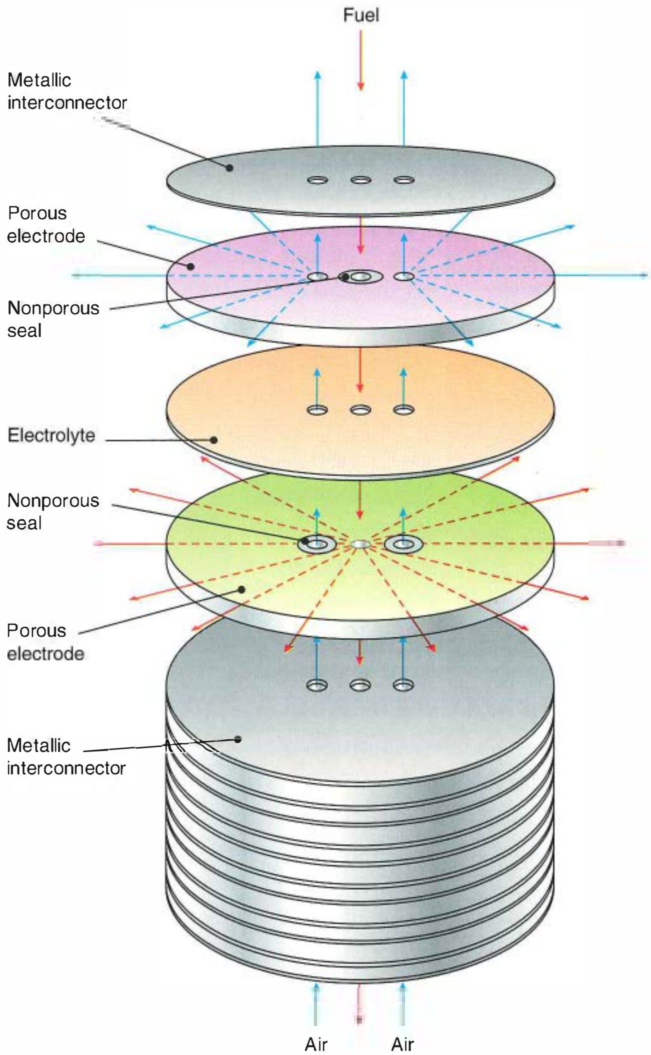
Two Westinghouse 20-kW units at the Rokka Island Test Center for Advanced Energy Systems (near Kobe, Japan), operated by the Kansai Electric Power Company. One of the units has run in excess of 6500 hours.

inated by channeling fuel and air flow to opposite surfaces of hollow, closed-end tubes. Air enters a tube interior from above, while fuel surrounds the tube exterior. Negatively charged oxygen ions derived from oxygen in the air stream flow through the solid electrolyte and react with hydrogen or carbon monoxide from the fuel stream. After undergoing electrochemical reaction in the tube walls, the two gas streams—which now include reaction products—exit into a small combustion zone above the tube assembly, where unreacted fuel is burned to preheat the inlet air for additional efficiency.

The problems of cracking and delamination due to uneven thermal expansion of adjacent components are solved by closely matching thermal expansion characteristics and by making the various layers of the tube grow into each other during fabrication. First the relatively thick, porous air electrode (cathode) is constructed, which provides physical support for the rest of the 0.5–1.5-meter-long tube. The YSZ electrolyte is then created in two steps. A thin layer of yttrium and zirconium chlorides is deposited on the inner (air) electrode, penetrating pores in its exterior surface. Then oxygen is forced outward through the electrode, where it reacts with metal chlorides to create a YSZ layer that is firmly bonded to the electrode surface. The outer, fuel electrode (anode) is created by anchoring nickel particles onto the exterior surface of the YSZ electrolyte through a similar two-step process.

A complete fuel cell generator consists of multiple tubes assembled into a semirigid bundle and attached to gas manifolds. Electrical contact between tubes in a bundle is provided by a thin interconnection strip built into each tube and by a soft plug of nickel felt (metal fibers bonded together) positioned between adjoining tubes. Tubes are connected both in series, to boost voltage, and in parallel, to increase amperage.

Westinghouse hopes to make its tubular SOFC cost-competitive by the late 1990s and has taken a major step in its commercialization program by establishing a



PLANAR POROUS-ELECTRODE CELLS A planar design from Technology Management, Inc., uses the innovative approach of distributing fuel and oxidant within its cells radially through porous electrodes. This design is expected to be particularly easy to manufacture, since it does not require high-temperature bonding of the cell elements. A 100-W demonstration unit is expected to begin operation early this year.

PLANAR DESIGN FROM ZTEK Ztek's planar SOFC distributes fuel and air to electrode surfaces through grooves in a flexible metal interconnector between individual cells of a stack. Plans call for two proof-of-concept demonstrations, one featuring a 100-W stack and the other a 1-kW stack. If all goes well, the Tennessee Valley Authority expects to install a 25-kW unit on its system in 1995.

prepilot manufacturing facility near Pittsburgh. Two 20-kW Westinghouse units began operating in Japan during 1992. One of these units has now passed 6500 hours at power. The first American demonstration of this technology is scheduled to begin at the Highgrove substation of Southern California Edison Company (SCE) in mid-1994. EPRI will participate in the operation, testing, and evaluation of the 20-kW Highgrove unit. Eventually SCE hopes to establish a national fuel cell test and evaluation center at the Highgrove site. Plans currently include the installation, with EPRI participation, of a 100–1000 kW Westinghouse SOFC, which is to begin operation in 1996 or later. This facility would also test units of several other fuel cell technologies.

Toward other configurations

Despite its early success, tubular geometry may not be the final word on SOFC design. To provide an objective comparison of the performance potential of various SOFC configurations, EPRI has sponsored a study that evaluates resistance losses in SOFC elements for each configuration according to a common analytical routine. This study found that tubular designs had inherently higher resistance losses because of the long current paths inside the electrodes. Because of these losses, the study predicted that the maximum potential power density of tubular SOFCs would remain considerably below that of configurations in which flat elements were stacked on top of each other.

There are two options for stacking. In the so-called planar configuration, cell components are just flat plates layered in direct contact with each other. Oxygen and fuel flow laterally from manifolds, either through grooves in the metallic or ceramic interconnectors between adjacent cells or through porous electrodes. In the cross-flow configuration, electrodes and interconnectors are corrugated or ribbed to allow the flow of fuel and oxidant from external manifolds across electrode surfaces. Although a variant of the cross-flow design being developed by Allied-Signal Corporation could potentially have the highest power density, it is proving difficult to fabricate. EPRI work on alternative configurations is thus focused on two approaches to planar SOFCs.

The first of these involves a design by Ztek Corporation of Waltham, Massachusetts, in which a flexible metal interconnector is placed between the rigid ceramic elements that make up the electrochemically active SOFC components. Grooves on the interconnector distribute fuel and air over the corresponding electrode surfaces of a cell. The interconnector also provides a low-loss electrical connection between adjacent cells and conducts heat away from the electrode surfaces toward the outer edge of the cell—making this the only SOFC design that is cooled by thermal radiation rather than by gas convection. The advantage of such a cooling scheme is that it facilitates size reduction, lowers materials costs, and minimizes gas handling.

A 100-W planar SOFC was expected to begin operation at Ztek's facilities in February 1994, with a 1-kW stack to follow in April. Work on these proof-of-concept demonstrations has been cofunded by EPRI and the Tennessee Valley Authority. If the tests are successful, a planned 25-kW unit will be installed at TVA; startup is tentatively scheduled for the end of 1995.

The second type of planar SOFC utilizes highly porous electrode materials to distribute fuel and oxidant across a cell. This design should be relatively easy to manufacture, since it does not require high-temperature bonding of the cell elements to control gas flow. Initial economic projections indicate a potential system cost of about $500–$700/kW—substantially lower than that of alternative planar designs. Energy density would also be significantly higher than that of the other SOFCs, but the development status of this design option has not advanced as far.

This design was invented by Sohio but discontinued after a corporate takeover by British Petroleum (BP). The porous-electrode SOFC is now being developed by Technology Management, Inc., of Cleveland, Ohio, under BP license. Funding for this work is being provided by EPRI, the Gas Research Institute (GRI), SCE, and the U.S. Department of Energy. A 100-W unit is scheduled to begin operation at Technology Management early this year, and current plans call for the development of a 100-kW system for utility installation by around 1997. Another planar SOFC is being developed by Ceramatec of Salt Lake City, Utah, under GRI and DOE sponsorship. EPRI will continue to monitor the progress of this effort.

Lowering temperatures

The 1000°C operating temperature required by SOFCs with a YSZ electrolyte is a mixed blessing. It produces high-quality steam and reforms the fuel internally, but reforming could take place at more moderate temperatures and efficiency could be increased simultaneously. Unlike heat-based systems for energy conversion, electrochemical systems have efficiencies that rise as temperature falls, since a smaller portion of the reaction energy is lost as heat and more goes to generate electricity. A decrease in operating temperature from 1000°C to about 700–800°C would increase efficiency about 6%.

Lower temperatures would also permit the use of metals, such as silver, in the electrodes—thus reducing their resistance, making them less expensive, and simplifying cell fabrication. The cost of the materials used in cell support and heat removal could also be cut, especially as stainless steel is replaced by less-temperature-resistant and less-expensive grades of steel. For all these reasons, EPRI is pursuing an active exploratory research program designed to lower SOFC operating temperatures to about 700°C.

One approach is to continue using YSZ as an electrolyte but to create cells from thin films. Very thin layers (less than 10 μm) have low resistance losses and thus permit reduced operating temperatures. Such thin films can be created by a technique called magnetron sputtering, which is commonly used in processing large-scale semiconductors and which gives good control over the properties of the finished products.

Pursuing this approach, researchers at Northwestern University have created one of the world's thinnest fuel cells—

an operating SOFC less than half the thickness of a human hair. EPRI cosponsored this work with GRI. The electrolyte for the Northwestern device consists of three layers of catalytically active oxides: YSZ in the center, bismuth oxide on the cathode side, and cerium oxide (ceria) on the anode side. The advantage of this multilayered electrolyte, researchers found, is that it has lower resistance than YSZ alone.

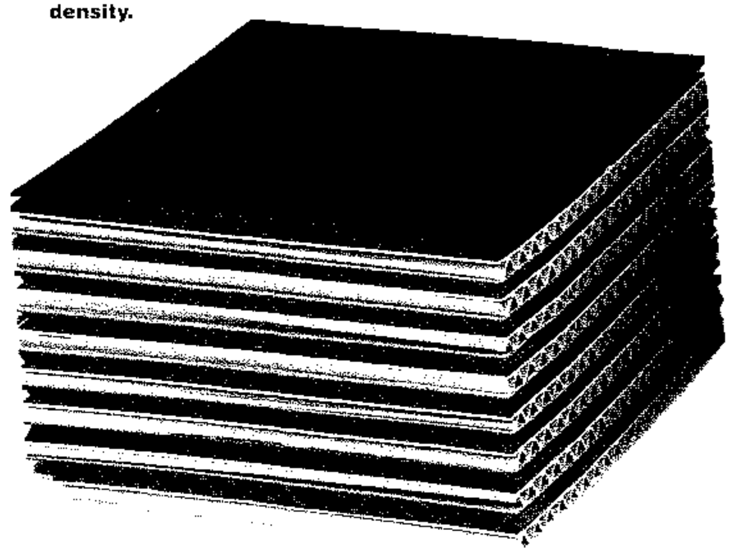
The problem with using ceria or bismuth oxide as the electrolyte, however, is that performance tends to deteriorate. When exposed to a reducing (fuel-side) atmosphere, ceria becomes more electrically conductive and bismuth oxide reduces to metallic bismuth, thus shorting out the cell. In the Northwestern design, shorting is prevented by the presence of the YSZ layer in the electrolyte. Taking a somewhat different tack, a project at the University of Utah involves the use of a ceria electrolyte and protects it with an ultrathin (50-nm) layer of doped zirconia. While this layer allows oxygen ions to flow through, it acts as a barrier to electrons and thus prevents shorting. Utah researchers have created and tested a 1-W cell that uses a zirconia-ceria bilayered electrolyte.

The use of ceria-based electrolytes has very good promise, according to Goldstein. "We have long recognized the high ionic conductivity of ceria—as well as the fact that it can operate at lower temperatures, about 800°C. Getting around the shorting problem really makes ceria-based designs viable. What we've accomplished through research on ceria electrolytes at Northwestern is an ultrathin cell that could lead to low-cost production and a high energy density. At Utah we have a cell that isn't as thin but that has an even higher energy density."

A concern in making thin-film SOFCs is how to adapt them for mass production. EPRI is currently sponsoring research at the Jet Propulsion Laboratory (JPL) in Pasadena, California, that is examining an important aspect of this question—how to create suitable interconnectors for thin-film cells. Such interconnectors must be capable of carrying current and heat while remaining stable in both oxidizing and reducing atmospheres, and they may also be used to manifold and deliver fuel and oxidant.

JPL researchers are considering various designs for thin-film cell interconnectors, including one based on an ancient metalcasting technique—the lost-wax method of creating intricate patterns in heat-resistant materials. To make grooves for gas distribution between an interconnector and an electrode, for example, the desired pattern could be created on the interconnector surface by using a transient material like wax. The electrode could then be deposited by means of a process, such as sputtering, that doesn't involve heat. Finally, the assembly would be heated to drive off the transient material. JPL expects to have fabricated complete stacks of thin-film SOFCs for testing by mid-1995.

MONOLITHIC DESIGN **A monolithic, cross-flow SOFC developed by Allied-Signal has the potential for maximizing power density.**



New electrolytes

Another way to lower SOFC operating temperatures is to use some material other than YSZ as an electrolyte. Under the joint sponsorship of EPRI, GRI, and DOE, researchers at Argonne National Laboratory have synthesized several new electrolyte materials that have desirable ion-carrying properties and remain stable at moderate operating temperatures. One group of materials, called orthosilicates, has a crystal structure with "tunnels" large enough to accommodate migrating oxide ions. Another group, the sheelites, is composed of alternating layers of loosely bound groups of atoms, permitting oxygen-ion transport through the space between the layers.

Although the Argonne work has contributed significantly to the scientific understanding of electrolyte behavior, the performance of the orthosilicates and sheelites has not been as good as hoped. The Argonne researchers are therefore shifting their emphasis toward testing cells from the University of Utah and other sources and optimizing their composition.

Electrolytes that conduct protons, rather than oxidant ions, can also be used to construct SOFCs and may simplify the task of finding a suitable material to lower operating temperatures. When a proton conductor is used, H^+ ions move from the anode to the cathode, where they react with O^- ions to produce water. The other electrochemical processes remain similar, and carbon dioxide is still produced at the anode.

The initial EPRI-sponsored research on

proton-conducting electrolytes was conducted at Stanford University, where barium cerate was identified as having good potential for SOFC applications. Currently, the Georgia Institute of Technology is exploring methods of fabricating cells that use this new material, with funding provided by EPRI and the National Science Foundation.

Spectrum of applications

As SOFC technologies continue to mature, they will join other types of fuel cells in competing for a variety of applications that are beginning to emerge. "Market niches for fuel cell power plants are appearing in the range from 100 kW to 2–5 MW; at this scale, their benefits have the potential to more than offset their higher per-kilowatt investment cost, compared with much larger, central-station power plants," says EPRI's Ron Wolk, director of the Advanced Fossil Power Systems Department. "These applications vary widely and will be optimally served by different types of fuel cells. Significant market penetration, however, will occur only when product costs are reduced to the $1000–$1500/kW level."

Phosphoric acid fuel cells will probably be most useful in circumstances where there is an economic value in the relatively large proportion of waste heat produced, according to Wolk. Such large volumes of relatively low temperature heat can be used for water heating and space conditioning, and markets are now opening in the United States and Japan for standalone, packaged PAFC units in the range of 50–200 kW.

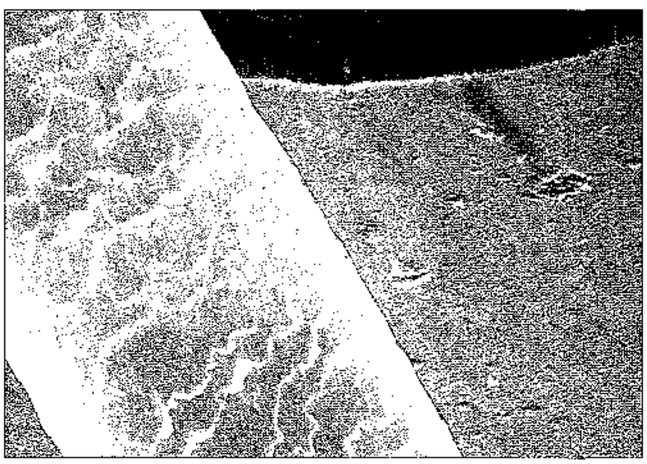
Molten carbonate fuel cells are expected to fit best into a market niche addressing local-area utility needs or to serve as distributed generators at customer sites. MCFCs use less-expensive materials than PAFCs and are more efficient because of internal fuel reforming. Most of the early applications will be in the range of 1–5 MW, although modular units could eventually be assembled for larger, central-station applications if their economic characteristics prove favorable.

"Solid-oxide fuel cells, which are the least developed at this point, may ultimately be useful across the entire spectrum of generation sizes," Wolk says. "A variety of innovative approaches are under investigation as potentially low-cost techniques for the fabrication of small SOFC units, and if this work is successful in reducing costs, it could lead to the development of significant new markets. The spectrum of activities discussed here has resulted in several significant advances in the state of the art. EPRI researchers have played a major leadership role in coordinating these activities and synthesizing a program focused on meeting utility needs."

The SOFCs used initially are expected to be rated at less than 100 kW and to be employed in situations where very high electrical conversion efficiency is important—such as in residential complexes or commercial establishments. The high-temperature steam produced by SOFCs could also make them suitable for use in some industrial applications. In addition, SOFCs have the advantage of producing a pure carbon dioxide stream that could more easily be sequestered if CO_2 disposal becomes an important consideration.

"EPRI's current approach is to monitor PAFC development, to support MCFC utility demonstrations at the multimegawatt level, and to act as a major sponsor of SOFC R&D," according to Goldstein. "One reason we're concentrating on MCFCs and SOFCs is that they are modular and thus lend themselves well to distributed generation. They're clean enough to build close to customer demand sites, and utilities can thus save the considerable capital expense of transmission and distribution facilities associated with more-remote central-station plants. Also, although these cells have good load response characteristics, most users run them flat out as part of baseload capacity because they're the most efficient units on the system. I see a particularly exciting period of rapid development ahead for SOFCs, leading to large-scale use toward the end of this decade." ■

THIN-FILM FUEL CELLS Researchers at Northwestern University and the University of Utah are investigating the use of very thin films in the fabrication of SOFC electrolytes. A 3-μm-thick electrolyte of this type (shown here in comparison with a human hair) is hundreds of times thinner than the YSZ layer now used in high-temperature SOFCs.

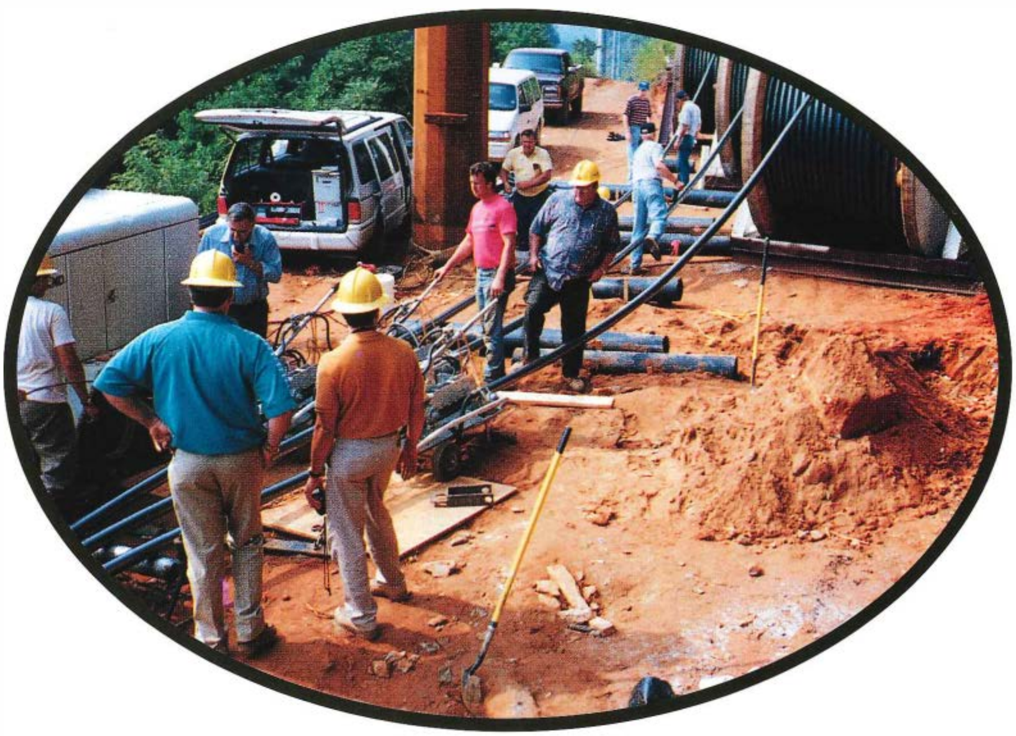


3-μm film

Background information for this article was provided by Rocky Goldstein and Ron Wolk of EPRI's Generation & Storage Division.

by Leslie Lamarre

INNOVATIONS UNDERGROUND



THE STORY IN BRIEF A simple promise to bury an overhead transmission line turned into a big problem for Georgia Power Company when Native Americans pointed out that sacred burial grounds were located along the right-of-way. Complex geology added to the difficulties, making the job seem impossible to complete. Working with EPRI, Georgia Power found the answer in emerging technologies. Used together in the field for the first time, these technologies allowed workers to complete the job swiftly and more cost-effectively than would have been possible with conventional methods. The end result not only pleased Georgia Power but also left community members with a high level of confidence in the utility.

Before Georgia Power Company installed a transmission line in northern Georgia last summer, utility officials notified a local Native American chief, who came to bless the site. Such is not the ordinary course of business for Georgia Power, but then again, this was no ordinary project. The challenge was to move an existing 115-kV line underground without disturbing sacred Cherokee burial grounds along the right-of-way.

The burial grounds weren't the original problem, however. It all started back in 1989, when Georgia Power installed an overhead transmission line that sliced through the Nacoochee Valley in the foothills of the Blue Ridge Mountains. Although the concrete poles supporting the line were specially selected for their relatively unobtrusive appearance, the local community didn't like them one bit. "They were really out of scale with the surroundings and just overpowered the view of the valley," says Jimmy Johnston, the executive director of the Sautee-Nacoochee Community Association, which works to preserve the historical, environmental, and cultural aspects of the Sautee-Nacoochee region.

The heavily wooded Nacoochee Valley is a popular spot among tourists, who often take advantage of nearby camping and hiking facilities. Just a couple hours' drive from the Atlanta region, it lies only 10 miles from the Appalachian Trail. The Chattahoochee River, which winds through the valley, offers trout fishing, canoeing, and other types of recreational opportunities. Tourists also come to see the nearby town of Helen (population 300), which underwent a face-lift in the 1960s that turned it into a Bavarian-style village. Every autumn Helen hosts a six-week Oktoberfest celebration that draws thousands from across the state.

Listed on the National Register of Historic Places, the Nacoochee Valley is home to some well-preserved Victorian churches and homes. Ancient Native American mounds are still visible in the valley, offering evidence that a significant Native American population inhabited the region some time ago.

The challenge

As soon as Georgia Power began erecting the concrete poles to carry the transmission line across the Nacoochee Valley five years ago, members of the Sautee-Nacoochee Community Association called the utility to complain. Before long, word got around to William Dahlberg, president of the utility, who decided to go to the area to see for himself. Once at the site, Dahlberg had to agree that the line and its supporting concrete poles detracted from the area's natural beauty. He promised that Georgia Power would move the line underground.

As it turned out, the task of laying an underground transmission line in the valley was far more complicated than utility officials had ever anticipated. Traditional installation procedures involve slicing open the earth and laying the cable in a trench. Georgia Power's technical experts who surveyed the site uncovered a number of geologic idiosyncrasies that they realized would make the project very difficult and expensive to complete by means of these open-trenching procedures. Among the peculiarities is a large quantity of river rock that lies just under the topsoil of the valley floor. Apparently the river rock, or cobble, was the original bed of the Chattahoochee River, which is believed to have been diverted in the early 1800s.

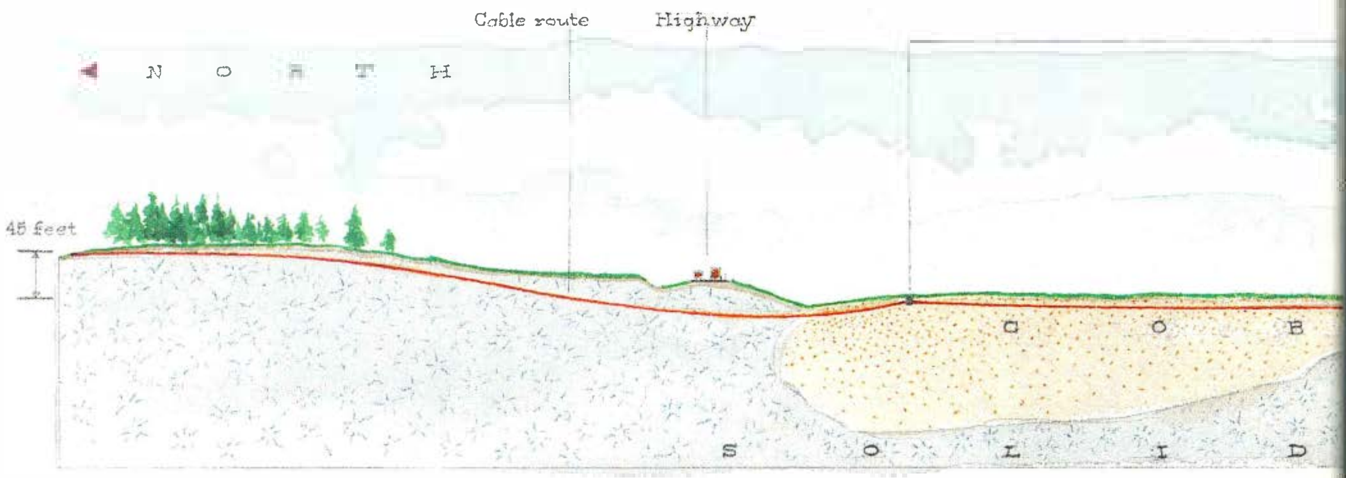
The combination of the river rock and the shallow depth of the water table in the area meant that an extrawide trench would have to be dug and shored up on both sides with special bracing. Water pumped out of the trench would have to be hauled away in container trucks. Crossing the Chattahoochee was also a major hurdle. Traditional techniques would require that half of the river be dammed at any one time for open trenching. But because the Chattahoochee is a state-designated trout stream, no construction is allowed within 100 feet of the river.

Environmental issues were not the only concern, as Georgia Power soon found out. Local Native Americans who had gotten wind of the proposal for the underground line pointed out that, according to historical records, the valley floor contains the remains of Cherokee families who lived there 300 years ago. Clearly the job could not be accomplished with traditional, open-trenching techniques. But officials at Georgia Power were not ready to give up. The utility's technical experts continued to attack the problem from different angles, trying to find a way to keep the company's promise to the Sautee-Nacoochee Community Association without disrupting the Native American burial grounds.

For more than two years the utility searched for a solution and maintained communications with the local community. "At one point it seemed there wasn't going to be a solution that would please everybody," says George Henefeld, assistant to Georgia Power's senior vice president for power delivery, and manager of the project. "We were really between a rock and a hard place because we had made the commitment to bury the lines. We were afraid the task might be insurmountable."

The Bavarian-style village of Helen, Georgia, draws thousands of tourists during its annual Oktoberfest celebration. The impending event put extra pressure on workers installing a 115-kV transmission line beneath the Nacoochee Valley floor last year. The workers regularly put in 14-hour days, finishing the job just two weeks before the festivities began.

UNDERGROUND PERSPECTIVE **Drill operators bored the 2600-foot underground channel in four lengths, maintaining a depth of at least 10 feet along the entire route. The channel passes under a two-lane highway, through 1100 feet of river rock, beneath the Chattahoochee River, and up a 20-degree incline packed with rocky clay and granite. The only topsoil disturbed in the**



The crossroads

Eventually it became clear that no available boring technologies were capable of drilling underground for a significant distance in such difficult conditions. That's when Rick Bush, a manager with Georgia Power's Research Center, got involved. Bush was aware of a couple of advanced technologies under development at EPRI that he thought might resolve the impasse. To find out more, he contacted EPRI's Tom Rodenbaugh, a manager of underground transmission research. "Rick's call was very timely," says Rodenbaugh. "We *were*, in fact, working on several technologies that appeared to be well suited for the task at hand."

Under contract to EPRI, the company Underground Research was developing a tungsten carbide drill bit capable of cutting through hard rock. Also under contract to EPRI, Guided Boring Systems, a subsidiary of Maurer Engineering, was developing a navigational system for underground-boring rigs. Rodenbaugh contacted Frank Kinnan, president and CEO of Underground Research, to discuss the potential for these technologies and for other pieces of equipment, including back reamers and cable pushers, being developed for EPRI by Underground Research. All in the beta phase of development, these tools were already being field-tested at various utilities but had never been used together. Nor had they been applied to such a challenging project. Nevertheless, Rodenbaugh and Kinnan concluded that they offered the best probability for success.

"We told Georgia Power that the project would probably involve some trial and error," says Rodenbaugh. "I figured there was an 85% chance it could work. And I knew nobody else could do it. Frank Kinnan is something of a magician. He's the experts' expert."

Georgia Power officials were skeptical at first. "He had to come here and convince me that he knew what he was doing," Bush recalls, referring to Kinnan. After hearing all the technical details on how the job would be performed, however, Bush was sold. At Georgia Power's request, Rodenbaugh assembled a team of experts to see the job through. The team included himself and representatives from Underground Research, Maurer Engineering, Georgia Power, and Directional Technologies, an offshore-oil-drilling consultant. Once the details were ironed out, George Henefeld called an open meeting for members of the Sautee-Nacoochee community to explain how the procedure would work. Bush was also on hand at the meeting, held in May of last year, to answer technical questions.

"From the charts and the layout and the presentation they gave, it made a whole lot of sense to me," recalls Richard Running Fox Dennis, a member of the Native American community that alerted Georgia Power to the presence of burial grounds in the valley floor. "It seemed like a solution that everybody could be happy with."

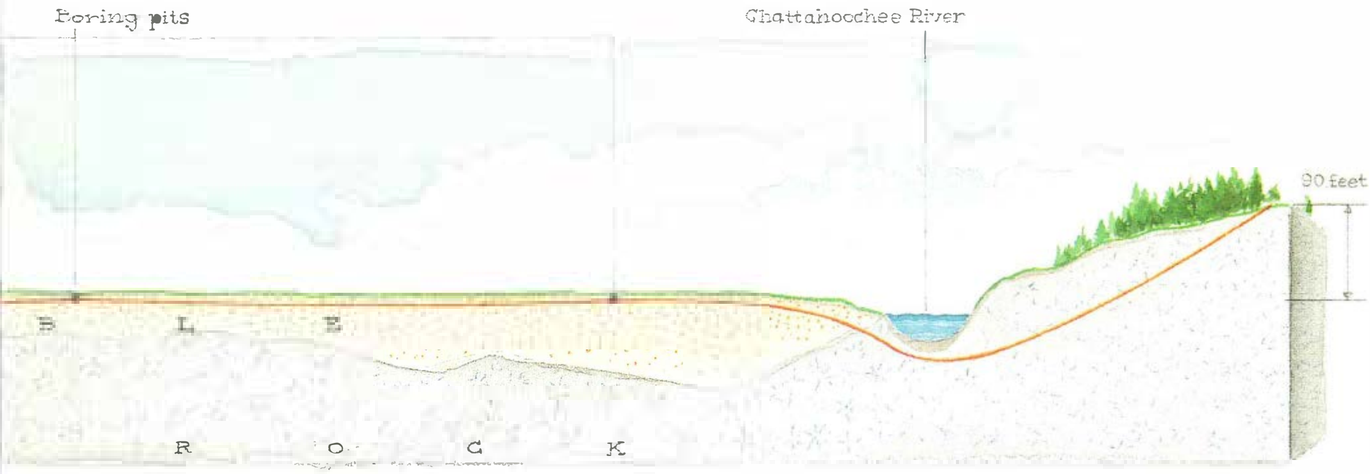
Down to business

With a vote of confidence from the local community, Georgia Power was ready to proceed. But there was no time to lose: the utility had committed to finishing the work before the Oktoberfest celebration, which would be kicked off shortly after Labor Day. Rodenbaugh communicated the urgency of the matter to EPRI's Contracts Division, which drew up a multiparty agreement, complete with specifics on patent rights, in two weeks.

In the meantime, the utility obtained the necessary environmental permits to conduct the project. Before work got under way on July 5 of last year, Dennis, who serves as vice chief of the southern band of Cherokees and Creeks as well as chief of the Cherokee Bear Clan, came to bless the site. Dressed in traditional Cherokee ceremonial clothing, he burned sagebrush to drive away evil spirits and sweet grass to welcome good spirits. As an offering to the Great Spirit, he sprinkled tobacco along the site. It was time for the project to begin.

Although Georgia Power officials had

valley during the drilling procedure was that removed from the three pits used to collect drilling slurry and to connect the polyethylene pipes that would hold the transmission line. Before the pits were dug, a staff archeologist at Georgia Power sifted the soil for artifacts. A specialist also scanned these areas with ground-penetrating radar.



already surmounted a lot of hurdles to reach this point, the start of the project revealed a whole new set of challenges. Soil samples taken every 100 feet along the right-of-way indicated that the geology might be even more complex than previously believed. (To help ensure that no holes were bored in archeologically significant areas, a specialist had examined the site with ground-penetrating radar.) Among the surprising findings was the abundance of the cobble beneath the topsoil. Most of the stone was between 1 and 6 inches in diameter, but some pieces measured up to 2 feet across. "We knew the cobble was there, but we didn't quite realize the extent of it," says Rodenbaugh. "Cobble is probably the toughest material to drill through. Not only is it hard, but it tends to collapse on itself as you drill."

The plan was to drill the 2600-foot underground channel in four segments that would traverse the valley from north to south. "Even though there was a chance that this could fail, there was no turning back," says Bush. "Once you get into a project like this, you have to make it work!"

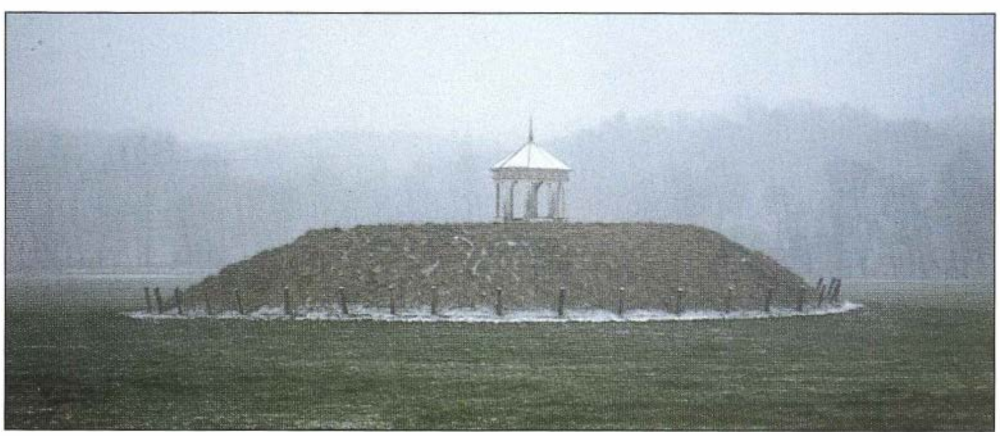
The only ground opened up in the valley was excavated to create three pits—each about 8 feet long by 4 feet wide—for collecting the drilling slurry and connecting the polyethylene piping that would house the transmission line. Georgia Power's archeologist, who had analyzed these three spots before the pits were dug, sifted the extracted soil to be certain that no artifacts had been unearthed. He found only small shards of pottery and flint.

One leg of the 2600-foot channel was bored 700 feet from north to south, running under the Chattahoochee River and up a 20-degree incline packed with rocky clay and solid granite. Two other legs were bored under the floor of the valley, totaling about 1100 linear feet, all of which was crammed with cobble. The final leg of 800 feet passed through clay and sandstone under Highway 75, a two-lane road, and ran up a gradual incline.

Tools and techniques

The drill rig used was developed by Underground Research and is capable of drilling distances nearly four times longer, and of cutting diameters up to three times larger, than those achieved by conventional drill rigs. The tungsten carbide drill bit, a technology based on 50 years of experience in the oil-drilling industry, was redesigned for cutting through hard rock surfaces. Shaped like a cone and embedded with buttonlike carbide cutters, the specialized drill bit is actually part of the steering system and is capable of turning on its own axis.

This ancient Native American mound testifies to the archeological significance of the Nacoochee Valley.



Similarly innovative is the navigational system used to guide the drill. Called AccuNav, this tool is based on technology designed for cruise missiles. Equipped with sensors that measure the earth's magnetic and gravitational fields, AccuNav is able to track the drill's location, pitch, and movement as the drill head progresses along its course. Every few seconds this information is relayed to a computer that is observed by the drill operator at the ground level. As a backup to the AccuNav system, the drilling crew used radio transmitters like those employed in conventional drilling operations. Located behind the drill head, the transmitters send signals that are picked up by a sensing device held by the drill operator, who must walk the course on foot to determine the drill's location. The radio transmitters are accurate only to a depth of 15 feet, which was far exceeded on the steep incline near the river. One of the transmitters actually burned out on this leg when temperatures at the drill head surpassed the device's 140°C limit as the bit cut through granite.

The initial bore, called a pilot hole, provided a path for the back-reaming tool, which drill operators attached to the drill head after removing the bit. Pulled backward through the pilot hole, the back reamer expanded the diameter of the channel to 16 inches. This was enough room for some drilling mud and a thick-walled polyethylene conduit with an exterior diameter of 10 inches. The drilling mud lubricated the channel for the polyethylene piping, which was pulled in behind the drill rig.

Once the conduit was in place along the full length of the 2600-foot channel, drill operators used compressed air to shoot a nylon line through the entire run. This fishing line hauled a steel rope surrounded by a tube made of Kevlar, a material used in bulletproof vests. The Kevlar tube provided a slippery surface that reduced the pulling tension. Its hollow core allowed workers to spray lubricant at the heads of the three transmission cables, which were pulled in by the steel rope. Together, the three cables weighed about 27 pounds per linear foot.

Advanced cable pushers developed by

A JOB FOR ADVANCED TECHNOLOGY

Pushing transmission cable through the underground polyethylene conduit

Computer readout generated by AccuNav, the underground-boring navigational system

In the past, overhead transmission lines ran parallel to Highway 75 through the Nacoochee Valley.

Underground Research allowed workers to push as well as pull the cables, helping to reduce stress on the wire. Equipped with microprocessor-based recording devices called dynamometers, these tools were able to measure the tension on the cables during the pulling process. "The dynamometers allowed us to make a judgment on the fly to pull the entire length of cable instead of stopping and splicing sections," says Bush, who notes that Georgia Power typically does not pull cable for distances greater than 400–500 feet. The dynamometers measured final tension at 8500 pounds, well below the estimated tension limit of 18,500 pounds.

Dedicated crew

In the thick heat of the Georgia summer—one of the hottest on record, with temperatures topping 100°F and humidity hovering around 90%—workers toiled 14-hour days regularly, enduring some heavy rain and even thunderstorms. To ensure that all the equipment would be ready to run the next morning, contractors put in even longer hours. "The challenges we encountered were massive and unexpected," says Bush. "It took us eight tries to get under the river because we kept breaking bits. Then we ran into a 20-foot boulder of granite in the hill beside the river. It also took five or six tries to cross under Highway 75."

Because of a special arrangement with the contractors, a local tool shop was available to repair broken drill bits after hours so that they would be ready for the workers by daybreak. "I can't say enough about the work ethic of our crew and the contractors," Henefeld says. "They demonstrated a tremendous commitment to this job." EPRI's Rodenbaugh was also on-site. He served as manager of the project and offered guidance to others on the team.

Although the job took two weeks longer than expected, everyone involved was pleased with the outcome, especially given the unanticipated difficulties encountered in the field. The new 115-kV transmission line was energized on August 23, about two weeks before the start of Helen's Oktoberfest celebration. The entire job cost $1 million, including the expense of the cable and other supplies. Of this sum, the installation cost was $400,000, shared by EPRI, Georgia Power, and Oglethorpe Power Corporation, a nearby cooperative.

Henefeld notes that the job cost far less than the $1.5 million he estimates the conventional procedure would have cost. Just as significant, Rodenbaugh points out, the procedure had minimal impact on the environment. "The icing on the cake was that the project helped the technologies progress further," he says. "The knowledge we gained was just tremendous. We probably saved EPRI $2 million in research costs with what we learned."

Since word about the project has gotten out, both Bush and Rodenbaugh have received calls from several utilities that are considering using the technologies demonstrated. "Of course, there's always going to be some application where it's inappropriate or too difficult," Rodenbaugh says. "But there are many cases in which utilities instinctively open-cut when they could benefit by employing the underground, guided-boring technique instead."

As for local community members, it would be misleading to say they were entirely satisfied: some of them would have liked to see the transmission line buried all the way to Cleveland, some 12 miles away. "We knew that was asking a lot," says Johnston with a chuckle. "We were very happy with the way it worked out. In the beginning there was some skepticism about whether Georgia Power would hold up its end of the deal. But despite the fact that they had a way to back out when given the news about the burial sites, they stuck with their commitment and carried through on their promise. This is a big plus for them."

Dennis agrees: "I feel good about the fact that Georgia Power, as a big company, decided to stop and listen to what the little people had to say." ■

Workers use an advanced midsize boring rig to install polyethylene piping under the Nacoochee Valley.

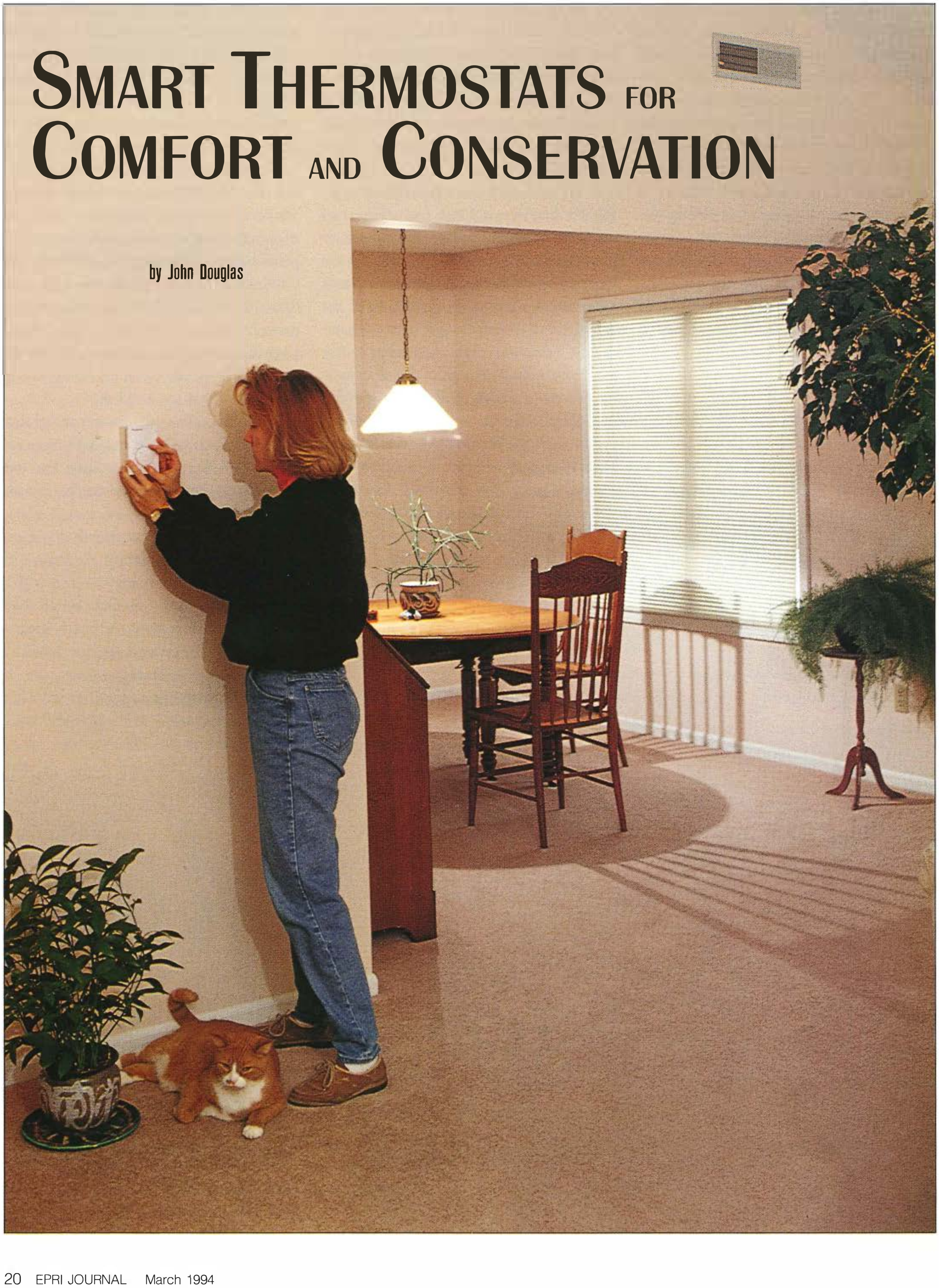
Tungsten carbide drill bit

Back reamer used to expand the diameter of the pilot hole

Background information for this article was provided by Tom Rodenbaugh, Electrical Systems Division.

SMART THERMOSTATS FOR COMFORT AND CONSERVATION

by John Douglas



Electric resistance heaters are often the lowest-first-cost choice for heating new residences. Moreover, they can save energy by facilitating zoned heating, in which unoccupied rooms are maintained at a lower temperature. The problem with such zoned electric heating systems has been that the rooms in use sometimes seem uncomfortable because of wide temperature swings during heater operation. Rather than tolerate extended cool periods between the times when the heaters are on, many people set their thermostats several degrees higher than the desired average temperature. The result is increased energy use and periods when rooms are unnecessarily warm.

Such difficulty in maintaining a near-constant temperature is generally caused by the inherent limitations of electromechanical line-voltage thermostats, which use a bimetallic strip to directly control current to an electric heater. This strip consists of bonded thin sheets of two metals that have dissimilar coefficients of thermal expansion. As a room cools down, the bimetallic strip bends until it makes contact with an electric switch that turns on the heater. When the thermostat's set point is reached, the bimetallic strip springs away from the switch, turning the heater off.

A typical bimetallic line-voltage thermostat uses a C-shaped element that provides enough mechanical force to actuate a snap-action switch. Thermostats based on this design are simple, inexpensive, and rugged, but they respond slowly and imprecisely to temperature change, and their performance tends to degrade over time. More-precise electromechanical thermostats can be made by adding a low-voltage intermediate switching stage. In this case, a much longer, spiral bimetallic element is used to move a mercury switch, which actuates a low-voltage relay that controls power to the heater. The disadvantage of this approach is higher cost—a particularly important consideration for zoned heating schemes, which require several thermostats to control the temperature in different parts of a house.

Now, with EPRI's help, the humble thermostat has gone high tech. Although previous attempts have been made to produce electronic thermostats with precise temperature control, the results have tended to be relatively complex and too expensive for routine use with zoned electric heating. Through EPRI-sponsored research two manufacturers have developed microprocessor-controlled line-voltage thermostats that cost substantially less than previous electronic models. They provide greater comfort with electric resistance heaters than electromechanical thermostats do, and they may also reduce energy consumption by maintaining room temperature closer to the desired level, eliminating the need to set thermostats higher to prevent cold excursions.

By maintaining room temperature closer to the desired level, electronic line-voltage thermostats make electric resistance heating more comfortable for occupants and reduce energy consumption as well.

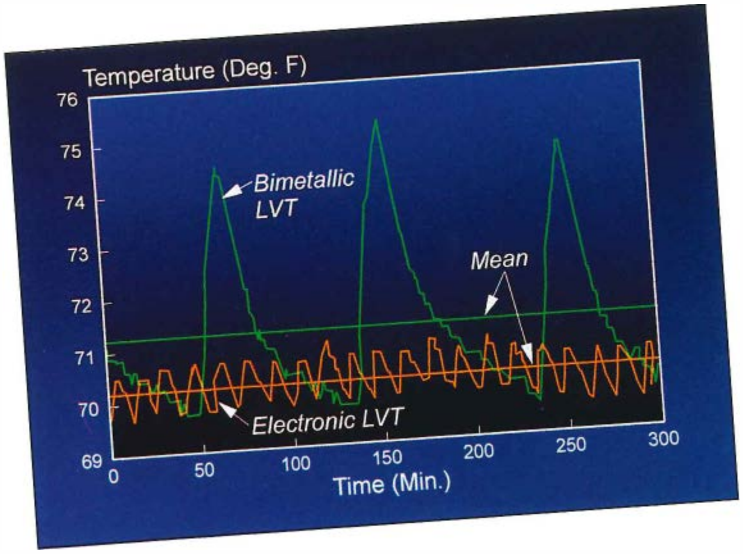
Three keys to performance

How well a thermostat can maintain room temperature near its set point depends on three factors. First is the so-called deadband—the temperature range through which a thermostat cycles between the time it turns the heater off and the time it turns the heater back on again. To keep the occupants of a room comfortable, a thermostat's deadband should be less than 4°F. (The smallest temperature difference people normally notice is about 2°F.) Many electromechanical line-voltage thermostats, however, have a deadband of nearly 8°F. Thus, for a set point of 70°F, the temperature in a room may swing from 74°F to 66°F. Under such circumstances the occupants may simply raise the thermostat setting until the heater switches on when the temperature falls to 70°F, creating a temperature cycle that peaks at 78°F and wastes considerable energy.

Closely related is a second factor, cycle frequency. Part of the reason that electromechanical thermostats have such a wide deadband is that they respond slowly to temperature changes. Typically such thermostats go through only one or two on/off cycles per hour. Electric heaters should cycle four or more times per hour to keep room temperature near the set point.

The third factor is what is known as droop—the reduction in room temperature that occurs when a thermostat shuts off prematurely because of internal heat buildup. The heat comes from the passage of current through the thermostat on its way to the heater. Droop typically in-

TEMPERATURE PROFILES **An ordinary, electromechanical line-voltage thermostat (LVT) allows room temperature to vary over a wide range, and homeowners often raise the set point to keep the minimum temperature at a comfortable level—around 70° in this case. New, electronic thermostats can keep temperature variations within a much narrower band, increasing comfort and saving energy with a lower mean temperature.**



creases the more a heater is used during a day. Thus a thermostat setting that is comfortable during mild winter weather may not be appropriate on very cold days because of the droop caused by increased heater use. Room occupants may respond to this droop by raising the set point, increasing the demand on the heater and causing even more droop. To ensure comfort, thermostat droop should be less than 2°F.

"Many utility customers have not been getting the full benefit of zoned electric heating systems because of inadequate temperature control by electromechanical thermostats," says John Kesselring, a research manager for residential systems in EPRI's Customer Systems Division. "Our goal in recent research has been to produce more-precise line-voltage thermostats that have costs low enough to compete in the zoned electric heating market."

Toward smart thermostats

With EPRI support, two companies—PSG Industries and Honeywell—have developed electronic thermostats that meet high standards for the three performance factors just discussed. Each has a deadband and a droop of 2°F or less and can cycle five or more times per hour if needed. Using smart solid-state microcircuits, the thermostats measure temperature shifts by interpreting changes in the resistance of a thermistor—a sensor made of a semiconductor material having a resistance that changes rapidly and predictably with temperature.

The PSG product, trade named Līn-STAT, has been commercially available since June 1993, and more than a quarter of a million units have been sold. It features a digital liquid crystal display, an electromechanical relay switch that controls line voltage to the heater, and an anticipator function that turns the heater off in time to allow its residual heat to bring a room up to the set-point temperature. This function prevents the heater from overshooting the set point, which wastes energy and makes a room too warm. Līn-STAT requires three-wire installation, however, so some wiring modifications may be required when the device replaces a conventional two-wire bimetallic thermostat.

The Honeywell electronic thermostat gets around this wiring problem by incorporating a patented technology based on a solid-state relay that switches power to the heater. This design enables the thermostat to draw the small amount of current required for its operation through the heater circuit even when the heater is off—facilitating two-wire installation and making the unit easier to retrofit. Honeywell's new thermostat becomes available in the United States in March 1994.

Field tests have confirmed the advantages of the more precise, electronically based thermostats. Pennsylvania Power & Light Company (PP&L), for example, participated in an EPRI field test of Līn-STAT and found that it increased the comfort of home occupants and their satisfaction with electric heating. Data from this field test also suggested potential customer energy savings of 8–12%, since the absence of wide temperature swings in fact prompted homeowners to set their thermostats to a somewhat lower temperature. As a result, PP&L is considering adding the PSG thermostat to its ongoing Comfort Home program, which is dedicated to ensuring good thermal performance of electric heating systems in new homes.

Quantifying benefits

To quantify some of the benefits of the new thermostats, EPRI sponsored carefully controlled tests by Geomet Technologies of Germantown, Maryland. These field tests were conducted in an unoccupied research house that had been divided into four heating zones and equipped with a computerized data acquisition system and a computer-programmed occupancy simulation. The data acquisition system recorded heating energy consumption and indoor comfort parameters for each of the zones, in addition to ambient weather conditions. The performance of conventional thermostats was compared with that of both electronic thermostats.

Analytical models were used to estimate thermal comfort as a function of air temperature, humidity, and other variables. The calculations showed that all of the thermostats could provide an acceptable average temperature. But bimetallic thermostats often failed to provide an acceptable level of comfort in terms of the magnitude and frequency of temperature variations, while the electronic thermostats did satisfy those transient comfort criteria.

The projected energy savings from the replacement of electromechanical thermostats with electronic units depend heavily on the assumptions made about occupant behavior. If the mean temperature maintained by an electronic thermostat is 70°F, for example, and it is assumed that occupants would set a bimetallic thermostat to obtain an average temperature of 71°F to achieve a comparable comfort level, then energy savings of 7% could be realized by using the more sophisticated device. On the other hand, given a bimetallic thermostat with a very large deadband, the average-indoor-temperature difference required to maintain comparable comfort levels might be as high as 4°F—equivalent to a 28% difference in energy consumption.

Meanwhile, several utilities are beginning to collect data on the actual energy savings achieved by customers who use the new thermostats. The data are still preliminary, but the results are promising. Jersey Central Power & Light Company, for example, has launched an active retrofit program to install PSG's Līn-STAT devices to help its electric heating customers save energy.

SMART THERMOSTATS **Two electronic line-voltage thermostats have been developed with EPRI support. The Līn-STAT from PSG Industries features a digital readout and has sold over a quarter of a million units. Honeywell's electronic thermostat recently became available and is designed for two-wire installation, making it easier to retrofit.**

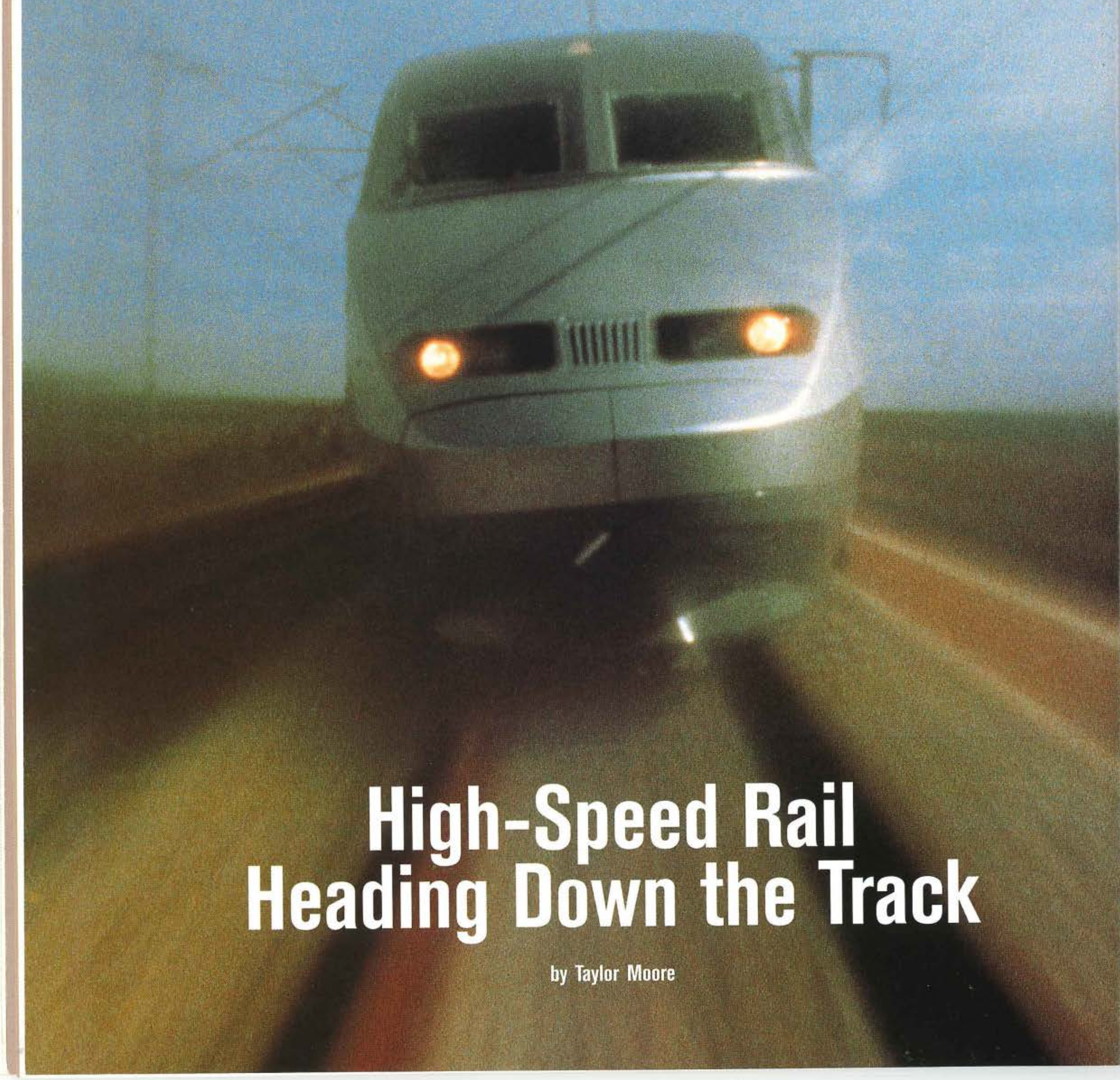
Additional features

Currently EPRI is working with Honeywell and PSG to include additional features in their electronic thermostats. One of the most important of these is a user-programmable setback capability, which lowers the set point when a room is unoccupied—thus saving additional energy. This function could be based either on a time schedule or on motion detection, in which the set point would be adjusted after a certain period when no motion is detected in a room. The time-schedule setback feature is expected to be incorporated first.

"We expect that electronic thermostats will rapidly penetrate the electric heating market for new housing and will eventually become the standard for such installations," concludes Kesselring. "As their unit costs decline and as their energy-saving benefits become more apparent, I believe that a substantial retrofit market will also open up for these devices—particularly if utilities incorporate them into demand-side management programs." ■

Background information for this article was provided by John Kesselring, Customer Systems Division.

THE STORY IN BRIEF Heightened environmental awareness, increasingly congested airports and freeways, and advances in passenger transportation technologies used in other countries are prompting many regional government agencies to rethink intercity travel. New, electric ground transportation options such as high-speed rail and magnetic levitation (maglev) systems are under consideration in many areas of the country. EPRI and its members are pursuing an R&D agenda that is developing the information utilities need to prepare for the advent of high-speed rail and to evaluate the potential for more-extensive involvement in local projects.



High-Speed Rail Heading Down the Track

by Taylor Moore

High-speed electric trains that travel at least 150 mph—and someday 300 mph—are eventually coming to America. Responding to a growing sense of strangulation among travelers on the nation's highways and runways, a new administration in Washington has proposed a plan to make high-speed rail part of America's transportation infrastructure. Given the success of such technology in parts of Europe and in Japan, where high-speed rail systems have been operating for as long as 30 years, the administration's support may finally signal the movement of a seemingly futuristic vision closer to reality.

Nonetheless, even the most vocal proponents of high-speed rail foresee a bumpy ride ahead in the near term. Various proposals in more than a dozen states are vying for government funding as well as private support at a time of fragmenting political constituencies for multimillion-dollar, let alone multibillion-dollar, transportation development projects. But because freeways and air transit systems are already operating near capacity, the appeal of very fast electric trains in key, heavily traveled urban and intercity traffic corridors has in the last few years become virtually irresistible to urban and transportation planners. They and other supporters of high-speed rail, including the industries that would build the so-called supertrains and the dedicated tracks or maglev guideways they require, have succeeded in placing the subject on the national agenda; there it faces formidable foes among the myriad industries representing the existing, dominant modes of transportation, which are already extensively subsidized by the public.

Indeed, the future of high-speed rail and maglev as new modes in an increasingly competitive and intermodal worldwide transport system already hinges, in large part, on the outcome of competitive jockeying between fully developed, entrenched transportation technologies and the potential newcomers. Equally fierce nationalistic competition among companies within specific industries is also emerging. Several of the world's major electrical and electronic engineering and manufacturing companies are eagerly anticipating the emergence of an American market for high-speed rail systems like those they are already producing overseas. Last November a report by the National Maglev Initiative, culminating a three-year study by the U.S. Department of Energy, the Army Corps of Engineers, and the Federal Railroad Administration, recommended an $800 million program to establish an indigenous U.S. industrial base to build high-speed trains and maglev systems.

The U.S. electric utility industry has been enthusiastic about the idea of high-speed electric rail, both for the obvious reason that the technology represents a potential new load and because of the related economic development that modern, fast, and efficient trains would spur. Along with electric vehicles, high-speed rail systems would make historic new inroads for electricity as an environmentally preferred energy form for transportation. Most proposed projects around the country include terminus points at city centers —an arrangement likely to catalyze downtown redevelopment—as well as at outlying airports. Utilities, until now mainly passive supporters of the technology, are becoming actively involved in local high-speed rail projects.

Fast trains gaining speed overseas

Many of the strongest advocates of high-speed rail systems for this country became believers after riding on one or another of the dozens of lines operating in Japan, France, Germany, Spain, and most recently Italy.. In 1964 the first of Japan's Shinkansen bullet trains began whisking passengers over the 320 miles between Tokyo and Osaka at up to 125 mph. Since then, newer, faster trains have cut the trip to two and a half hours. Some 740 bullet trains—now in the fifth generation of technology development by Hitachi—run on about 1150 miles of high-speed rail lines in Japan, carrying over 750,000 passengers a day at speeds of up to 170 mph. Before long, connecting lines will extend from Nagasaki and Kagoshima on the western island of Kyushu, throughout western, central, and eastern Japan, all the way to Sapporo on the northernmost island of Hokkaido.

But it is in France that the fastest regularly scheduled trains in the world—known by the acronym for Train à Grande Vitesse, TGV—have captured the spotlight since the Paris-Lyon line began operating in 1981 at 168 mph. More-recent lines feature train sets running at over 186 mph. The Anglo-French consortium GEC Alsthom produces the TGV. The French National Railway set a world speed record of 320 mph in a special run of one of the original TGVs in 1990.

Later this year, special versions of TGVs called Transmanche Super Trains will star in ceremonies marking the start of passenger service on the first undersea rail link between Britain and the European continent, the English Channel Tunnel. Scheduled to operate at up to 180 mph, the trains will connect London and Paris in three hours. Other TGVs are planned that, beginning in 1997, will bolt Parisians straight to the Riviera at 217 mph. TGVs renamed AVEs—for Alta Velocidad Español—have been assembled and placed in service in Spain, and lines connecting France with Belgium and the Netherlands are planned.

In Germany, planning for high-speed trains began at about the same time as in France, but the more mountainous terrain and the dual passenger-freight use requirement entailed longer track construction times. Germany's 180-mph Intercity Express, or ICE, trains—which are operated by Deutsche Bundesbahn, the German federal railway—began running between Hamburg and Munich in 1991 and now also connect Munich with Stuttgart and Frankfurt; an extension from Frankfurt to Cologne is planned for next year. Manufactured by a consortium that includes Siemens, Krupp, and Messerschmitt-Bölkow-Blohm, ICE trains have made test runs at up to 250 mph.

Italy, meanwhile, has trains running as fast as 186 mph between Milan and Rome. Several high-speed lines feature a train set called the Pendolino, made by a unit of Fiat, that tilts to handle curves on conventional tracks at higher speed. They are

GEC Alsthom/Bombardier

French TGV Atlantique

all part of a 15-year, $15 billion high-speed rail project—Alta Velocità—of the Italian State Railways.

Besides these already operating high-speed rail systems, projects are planned in virtually every other developed industrial economy. Yet, says Joseph Vranich, president of the High Speed Rail/Maglev Association and the author of *Supertrains: Solutions to America's Transportation Gridlock*, "North America has no trains like the fast trains in Europe and Japan. The federal government, until now so overwhelmingly skewed to improving air and highway systems, has cast a shadow over the virtues of trains. The result is that the American public poorly understands the progress that has been made in rail service."

Vranich notes with irony that the federal, state, and local governments have lavished billions of dollars on highway and airport projects, including loan guarantees and tax-exempt bond financing. Yet because of more-pressing national priorities and a perceived unavailability of funds for new technologies, public officials and much of the public seem unwilling to invest in trains, despite an undeniable, inexorable climb in transportation demand and traffic on the highways and in the skies.

But several developments in recent years are giving supertrain advocates renewed hope. The most encouraging of these positive turns was Transportation Secretary Federico Peña's proposed five-year, $1.3 billion plan for high-speed rail announced last April, following through on one of President Clinton's campaign themes. Another was the nomination, recently confirmed by the Senate, of Jolene Molitoris—the former head of Ohio's high-speed rail authority and an outspoken advocate for the technology—to head the Federal Railroad Administration, which has statutory authority over intercity rail.

Although the administration's legislative package never made it to a vote in either house of Congress and is therefore as yet unauthorized and unfunded, supporters say it contains the first credible national development plan for high-speed rail and will almost certainly be reconsidered this year. The plan calls for $982 million in federal grants to state and local governments to finance projects that would require an additional $2 billion in private as well as regional public financing, and also calls for $300 million to develop new technologies such as maglev. "A strong, technologically advanced rail system to transport passengers is critical to our economic competitiveness," said Peña last April. But the administration's budget request for the coming fiscal year includes only $32 million for high-speed rail development, none of which is slated for maglev.

Vranich says that the administration's 1993 proposed plan for high-speed rail was an encouraging follow-on to the Intermodal Surface Transportation Efficiency Act of 1992, which was authored by Senator Daniel Patrick Moynihan of New York and called for a national maglev initiative and high-speed rail development. Vranich also points to recent legislation that places tax-exempt bonds for high-speed rail projects on a more equal footing with tax-exempt airport bonds. But he calls the administration's current budget request for high-speed rail disappointing.

A growing state-level chorus, however, is calling for federal leadership to get projects moving within the context of an integrated national plan, and it is possible that advanced technologies like maglev could become candidates for defense conversion funding. Despite the obstacles and the uphill climb facing high-speed rail, Vranich says he remains confident of his prediction three years ago that "versions of supertrains such as those already serving Europe and Japan will be running in the United States by the turn of the century."

More than maglev

"We aren't going to be able to ride high-speed trains tomorrow, but their operation in the United States is inevitable," says Vranich. By supertrains he means steel-wheel trains fast enough to compete with air travel (such as those already in wide service elsewhere) or magnetically levitated trains, which are under development outside the United States.

The futuristic image of sleek, aerodynamic maglev trains quietly defying gravity and propelling themselves at 300 mph on an elevated guideway certainly can be appealing, especially to a freeway commuter stuck in traffic. But it reinforces the inaccurate impression that high-speed rail requires advanced technology and all-new infrastructure that will take years to develop—and is therefore a transportation vision of the distant future.

Several of the more ambitious high-speed intercity rail projects around the country do include planning for maglev, and shorter airport connection links have been proposed to demonstrate the technology in this country. But as EPRI's Phil Symons, who manages research studies and cooperative projects related to high-speed rail in the Transportation Program, points out, "It's best to think of maglev as a long-term, potential piece of the transportation system rather than as a technology on its own. Too often we've tended to think of transportation in discrete pieces and terms—cars, trains, highways, airports—but not many people have thought about

© DPA/Photoreporters

German ICE Hamburg-Munich train

ETR-500 of Italian State Railways

© Prisma/Photoreporters

the overall picture." The High Speed Rail/ Maglev Association stresses that although maglev, assuming it is fully developed and demonstrated for high-speed passenger service, may be the preferred technology for longer rail lines over mountains, existing steel-wheel trains would be more economical and energy-efficient in areas where new, straight high-speed rail lines can easily be built.

Symons notes that steel-wheel high-speed rail systems like the TGV and ICE systems can be built and placed in service for about $10 million to $15 million per mile, some 80% of which is for track and systems other than the train sets themselves. "That is comparable to the cost per mile of a new superhighway."

While the experience of France and Germany is that high-speed intercity rail does indeed take a substantial amount of traffic off the highways, U.S. transportation experts are most attracted to its proven potential for supplementing or extending the capacity of the nation's air transport system by providing a comparable alternative, in terms of trip time, to air travel between cities within 600 miles of each other. Most of this country's interurban air travel falls within that distance.

High-speed rail connections between cities in major air traffic corridors could free up a lot of takeoff and landing slots now occupied by short- to medium-haul flights, easing the pressure on the air traffic control system—problems with that system have added 20 minutes to the average U.S. airline flight over the past 15 years, according to the Federal Aviation Administration (FAA)—as well as the pressure to build ever bigger and more-costly airports, which few communities today are willing to do.

A new airport outside Denver was recently completed at a cost of $3.2 billion, not including the cost of associated highway access. "You could put in a lot of high-speed rail for that kind of money," says Symons. "Planners all over the country are interested in high-speed rail because the air transport system is beginning to get so congested it might collapse."

A 1989 study by Argonne National Laboratory for DOE first proposed a 50-city, 2000-mile network of maglev trains as a revolutionary alternative that could alleviate the approaching "winglock" at major airports. Such a network would reduce energy use for transportation and reduce key air pollutant emissions, in addition to easing air and highway traffic congestion. Argonne researchers estimated that the annual cost of building such a rail network over 20 years would be comparable to what the FAA estimates that air traffic delays now cost airlines and their passengers every year—$5 billion. A double-track maglev system was estimated to cost $15 million to $20 million per mile. (A more recent estimate puts the cost of maglev at $45 million per mile.) The Argonne study suggested that maglev systems could be built to operate from the terminals of existing airports, much like the German trains that provide scheduled connecting service between the Frankfurt and Düsseldorf airports. (This line was first operated by the German airline Lufthansa; recently it was turned over to the federal railway.)

Several proposed U.S. high-speed rail

SYSTEMS SPEED THROUGH EUROPE **High-speed rail systems are spreading across the European continent. First came France's Train à Grande Vitesse, or TGV, then Germany's Intercity Express, or ICE, trains. High-speed lines in Spain and Italy followed, and soon passenger and car-shuttle service will link London and Paris via the English Channel Tunnel. Extensions of TGV lines into Belgium and the Netherlands are on the drawing boards; other plans call for links with lines in Germany, eventually extending into central Europe and Scandinavia.**

French TGV on Paris-Lyon Southeast line

© DPA/Photoreporters

French TGV on Paris-Bordeaux Atlantique line

GEC Alsthom/Bombardier

PANA/Jiji Press

This train makes the 320-mile trip between Tokyo and Osaka in two and a half hours.

THREE DECADES OF SHINKANSEN The world's first high-speed electric trains—Japan's Shinkansen, or bullet trains—began running between Tokyo and Osaka in 1964. Today there are about 1150 miles of high-speed rail lines in Japan, and over 740 bullet trains carry more than 750,000 passengers a day at speeds of up to 170 mph.

The Tohoku Shinkansen line connects Tokyo with Morioka.

Japan Railways Group

Various generations of bullet trains

Japan Railways Group

projects specify maglev technology, including a Pittsburgh airport–downtown link, an Anaheim–Las Vegas line, and a link between the Orlando airport and a station near the entrance to Disney World. Most of the interest in high-speed rail as an integrated alternative to intercity passenger flights, however, is now focusing on already mature steel-wheel technology, such as the TGV (which would be built in North America by GEC Alsthom's Canadian licensee, Bombardier Corporation) and the German ICE trains from Siemens. ABB Traction, a unit of the international conglomerate ABB Asea Brown Boveri, is also developing a high-speed train based on its X2000, a tilt-train that has operated in Sweden at up to 170 mph.

Last year Amtrak conducted test runs of both the X2000 and the ICE train on the heavily used New York–Washington line in order to gather data for specifications for 26 new high-speed train sets it plans to begin operating between Washington, New York, and Boston in 1997. The TGV, ICE, and X2000 trains all feature advanced ac motors, high-power electronic controls, and regenerative braking, which returns some electricity through an overhead supply catenary during deceleration.

As an example of the perspective that is developing on the role of high-speed rail, Symons says EPRI recently cosponsored a study that looked at the feasibility of a link between Chicago's O'Hare International Airport and the nearby airport in Rockford, Illinois. The idea is that if connecting rail service between those locations were fast enough, the Rockford airport could be expanded and flights could be scheduled through it on a connecting basis with those at O'Hare, which serves a high proportion of travelers headed for some other city only a few hundred miles away. That would eliminate the need to site and build yet another major airport in the Chicago area.

"It turned out that if you had a maglev system, you could move people between the airports in less than an hour, as though they were terminals of the same airport," says Symons. "But high-speed steel-wheel probably would not be fast enough. Still, with a downtown connection and intermediate stops along the way, any high-speed rail could have enormous economic value in terms of deferred airport investment and economic development. But it would, of course, involve a multibillion-dollar investment."

Building a utility perspective

A major focus during the last year of EPRI's admittedly modest efforts to advance high-speed rail has been a recently completed study by Argonne's Center for Transportation Research and Bevilacqua Knight, Inc., of the potential ridership along a number of routes and the implications for utilities with respect to energy and power demand. "We're building a justification from a utility perspective with regard to high-speed rail projects," says Symons. "We looked at the magnitude and nature of the loads for specific corridors, using some pretty good models for estimating ridership.

"We found that, even though high-speed electric trains would carry a lot of people, the load implications are not nearly what you might imagine. They are within the range of comparability with the load today of a large urban mass transit system, such as the New York Metropolitan Transit Authority's 600-MW peak demand, which is readily accommodated by the New York Power Authority."

The EPRI study projects travel for 78 major metropolitan areas via air and highway, identifies the 12 highest-density corridors, and describes the potential for high-speed ground transportation systems to substitute for some of that travel by the year 2010. The study also estimates the energy demand and power requirements for representative high-speed steel-wheel and maglev systems for each corridor and for corridor connections.

As a starting point, researchers note that high-speed trains are a more energy-efficient form of transportation than either cars or planes. A fully loaded modern electric train set such as the French TGV, for example, requires a total energy input of 1819 Btu per passenger-mile when traveling at 200 mph, compared with the 2505 Btu per passenger-mile required by an automobile moving at 60 mph. A 300-mph maglev vehicle's energy requirement is put at 2747 Btu per passenger-mile, while the equivalent rating for airplanes is 9645 Btu per passenger-mile. As converters of electricity into kinetic energy, high-speed

Siemens Transportation Systems

Germany's ICE train

AMTRAK PLANNING FASTER TRAINS IN NORTHEAST CORRIDOR **Last year Amtrak made numerous runs using the X2000 tilt-train from Sweden and the German ICE train in regular passenger service along the New York–Washington leg of the heavily traveled Northeast rail corridor. The tests gathered data to support a request for proposals to place about two dozen high-speed electric trains in Amtrak passenger service on upgraded track in the corridor by 1997. A hydraulically controlled tilting system allows the X2000 to take curves on existing tracks at about 112 mph, or about 50% faster than conventional trains can; it has operated in Sweden at up to 170 mph. In Germany, ICE trains regularly run at over 180 mph.**

Sweden's X2000 tilt-train

ABB Traction

Transrapid International

GETTING MAGLEV MOVING

The most recent prototype of a synchronous-linear-motor magnetic levitation technology developed by Transrapid International has operated at speeds of up to 310 mph on a test track at Emsland, Germany. Maglev technology has been proposed for several high-speed rail projects in the United States.

The technology for magnetic levitation vehicles, first proposed in 1909 by the American rocket pioneer Robert Goddard, was invented in the United States by scientists at Brookhaven National Laboratory in the 1960s, but operating prototypes have been built only in Japan, Germany, and Britain. No high-speed maglev has yet entered passenger service.

Although maglev definitely works, the expected high cost of further technology development and the cost of building the maglev systems themselves have prompted many experts to regard it as an advanced form of high-speed rail that is still at least 10, and perhaps 20, years away from significant use. Most of the technology development over the past 15 years has taken place in Germany and in Japan.

The most developed maglev technology is said to be that of Germany's Transrapid International, a joint venture of Krauss-Maffei, Messerschmitt-Bölkow-Blohm, and Thyssen Henschel. Full-scale maglev trains have been running at the government- and industry-funded Transrapid test facility in Emsland, Germany, since 1984. Hundreds of demonstration runs have been conducted—both low-speed runs with passengers and high-speed unmanned runs. Cattle grazing beneath the 25-mile test guideway take little notice when the maglev trains glide by overhead.

The newest and fastest version, the Transrapid-07 Europa, set a maglev speed record of 271 mph with passengers in 1989; test runs of up to 310 mph have been made without passengers. Meanwhile, a 30-mph maglev people-mover licensed by Transrapid connects the Birmingham, England, airport with a train station a little over a quarter mile away; similar systems have been demonstrated in Hamburg and Berlin.

The Transrapid Europa floats above its guideway by about ⅜ inch. Powerful magnets on the wraparound undersides of the train are pulled up by electromagnetic attraction to magnets under the guideway. Experts say the trains can climb grades as steep as 10% and take curves as fast as 250 mph; thus the need for tunnels and circuitous routes, which account for the largest part of the cost of high-speed rail, would be reduced.

The other main maglev technology is electrodynamic repulsion, in which magnets on the top of the guideway push magnets on the bottom of the train upward, creating an air gap of more than 4 inches. With both technologies, sophisticated control systems rapidly alternate the flow of current through the magnets to create powerful push and pull forces that smoothly propel the vehicles.

Electrodynamic technology has been pursued in Japan by a government-industry development program that has invested more than $1 billion since the 1960s. Unmanned vehicles using this technology have reached speeds of 323 mph. Researchers acknowledge that the electrodynamic system requires substantial further development. Magnets made from new superconducting materials that conduct electricity without resistance are expected eventually to reduce the electric power requirement for maglev systems.

The Japanese have also developed several models of an electromagnetic-attraction-type maglev system, the High-Speed Surface Transport (HSST). Demonstration models carrying over a million paying passengers have operated at exhibitions in Yokohama, near Tokyo, and in Vancouver, British Columbia. A low-speed (62-mph) transit-type HSST, like that used in a recently completed two-year demonstration in Nagoya, has been proposed by Japanese experts as the first such line in the United States, linking the Las Vegas airport with downtown.

A proposed 13-mile maglev system linking the Orlando, Florida, airport with a station near the entrance to Disney World was to feature the Transrapid Europa, but the company that has a state franchise to pursue the project recently announced a reevaluation of candidate systems—a development that has left the projected 1997 startup uncertain.

Meanwhile, a 19-mile maglev train linking downtown Pittsburgh with its airport has been proposed by a collaborative venture that includes as equity partners Duquesne Light Company, steelmakers USX and Wheeling-Pittsburgh, Pittsburgh-based USAir, and AEG, the electrical engineering subsidiary of Daimler-Benz. State and local transportation agencies are also supporting the project. The technology and supplier have yet to be selected (five routes are being evaluated), and the proposal is contingent on federal government cost sharing. Maglev has also been proposed for a 275-mile California-Nevada line linking Anaheim and Las Vegas.

Continuing research in maglev technology includes studies of ways to further reduce the electromagnetic fields inside vehicles. Concerns have been raised about the possible health effects of human exposure to magnetic fields. Such possible effects are the focus of other, ongoing research programs at EPRI and elsewhere. □

electric trains are about 77% efficient, while maglevs are about 73% efficient.

But because of the potential variation in a high-speed rail system's demand for power as trains accelerate, cruise, and decelerate into stations—in greater numbers at peak travel times—and because of the fact that trains represent sizable but geographically moving loads, it is possible that electric utilities could view such loads as less than ideal, the study found.

Both steel-wheel and maglev systems require energy to accelerate to a certain speed and more energy to overcome the resistance associated with traveling at that speed. The energy requirements of both technologies produce an overall power demand for individual trains or vehicles that increases with speed, with the requirement for maglev slightly lower at any given speed. The power demands at top speed are comparable for high-speed rail and maglev because maglev operates at a higher speed.

A 485-seat steel-wheel train (eight or more passenger cars and one or more locomotives) requires about 10.5 MW of power at startup and 7 MW while cruising at 200 mph, according to Argonne's calculations. A 150-seat maglev vehicle will require approximately 20 MW of power at startup and 5.4 MW while cruising at 300 mph.

A high-speed train's power demand is nonlinear. Moreover, the peak demands of a high-speed rail system tend to coincide with peak loads in the rest of the utility system (at midmorning and in late afternoon). Regenerative braking will recapture some of the kinetic energy of a train's speed and turn it back into electricity, and researchers believe there may be new opportunities for energy storage technologies to manage potentially sudden pulses of energy being dumped back onto the grid.

Storage technologies like batteries, flywheels, superconducting magnetic energy storage, and compressed-air energy storage—either on the vehicle or at some wayside locations—could potentially store this braking energy for reuse later for acceleration. Onboard storage capacity admittedly might be low, and wayside storage might not be practical at all points along a high-speed rail corridor, so some braking energy might be dumped into resistors.

In addition, large off-board storage facilities could be used to reduce peak loads for high-speed rail. Such equipment could be distributed along a rail corridor and charged either from baseload power plants at night or from a utility's spinning reserve.

EPRI's study analyzed the profiles of potential travel and electricity demand for three sample high-speed rail line segments: Boston–New York, Los Angeles–San Francisco, and Miami-Orlando. The 249-mile Boston–New York segment, using an estimated 296 maglev vehicles or 62 high-speed trains in daily service, was calculated to represent an average power demand of 49–87 MW for high-speed rail and 204–405 MW for maglev, for example. In comparison, the New York Power Authority serves the 600-MW peak load of the Metropolitan Transit Authority (which includes trains serving New York City and its suburbs).

A 395-mile Los Angeles–San Francisco high-speed line would serve passengers traveling between those cities as well as to Sacramento, San Diego, or Las Vegas. A maglev vehicle could make the trip in two hours, while a high-speed train would take three hours. Some 48 train sets or 324 maglevs would be needed to serve the estimated trip load. On the basis of average acceleration rates, the average power demand was estimated to be 49–122 MW for high-speed rail and 367–582 MW for maglev. In comparison, Pacific Gas and Electric Company, which serves about two-thirds of the length of the segment, already serves a summer peak system demand of over 19,000 MW.

For a 235-mile high-speed rail system running from Miami to Orlando, the average power demand was estimated to be 30–49 MW; for maglev, 122–202 MW. The utility in this area serves a summer peak demand of about 14,000 MW.

From their analysis of the potential travel demand for high-speed ground transportation systems in the 12 highest-density corridors in the year 2010, re-

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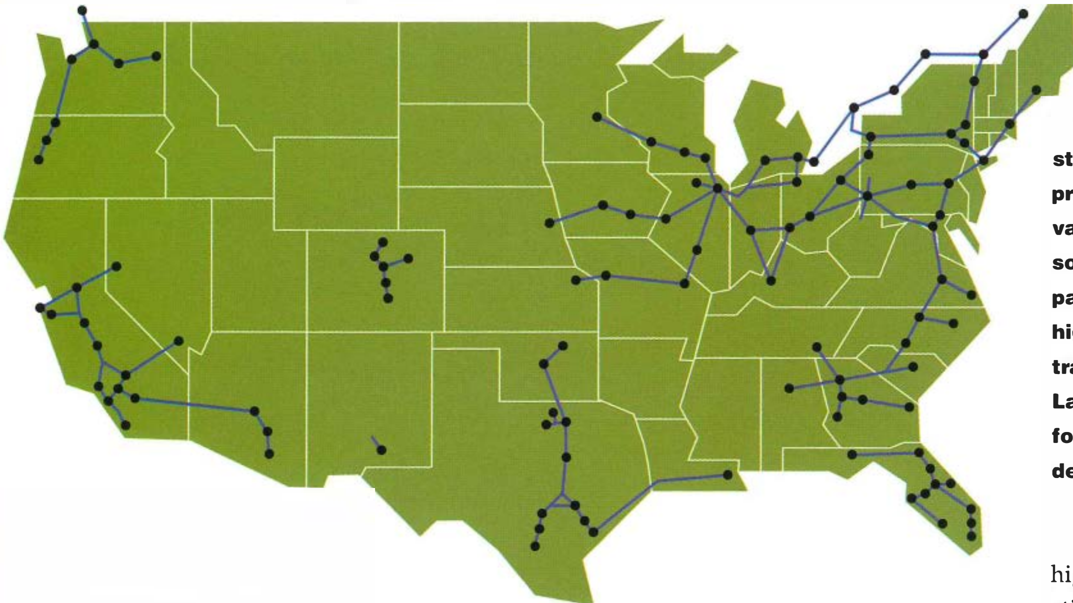


AMERICA'S FUTURE HIGH-SPEED RAIL NETWORK? This map represents the High Speed Rail/Maglev Association's composite of proposals, studies, and plans for high-speed steel-wheel and maglev transportation projects by government agencies, private companies, and public-private consortia as of the end of 1993. The accompanying list indicates the country's 12 highest-density intercity air and highway traffic corridors, which Argonne National Laboratory examined in a recent study for EPRI on high-speed transportation demand.

THE DOZEN DENSEST TRAVEL CORRIDORS

1. **Washington–Baltimore–Philadelphia–New York City–Hartford–Boston**
2. **New York City–Albany–Syracuse–Rochester–Buffalo**
3. **San Francisco–Los Angeles–San Diego**
4. **Los Angeles–Las Vegas**
5. **Miami–Orlando–Tampa**
6. **Dallas–Houston**
7. **Dallas–Austin–San Antonio**
8. **Houston–Austin–San Antonio**
9. **Chicago–Detroit**
10. **St. Louis–Springfield–Chicago–Milwaukee–Madison–Minneapolis/St. Paul**
11. **Philadelphia–Harrisburg–Pittsburgh**
12. **Detroit–Toledo–Cleveland–Pittsburgh**

searchers drew the following conclusions:

▫ High-speed rail could be expected to attract nearly one-third of the airplane trips, 85% of the rail and chartered-bus trips, and 4.7% of the automobile trips in the selected corridors.

▫ Maglev, in comparison, could be expected to attract over half of the airplane trips, nearly three-quarters of the existing rail trips, and 5.4% of the automobile trips in the corridors. Maglev could also attract a significant percentage of trips from outside the corridors and connected cities. It is estimated that maglev would attract about 50% more use than high-speed rail but consume more than twice as much electricity overall, although the total energy and demand requirements of either technology are clearly within the present capabilities of existing utility systems.

▫ Maglev draws power from all three phases of utility ac power systems, resulting in a relatively evenly distributed power demand for many hours of the day. However, high-speed rail requires some phase switching or converters in order to distribute the load on all phases and avoid drawing power from one phase at a time.

▫ Extended times between trains might cause marked peaks and valleys in the power demand of high-speed rail systems, which is typically estimated to be under 100 MW—except for a Los Angeles–San Francisco segment, for which a maximum midafternoon peak of 122 MW is projected. The maximum projected demand for a maglev system on the California segment in midafternoon is 582 MW.

▫ If high-speed ground transportation systems are served with long-distance high-voltage circuits that are sufficiently stiff (having constant voltage independent of load), they should prove to be quite manageable loads for utilities.

A reality waiting to happen

In much of Europe and Japan, efficient and comfortable high-speed electric rail systems are not a futuristic vision but a daily reality that represents a true alternative to air and highway transport. It remains an open question whether the United States, with its many pressing domestic priorities, will manage to muster the political will to encourage the kind of public and private capital investment necessary to get beyond studies and get projects rolling. Advocates of high-speed rail point out that technology is not the issue, that to bring high-speed trains from concept to reality mainly requires the elimination of institutional and financing roadblocks. They insist that having the world's finest high-speed rail system is an achievable goal for America. ■

Further reading

Travel and Electricity Demand Analysis of Potential U.S. High-Speed Rail and Maglev Corridors. Final report for RP3025-3, prepared by Argonne National Laboratory and Bevilacqua Knight, Inc. February 1994. EPRI TR-103444.

Proceedings: High-Speed Rail and Maglev Workshop. Report for RP3025-2, prepared by Bevilacqua Knight, Inc. April 1993. EPRI TR-101700.

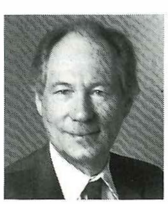
Joseph Vranich. *Supertrains: Solutions to America's Transportation Gridlock.* New York: St. Martin's Press, 1991 and 1993.

Background information for this article was provided by Phil Symons, Customer Systems Division.

GOLDSTEIN

RODENBAUGH

KESSELRING



SYMONS

Solid Futures in Fuel Cells (page 6) was written by science writer John Douglas with assistance from **Rocky Goldstein** of the Generation & Storage Division. Goldstein has managed research in EPRI's Fuel Cell Program since joining the Institute in 1985. Previously he worked for 24 years at International Fuel Cells, which originally was the Power Systems Division of United Technologies Corporation. Goldstein worked on numerous fuel cell projects during his tenure at IFC, including the Apollo space program and the 4.8-MW fuel cell programs in New York and Tokyo. He received a BS degree in physics from Northeastern University. ■

Innovations Underground (page 14) was written by Leslie Lamarre, *Journal* senior feature writer, with background information from **Tom Rodenbaugh,** a manager of underground transmission research in the Electrical Systems Division. Rodenbaugh joined EPRI in 1974 after two years as a physics instructor for graduate and undergraduate students at San Jose State University. He received a BS in physics from the University of California at Berkeley and an MS in solid-state physics from San Jose State. ■

Smart Thermostats for Comfort and Conservation (page 20) was written by science writer John Douglas with technical information from **John Kesselring** of the Customer Systems Division. Kesselring, a research manager for residential systems, came to 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 spent 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. ■

High-Speed Rail Heading Down the Track (page 24) was written by Taylor Moore, *Journal* senior feature writer, with assistance from **Phil Symons** of the Customer Systems Division. Symons, who manages public transportation projects, joined the Institute in 1992 after spending 12 years as a consultant in research and engineering related to batteries, fuel cells, and other electrochemical devices. From 1968 to 1980, he worked for a number of companies involved in RD&D on the zinc/chlorine hydrate battery (which Symons invented in 1968) for both electric vehicle and electric utility energy storage. Before that, he worked for the United Kingdom subsidiary of Procter & Gamble Company. Symons received a BS degree in honors chemistry and a PhD with research in electrochemistry, both from the University of Bristol (England). ■

Strategies for a Competitive Market

New Research Benefits Small Businesses

Traditionally, the needs of small-business customers were not always high on the agenda of electric utilities. After all, many problems of this market segment require close and specialized attention that can take significant time away from larger commercial and industrial customers. But times are changing, and as the electric utility industry becomes more competitive, a growing number of utilities are deciding it's time to pay more attention to the small-business market segment.

"High-quality service today doesn't just mean ensuring that customers get uninterrupted power at a reasonable cost," says Wayne Krill, a manager in EPRI's Customer Systems Division. "It also means going the extra mile to fulfill the new utility role of energy advisor, offering expertise that customers can use in making critical decisions."

To help utilities fulfill this new role, EPRI recently launched a three-year project geared toward addressing the needs of small-business customers. So far, the research has identified a number of electrotechnologies that can help solve various problems faced by this market segment. In fact, the first product of EPRI's small-business efforts, the *Guidebook of Environmental Solutions for Small Businesses* (TR-102843), published last fall, highlights a number of electricity-based technology solutions to the environmental problems of small businesses.

For instance, the guidebook says that ultraviolet oxidation, a process widely used to treat municipal solid waste, could be employed by wood-preserving shops that normally pay to have their hazardous waste hauled away for storage or disposal. The process, which renders hazardous compounds nonhazardous, could be used to treat the wood waste on-site. Wood-preserving shops are just one business that can find environmental advice in the guidebook. Others are wholesale bakeries, electroplating shops, dry cleaners, photofinishing laboratories, automobile paint shops, medical clinics, and R&D laboratories.

"It's in the best interest of utilities to help these customers resolve their environmental problems," says Krill. "In some

cases, a small-business customer may move out of one service territory with strict environmental regulations and into another, less restrictive one if it finds it is unable to address certain environmental issues."

Further studies will include a broader array of businesses and will expand beyond the environmental focus to include techniques for making small-business processes more efficient and effective.

■ *For more information, contact Wayne Krill, (415) 855-1033.*

New Data for Risk Assessment

Population Studies May Help Define Risk From Arsenic

In an effort to better define the health risk posed by exposure to arsenic, EPRI recently undertook two observational studies of small populations that are likely to be exposed to relatively high levels of the carcinogen. Present in trace amounts in fly ash from utility coal plants, arsenic is among 189 chemicals that the 1990 Clean Air Act Amendments list as "hazardous air pollutants."

Initiated late last year, the studies are intended to provide further insight into the bioavailability of arsenic—that is, the extent to which trace arsenic compounds from a complex matrix like fly ash are capable of being absorbed into the body, and the extent to which they are then available to interact with metabolic processes. One study involves the observation of workers at a coal-fired power plant in Slovakia, formerly part of Czechoslovakia. Coal used at this plant contains significantly higher levels of arsenic than do coals typically used at U.S. plants. The other study is examining a community in north central Mexico where high levels of arsenic exist naturally in the drinking water.

Focusing on airborne as well as waterborne arsenic, the studies address different potential effects from exposure by inhalation and exposure by ingestion. EPRI's Janice Yager, manager of the projects, points out that this dual perspective is important, since community exposure to arsenic in fly ash may occur either because of air emissions or because of runoff into groundwater supplies from fly ash deposited on the soil.

The study in Slovakia involves a group of about 40 workers at a coal plant located in a small town in the central part of the country. Researchers monitored the workers' exposure to airborne arsenic over a five-day period of cleaning and maintenance—a time when arsenic levels are at their peak. For comparison, researchers monitored airborne arsenic levels for two consecutive days inside and outside the homes of 20 community residents who do not work at the power plant. Urine samples were collected from all participants daily during the period of study. This approach allowed for observation over a wide range of exposures, from very low to quite high.

Researchers conducting the study in Mexico have taken samples of drinking water from two remote villages in the country's Región Lagunera. The water in one of the villages contains very high levels of arsenic, which occurs naturally because of certain geologic formations. The water in the second village contains very low levels of arsenic. Researchers have also taken urine samples from 30 participants in each village. They plan to compare the arsenic levels in the drinking water from both villages with the arsenic levels in the urine samples. The intent is to assess the bioavailability of arsenic in the body and to determine whether differences in metabolism can be discerned at different exposure levels.

Participants in both studies completed detailed questionnaires covering occupational and health history as well as lifestyle factors, such as smoking and eating habits, that might influence how arsenic is utilized in the body. Data collected from the studies will be analyzed over the next few months. In the meantime, EPRI has undertaken a separate study that will explore in further depth whether nutritional deficiencies affect the way the body processes arsenic.

Notes Yager, "Current risk estimates for arsenic toxicity come from situations involving very high exposures. We are trying to find out whether there are differences for lower exposures or for different routes of exposure, or differences in metabolism—information that can allow the more accurate assessment of health risk over a wide range of exposures."

■ *For more information, contact Janice Yager, (415) 855-2724.*

Power System Efficiency

More-Precise Weather Forecasts May Help Utilities Manage Supply Systems

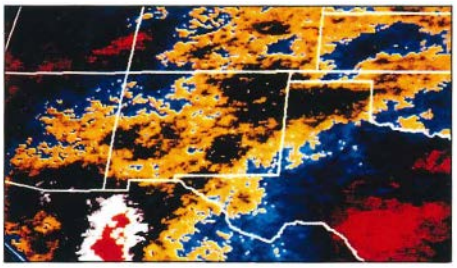
In the scorching heat of July and August, the monsoon season descends on Phoenix, Arizona, bringing torrential rains and violent winds. Each storm cools the area significantly, causing air conditioners—the local utility's biggest single variable load—to cycle less frequently.

"A high peak on a summer afternoon may exceed 3000 MW," says Jon Skindlov, a meteorologist for the Salt River Project (SRP), the utility serving the area. "A storm can lower that peak by 500–1000 MW." The result is the inefficient use of the utility's generating units because of the time required to take the units to a shutdown or standby mode. However, advanced weather-watching technology that allows more-precise forecasts may help the utility deal with this situation. SRP has teamed up with EPRI and the National Severe Storms Laboratory (NSSL) in an effort to use this technology to improve power supply system management.

The joint project was inspired by a new weather radar system implemented by the National Weather Service. Currently being installed at some 130 locations across the country, including Phoenix, the system measures wind speed and direction, key indicators of how damaging winds might be. It can also better estimate the strength and spatial resolution of an approaching storm, offering predictions on how much rain will hit a given area.

The EPRI-SRP effort, which got under way last June, focuses on adapting software developed by NSSL for use with the new radar system. The adapted software, also being developed by NSSL, interprets the radar data and makes a 1- to 3-hour forecast. On the basis of the weather situation, it adds symbols, other visual aids, and audio alarms to make the resulting display in the utility's dispatch center more easily understandable to the nonmeteorologist.

Since last summer, a preliminary version of the new software has been used to display weather information on a computer monitor at the SRP dispatch center in the Phoenix area. NSSL will work with the dispatchers to improve the quality of



the displayed information. As Skindlov points out, the new system should help SRP better prepare for potential damage from approaching storms.

The ultimate goal of this tailored collaboration project, which will be completed in late 1995, is to improve the reliability of the short-term weather forecasts received by SRP's dispatch center so that the utility can more efficiently manage its day-to-day operations. According to EPRI's Douglas Morris, who is managing the project, the software under development can be modified for other regions of the country once the factors influencing local weather patterns have been established.

■ *For more information, contact Douglas Morris, (415) 855-2924.*

FACTS Controller in Testing at Substation

A one-year field trial of one of the first operating elements of EPRI-developed FACTS (Flexible AC Transmission System) technology is under way in northern Oregon. The trial features a complete, three-phase prototype of a high-power, solid-state controller—a thyristor-controlled series capacitor (TCSC) system—installed on a 500-kV transmission line at Bonneville Power Administration's Slatt substation. Initial testing of the prototype was completed last year. Executives of General Electric Company, EPRI, and BPA had earlier dedicated the unit, built by GE with funding from all three organizations.

Hailed as a major breakthrough in the control of high-voltage power systems, the TCSC will permit increased loading of existing utility lines. Thus it is expected to help utilities save money because they will not have to build as much new transmission capacity to meet demand. The prototype TCSC was installed on a transmission line that experiences fault levels typical of extra-high-voltage transmission and so will allow evaluation of the system at the limits of current technology.

The fast-acting controller is designed to modulate line reactance, thereby directing the flow of electricity along specific lines, and to dampen system swing modes to a level unequaled by any other device. The system can also greatly reduce the potential for subsynchronous resonance at power plant generators near lines with series compensation. This advanced series compensator is the first of a new generation of system controllers and other components being developed by EPRI to enable utility transmission networks to operate more electronically.

■ *For more information, contact Ben Damsky, (415) 855-2385.*

Penstock Screen Provides Cost-Effective Fish Protection for BC Hydro

Juvenile salmon and other migrant fish are being safely diverted past a hydroelectric plant in British Columbia as the result of a decision by BC Hydro to install a new type of fish screen. The selection of the new screen, called the Eicher screen, was based on EPRI data and field test results.

Designed for lower capital costs than vertical and drum screen alternatives offer, the Eicher screen features special wedgewire material that enables it to operate at higher velocities than most other screens, and it can be installed in small areas like penstocks. BC Hydro, an international affiliate of EPRI, has calculated the net benefit in avoided generation losses and increased fishery value upstream of its 27-MW Puntledge hydro plant at over $31 million in 1991 Canadian dollars (over $26 million in 1991 U.S. dollars).

The plant is located on the Puntledge River, which in the past supported large runs of chinook, coho, and steelhead. But when the provincial utility's predecessor agency increased water diversion to the powerhouse in the 1960s, fish mortality rates rose, and eventually fish migrant access to the river above the dam was closed off. In the late 1980s, when the upper river began to be used for planting hatchery fish, BC Hydro tested chain curtains, strobe lights, underwater sonic hammers, and electrified arrays in unsuccessful efforts to safely divert fish downstream past the turbine after spawning.

In 1991 the utility decided to consider fish screens and was particularly interested in EPRI studies of the Eicher screen. EPRI-sponsored tests of the screen had found excellent (> 98%) survival rates for chinook, coho, and steelhead juveniles. BC Hydro used the EPRI data to evaluate a number of alternatives and found the penstock screen to be the most cost-effective. Two of the Eicher units were installed in time for the spring migration in 1993. Field reports suggest that again this spring, as last, the young fish will bypass the turbines at Puntledge with very low mortality rates.

"BC Hydro is committed to balanced solutions that address environmental, social, and financial considerations," says Hugh Smith of the utility. "The new penstock screens helped us work toward a balance of these considerations at our Puntledge hydro facility."

■ *For more information, contact Charles Sullivan, (415) 855-8948.*

EPRI High-Concentration Solar Array Certified for PVUSA Project

EPRI has reached a major milestone in its development of a potentially low-cost, high-efficiency photovoltaic technology: a 1-kW array operating on the Georgia Power Company system has qualified for participation in the PVUSA (Photovoltaics for Utility-Scale Applications) project. The prototype integrated high-concentration photovoltaic (IHCPV) array is installed at the utility's Shenandoah Environment & Education Center in Newnan, Georgia.

Georgia Power, Arizona Public Service Company, Pacific Gas and Electric Company (PG&E), the Los Angeles Department of Water & Power, and Southern California Edison Company cosponsored the development of the technology with EPRI. AMONIX, Inc., of Torrance, California, led a team of EPRI contractors in developing the 1-kW array and also a larger, 20-kW unit to be installed this year for testing at the Shenandoah facility. Other utility demonstrations are now being sought to test and evaluate several arrays.

The IHCPV arrays use molded Fresnel lenses to concentrate sunlight 260 times onto small-area solar cells. A stabilized efficiency of 15.5% has been measured for the technology, making it one of the most efficient photovoltaic systems available. And stabilized efficiencies of more than 25% have recently been demonstrated by AMONIX for individual cells.

Verification for PVUSA is considered a major step toward the commercialization of the IHCPV technology by AMONIX and EPRI. PVUSA, which is managed by Bechtel Construction Company, is a joint government-utility project led by PG&E. The 1-kW IHCPV array successfully passed qualification testing according to the Department of Energy's Sandia National Laboratories specification.

"The verification tests show that system simplicity and good performance can be achieved simultaneously," says Ross Kist, assistant to the executive vice president at Georgia Power. "Solar power now comes that much closer to being a real option for utilities." The IHCPV technology's installed cost is expected to be below $2000 per kilowatt at multimegawatt production levels. And in regions with good sunlight, such as the desert Southwest, its cost of electricity is expected to be competitive with other forms of utility power generation in a range of applications.

■ *For more information, contact Frank Dostalek, (415) 855-2162.*

Exploratory Research

Managing Complexity in Large System Models

*by Jeremy Bloom and Charles Clark, Integrated Energy Systems Division,
and Martin Wildberger, Office of Exploratory & Applied Research*

ABSTRACT *Many complex utility systems, such as power grids and hydroelectric networks, involve so many interacting considerations that comprehensive analysis or simulation for planning or control purposes is at present impractical or impossible, using even the largest computers. EPRI has sponsored exploratory research to develop systematic procedures for managing complexity in large system models—procedures designed to enhance the ability of utility planners to optimize current operations while hedging against uncertainties that could significantly influence future costs. Related procedures are being applied to optimize hydroelectric scheduling under uncertainties associated with weather and other factors. And in ongoing exploratory work, additional computational and conceptual approaches for managing complexity in utility planning and control applications are being investigated.*

One of the most difficult challenges faced by utility planners is to maximize the efficiency of current operations while hedging against uncertainties that could significantly affect future costs. Optimal planning must account both for likely events and for events that could have catastrophic or especially beneficial effects. For example, in hydroelectric scheduling, planners must consider the existing water supply as well as various scenarios for future water availability. When heavy rainfall or snowmelt is expected, reservoirs can be lowered in order to generate inexpensive electricity—at the risk of reducing or eliminating hydroelectric capacity should dry conditions occur. Conversely, if dry weather is expected, high reservoir levels can be maintained in order to provide flexibility for future power production—at the risk of wasted hydropower potential should wet weather lead to reservoir spillage.

To optimize decision making for complex systems, planners typically rely on large computerized models. However, many utility planning models are so complex that computation becomes impractical or impossible because the multitude of variables and contingencies (dimensions) required to characterize such systems in a meaningful way overwhelms even the fastest computers. This difficulty, known as the curse of dimensionality, also plagues simulations for optimizing the control of regional power grids and other large, interconnected engineering systems.

Removing the curse

The effective complexity of a system can be altered by changing the scale at, and viewpoint from, which it is viewed; the complexity-altering processes by which scale and viewpoint are modified can be thought of as "chunking" procedures. Through chunking, the conceptual elements of a system are combined or broken into other independent or loosely coupled components, such as process streams or subsystems. For example, an astronomer might conceive of the entire universe as a single chunk that can be modeled by applying just the laws of thermodynamics. A nuclear physicist, on the other hand, might consider the universe an almost infinite number of chunks modeled by accounting for each subatomic particle and recomputing all pertinent parameters at each nanosecond. Appropriate chunking both illuminates the essential relationships within a system and constrains them to the problem at hand, allowing the behavior of complex systems to be modeled and understood.

Currently, chunking is often applied on an unstandardized, case-by-case basis and is therefore of limited applicability in automated analysis. In recent EPRI-funded exploratory research (RP8010-9), however, scientists at Stanford University have developed advanced systematic chunking schemes for managing complexity in many large system models, schemes that should help utility planners optimize current operations while hedging against future uncertainties.

Solving complex planning problems

Over the past 50 years, many large planning models have been formalized and optimized by using linear programming methods, which are matrix-based procedures initially developed in the 1940s. To apply these procedures, mathematical statements that as completely as possible characterize the choices, constraints, and goals over the life of a planning problem are developed and combined in a large matrix. Standardized manipulations that simultaneously consider all these interacting—and often competing—factors are used to identify the combination of choices that best meets the planning goals.

When viewed geometrically, the mathematical statements describe a polyhedron having as many spatial dimensions as the problem of interest has choices and constraints. This multidimensional polyhedron encloses all the choices possible in the planning model, and the optimal combination of choices for satisfying the planning goals occurs at one corner of the figure. In conventional (simplex) analysis, the computational process begins at an arbitrary corner; then an adjacent corner is identified that more fully satisfies the planning goals. Through subsequent matrix computations, the polyhedron's surface is explored and successively better corners are identified. Typically, after about as many computations as the problem has choices and contingencies, the optimal corner—the set of decisions that best solves the problem—is reached. For many types of problems, this approach can quickly provide adequate solutions. However, for the large, complex systems of concern to utility planners—systems with billions of possibilities—such analysis is impractically slow and often impossible.

To shorten computation time and facilitate the solution of complex problems, the systematic chunking procedures developed in the EPRI-funded research at Stanford exploit certain characteristics frequently encountered in planning problems—for example, scenario similarity and ordered decision making. These chunking procedures can be thought of as reducing the complexity of the polyhedron of possibilities without fundamentally distorting its shape.

Time-staged, network-ordered, or otherwise structured decision making is frequently an inherent part of planning problems. In such problems, key decisions and contingencies are sequentially or otherwise related. Not all options have to be considered simultaneously, as is done in conventional linear programming analysis. Thus, computation can be simplified by breaking ordered problems into chunks that reflect natural relationships, much in the way a planner actually thinks about a problem. No information is lost; the mathematical formalisms governing the decomposition guarantee that the chunks always recombine to represent the original problem. Although decomposition procedures have been employed for two-stage simulations since the 1960s, only in the last 10 years have these methods been extended to include much more complicated multistage problems.

The Stanford researchers have adapted a partitioning technique known as nested Bender's decomposition in order to chunk ordered multistage problems into loosely coupled subproblems following the time-based and other relationships between choices. This chunking approach takes advantage of the limited interactions between stages in many planning models and significantly reduces computational complexity. Individual subproblems can thus be quickly optimized and the results combined to efficiently solve the initial problem.

A second source of structure in planning problems, especially those involving future uncertainty, is the numerous possible scenarios that must be considered for their ultimate impact on planning goals. For most such problems, nearly all of the scenarios fall into relatively few chunks related by similar eventual result. By selecting for comparison sufficient typical scenarios to represent most or all of the outcome chunks (without actually calculating the results for all the scenarios), computational complexity can be dramatically reduced with little loss in solution validity. It is important to note, however, that conventional random or simple likelihood-based scenario-sampling techniques, while useful for statistical simulations, do not provide a good selection of representative scenarios for most planning problems.

At Stanford, appropriate importance-sampling techniques have been developed to enhance scenario chunking and speed up computation. Both scenario likelihood and estimated eventual cost are considered by an outcome-approximating function that evaluates and selects for comparison the representative scenarios it identifies as most likely to affect planning objectives. Thus, only a few hundred scenarios out of the billions possible need be considered to accurately analyze a typical complex planning problem involving uncertainty.

By incorporating the importance-sampling function into the algorithm that controls decomposition, these systematic procedures reduce computational complexity so efficiently that problems previously insolvable on Cray supercomputers can be optimized on personal computers. For example, a planning problem involving 52 parameters subject to uncertainty—equivalent to 10^{27} dimensions if the problem could be stated deterministically—was solved on an 80386 laptop computer.

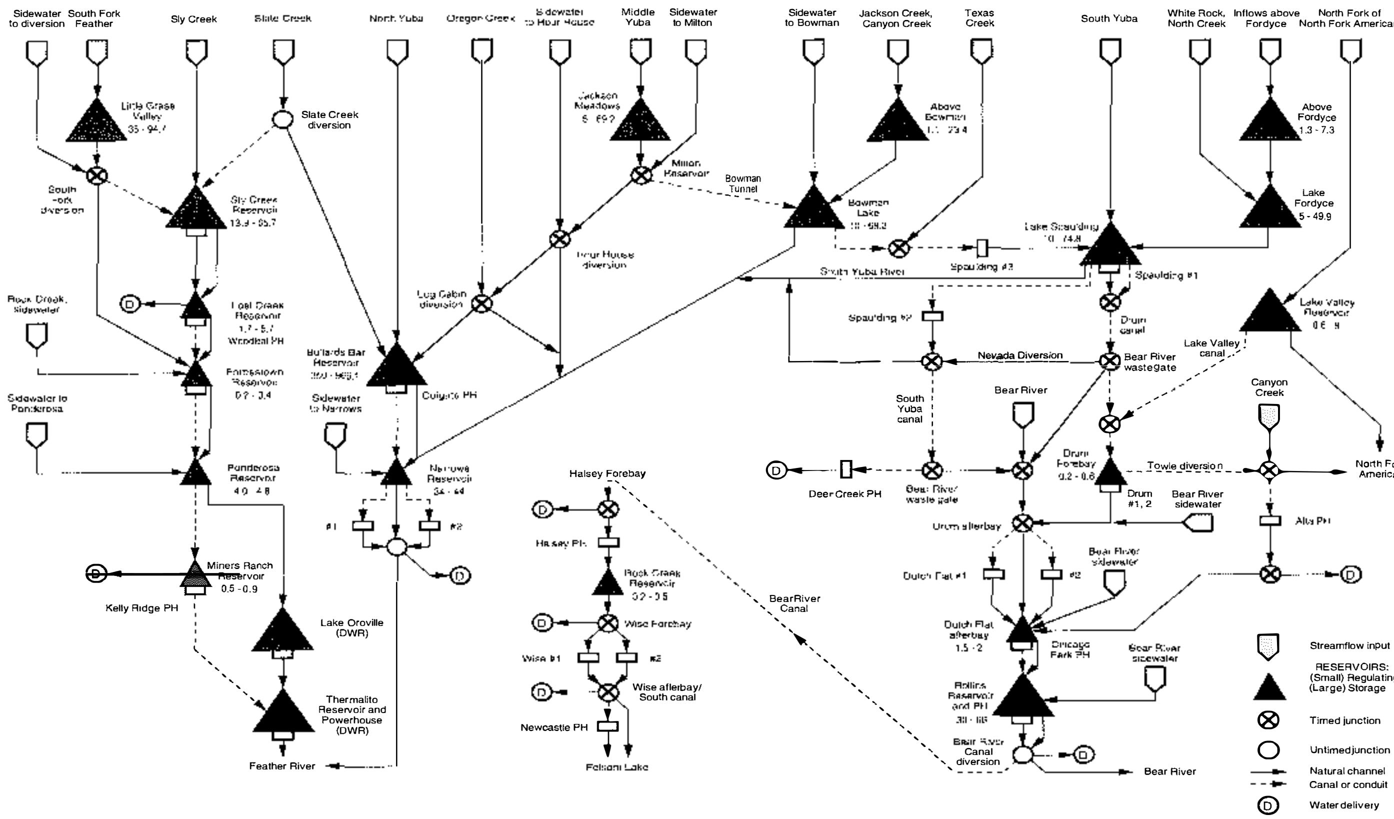
The Stanford researchers have also identified other methods for speeding up computation. One approach takes advantage of the limited interactions between decomposed subproblems. Because the chunked subproblems are independent or are only loosely coupled, parallel processors can be employed to solve them almost simultaneously without increasing complexity. A second procedure makes use of solutions to similar subproblems generated during previous simulations. This so-called warm-start process is geometrically equivalent to beginning the search for the optimal corner of a subproblem's polyhedron from a corner that is relatively near an earlier solution rather than randomly located. Using these techniques and 64 parallel processors in an Intel iPSC/2d6 hypercube multicomputer, additional speedups of up to 60% have been achieved for large problems.

Improving hydroelectric scheduling

Related computational procedures are being developed to optimize hydroelectric scheduling for Pacific Gas and Electric Company. Hydropower represents a substantial portion of PG&E's energy capacity; it also offers significant generating flexibility. However, scheduling is complicated by use limits and by the wide year-to-year variations in precipitation and streamflow. In addition, for each of PG&E's 11 hydrobasins, many decisions must be made as to water spillage, diversion, storage, and power generation; numerous dams, canals, reservoirs, and power plants are involved.

PG&E's current computerized model produces water-release schedules that maximize the value of hydroelectric generation

Figure 1 This schematic representation of Pacific Gas and Electric's Yuba–Bear–South Fork Feather River hydrobasin illustrates the complex, interconnected nature of utility hydroelectric networks, which include reservoirs, powerhouses, and other facilities. Optimal hydrogeneration scheduling requires not only accounting for all the interactions between network nodes but also hedging against future uncertainties in streamflow input.



within individual river basins over a period of up to 24 months. However, this model is deterministic and can consider only a single forecast for future water flows, a forecast based on historical stream data. Because this model does not consider weather-related uncertainties, its schedules often fail to fully account for future possibilities and are therefore of limited value.

To incorporate the relevant uncertainties, PG&E is developing a new scheduling system known as SOCRATES; enhanced decomposition and warm-start methods similar to those developed in the EPRI-funded work at Stanford are being employed to control the associated computational complexity. As a result, complex simulations considering as many as 45 future-weather scenarios can be solved in computation times that make the system practical for everyday use. For example, scheduling for a two-year simulation of the Mokelumne River system, a representative PG&E hydrobasin, can be accomplished in about 4 minutes using an HP 9000/750 workstation; dozens of representative scenarios for weather and streamflow are considered in the same amount of time that PG&E's current scheduling system requires to compute a single scenario with the HP computer. For the most complex PG&E basin, the Yuba–Bear–South Fork Feather River system (Figure 1), SOCRATES water-release scheduling takes about 7 minutes with the same equipment.

The development of SOCRATES parameters for PG&E's other hydrobasins is under way, and the utility expects to employ SOCRATES for scheduling a significant part of its hydro system during 1994. Through the application of importance-sampling and parallel-processing chunking techniques, SOCRATES will eventually be further expanded to include more-detailed uncertainties in weather and streamflow as well as to optimize the mix of hydrogeneration and other energy sources.

Exploring complexity management

Other computational and conceptual tools to manage complexity are also being examined in EPRI exploratory research efforts. Hierarchically structured neural networks are being investigated as possible controllers for complex dynamic systems in a project at Northwestern University (RP8017-4). Such networks, chunked into subnetworks that are related to system inputs, could outperform conventional black-box neural networks having internal structures that appear to be unrelated to system functions.

Nested-epsilon decomposition methods to optimize parallel computations of load flow equations are being investigated by researchers at the University of Santa Clara (RP8017-3). These calculations are key to understanding and controlling transient stability in large power grids.

Last fall, EPRI sponsored a workshop on visualization methods for utility industry applications. The workshop focused on how to present highly dimensional data to human operators by using chunking methods that retain pertinent information and relationships but reduce complexity.

Gas Turbine and Combined-Cycle Capacity Enhancement

by Henry Schreiber, Generation & Storage Division

Nonutility generators, which generally operate at baseload, have increased the load swings experienced by utility fossil units in providing peaking service. With rising peak demand, utilities must either acquire more peaking units, purchase expensive peaking power, or increase the capacity of their existing peaking units. To help utilities with these decisions, EPRI is exploring the technical and economic feasibility of enhancing the capacity of existing gas turbines and combined cycles. This work is investigating whether such enhancement can offer significant cost advantages over the other options.

Peaking gas turbines in utility service are a grossly underutilized capital investment, generally operating at capacity factors in the 1–2% range. If a utility must provide additional peaking capability, increasing the capacity of existing units can represent an attractive alternative to buying new capacity—an alternative that avoids or minimizes siting and permitting costs; design, procurement, installation, and construction costs; and additional operating and maintenance costs. Obtaining permits for an existing peaking unit to operate at a higher capacity is likely to be less difficult than getting permits for a new unit.

A current EPRI project, described in interim report TR-102412, is examining capacity enhancement options. It has a dual focus—enhancing existing units and designing new units. A unit capable of operating at a favorable baseload heat rate and also of meeting peaking demand with only a modest heat rate penalty is an attractive option, particularly in the case of a new combined-cycle unit. Such a unit eliminates the risk of unreliability in starting a separate simple-cycle peaker (since the unit is already running) and eliminates the capital, permitting, and O&M costs of a separate unit. Although operating a combined-cycle unit in a peaking mode will result in some heat rate penalty, it avoids the unfavorable equivalent heat rate of a peaker (which includes unproductive startup and shutdown fuel for a relatively short running time).

EPRI member utilities currently possess large fleets of simple-cycle peaking turbines. Many of these machines have relatively few fired hours, even though they have many starts. Although old, the units may be in sufficiently good condition to warrant a capacity enhancement upgrade. Because of their low capacity factor, the high heat rate of these older simple-cycle machines may not be as important as the avoided cost of new peakers or of purchased peaking power. Furthermore, some capacity enhancement techniques actually improve the heat rate of older units.

Still another incentive for a capacity enhancement retrofit is the favorable economics of demonstrating that capacity to a power pool, which may result in revenue payments or avoided shortfall penalties.

The project team is evaluating makes and models of gas turbine engines currently used in large numbers for utility peaking service. The engines selected were the United Technologies FT-4 series of aeroderivative units, which are used almost entirely in simple-cycle peaking service; the General Electric Frame 5 and Frame 7 heavy-duty series; and the Westinghouse 251 and 501 heavy-duty series. Each engine type was analyzed to identify the barriers that limit its capacity at a given operating point and to identify cost-effective retrofits to eliminate those barriers. Typical barriers to enhanced-capacity operation are compressor blade loading and surge margin, combustion stability and hardware limitations, hot-gas-path component metal temperature, torque limitations, and generator, transformer, and switchgear capacity.

Some of the older engines designed for lower firing temperatures have a large potential for capacity improvement through increased turbine inlet temperatures and the use of thermal barrier coatings on cooled blading. For engines with very low capacity factors, there are economic tradeoffs between increased capacity and shortened hot-gas-path component life. For example, an engine operating at a baseload firing temperature may require hot-gas-path component replacement after 40,000

ABSTRACT *There are a number of cost-effective ways to increase the capacity of existing peaking gas turbines and combined cycles by incorporating engine or unit system retrofits, according to new EPRI research. For simple-cycle gas turbines, capacity increases of up to 35% are possible for summer operations, at a capital cost ranging from $10/kW to $200/kW, depending on site-specific conditions and the technology chosen. While many of these techniques exact a slight heat rate penalty, some result in a heat rate improvement of up to 10%. Utility demonstrations of some of the techniques are under way.*

Table 1: Capacity Enhancement, FT4A-9 Turbine

	Firing Temperature Increase (°F)	Capacity Increase* kW	Capacity Increase* %
Airfoil with 0.007-inch coating	31	1325	6.5
Airfoil with 0.015-inch coating	70	3230	16

*Accounts for power losses resulting from inlet air filtration.

hours of operation. Increasing the firing temperature produces a large incremental power gain and heat rate improvement but may reduce the hot-gas-path component life to 10,000 hours. If, however, this engine runs only 150 to 200 hours per year, a 10,000-hour life is economically acceptable. Figure 1 illustrates the trade-offs in this approach. A beneficial by-product of the approach is an improved heat rate due to the higher turbine inlet temperature.

Several capacity enhancement modifications can be combined in the same engine. For example, Lincoln Electric System in Lincoln, Nebraska, has a GE Frame 7B peaking unit. The unit was originally oil-fired and produced 53 MW at design conditions of 101°F and 34% relative humidity. It was dispatched to operate four hours per day, five days per week, during summer peak demand periods. Adding evaporative compressor inlet air cooling boosted the unit's capacity to 57 MW. Later, the evaporative cooling system was replaced with an ice-storage-based inlet air cooling system; modified compressor inlet guidevanes were installed; and natural-gas-firing capability was added. That raised the design-day capacity to 67 MW. Finally, water injection, along with auxiliary generator and transformer cooling, raised the capacity to 72 MW—an increase of nearly 36% over the capacity of the original configuration.

The most cost-effective capacity enhancement approach for gas turbines and combined cycles must be determined on a case-by-case, site-specific basis, since it depends on the unit's mission, its make and physical condition, and site ambient and load conditions.

For the FT-4 engine series, thermal barrier coatings and other modifications to first-stage vanes, together with overfiring, can produce a capacity increase of up to 16% for as little as $10/kW of incremental capacity (Table 1). Inlet air filtration may be necessary to protect the thermal barrier coatings from erosion if many operating hours in a dusty environment are anticipated. Such filtration adds $80–$100/kW. This compares with $300/kW for new capacity, not including permitting costs.

For GE Frame 5 units, steam injection also appears to be advantageous for capacity and heat rate improvement, particularly if the steam is generated with an exhaust-gas heat exchanger. This need not be a full-size heat recovery steam generator (HRSG) but could be a small, once-through unit sized just large enough to generate injection steam. At a maximum steam injection rate of 5% of airflow, the capacity gain is 18% and the heat rate decrease 10%. This retrofit is estimated to cost about $210/kW of incremental capacity.

In the case of combined cycles, there may be a large advantage in designing a new unit so that it can operate at minimum heat rates under baseload conditions and can also operate at a higher capacity when peak demand must be met. Such peak load operation would result in a modest heat rate penalty. However, this approach has several advantages:

- Avoiding the capital, permitting, and O&M costs of a separate peaking unit
- Producing peak power at a lower heat rate than with a simple-cycle gas turbine
- Reducing the use of startup and shutdown fuel
- Eliminating the starting-reliability uncertainty associated with a separate unit
- Saving space, since the peaking combined cycle would have about the same footprint as a standard combined cycle

The incremental cost of the peaking combined-cycle unit would come from installing a duct burner ahead of the HRSG and from the larger steam turbine generator set and step-up transformer. The benefit would be a peaking-capacity increase equal to about 20% or more of the baseload capacity. The duct burner would produce additional steam to operate the steam turbine at its maximum design point, as well as the maximum steam necessary for injection into the compressor discharge air plenum of the gas turbine. For economic reasons, such steam injection would be used only for maximum peaking operations, since the steam is lost to the atmosphere with the exhaust flow. However, when this technique is used, it enhances the gas-side performance of the HRSG because steam has a higher heat capacity than air. The duct burner also compensates for the drop in gas turbine exhaust temperature due to steam injection.

In summary, this project's first interim report shows that technically feasible capacity enhancements costing about $200/kW or less can be a very effective way to add peaking capacity. Demonstration projects funded by tailored collaboration are under way and will continue into 1995. Interim reports will be published this year and next; the final report is scheduled for 1996.

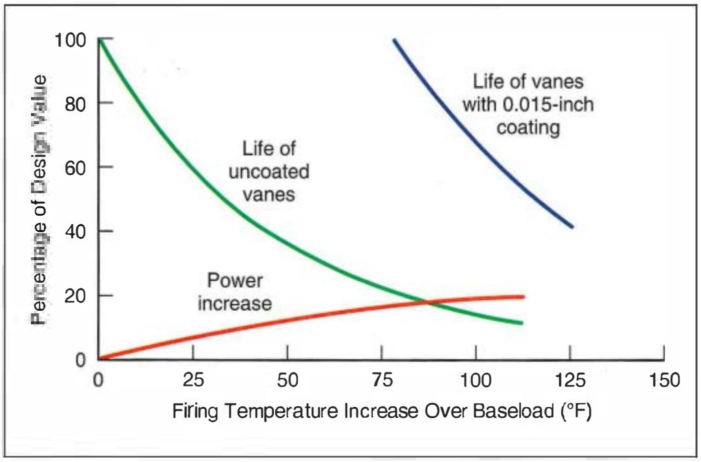


Figure 1 For some older gas turbines, increasing the firing temperature from the baseload level can enhance capacity, as shown here for United Technologies FT4A-9 and GG4A-7 engines. Although a reduction in hot-gas-path component life also results, it can be ameliorated by the use of thermal barrier coatings, as the graph shows for first-stage vanes. For turbines with very low capacity factors, the trade-off between increased capacity and reduced component life may be economically acceptable.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Customer Interface and Controls Program Development and Support (RP2830-16)	$238,800 28 months	Utility Consulting Service/*L. Carmichael*
Next Generation of Adjustable-Speed-Drive High-Performance and High-Power Inverters (RP3087-25)	$1,141,000 36 months	Ansaldo Ricerche/ *B. Banerjee*
Protocol for Measuring Electric and Magnetic Fields Associated With Electric Vehicles and Charging (RP3254-5)	$70,000 11 months	Power Quality & Electrical Systems/*M. Samotyj*
Geographic Information Systems and Related Technologies for the Electric Power Industry: Evaluation of Needs and Implementation (RP3337-16)	$190,000 18 months	Argonne National Laboratory/*G. Heffner*
Development of a Single-Package Heat Pump for the Manufactured-Housing Market (RP3646-1)	$369,100 17 months	Consolidated Technology Corp./*T. Statt*
Solar Heat Pump Engineering Support and Coordination (RP3647-1)	$342,400 24 months	Foster Miller/*T. Statt*
Demand-Side Management/Community Initiative (RP3737-3)	$60,300 3 months	Barakat & Chamberlin/ *G. Heffner*
Distribution Automation/Demand-Side Management Demonstration (RP3740-1)	$1,045,500 29 months	Florida Power Corp./ *L. Carmichael*
Commercial Lighting Retrofit Data Collection and Analysis (RP3819-12)	$101,800 17 months	Fleming Group/*R. Gillman*
Integration and Demonstration of the Market Analysis Tools Commercial CLASSIFY-Plus and MarketTREK (RP3825-2)	$150,300 19 months	Research Triangle Institute/ *T. Henneberger*
Electrical Systems		
Location of Faults on Primary Distribution Systems With Multiple T and Y Connections (RP2895-10)	$1,201,200 18 months	AT&T/*H. Ng*
UCA/DAIS Demonstration (RP2949-23)	$2,032,600 26 months	Pacific Gas and Electric Co./*B. Blair*
UCA/DAIS Demonstration (RP2949-24)	$1,116,300 27 months	Public Service Electric & Gas Co./*B. Blair*
Analysis of Control Interactions on FACTS-Assisted Power Systems (RP3022-33)	$303,000 25 months	University of Wisconsin, Madison/*A. Edris*
Comprehensive Framework for Analyzing Transmission Services and Evaluating Their Costs (RP3216-1)	$593,300 20 months	Casazza, Schultz & Associates/*A. Vojdani*
Superparamagnetic Polymeric Shielding Materials for Magnetic Fields (RP3335-11)	$249,600 23 months	SRI International/ *B. Bernstein*
Development of Custom Power Technologies (RP3389-14)	$1,925,700 31 months	Magnetek Power Technology Systems/*H. Mehta*
Intelligent Control of Complex Nonlinear Systems With Electric Power Applications (RP3573-5)	$105,800 30 months	Oregon State University/ *D. Maratukulam*
Field Operation Power Switching Safety (RP3573-9)	$299,900 16 months	General Physics Corp./ *G. Cauley*
Assessment of Voltage Security Methods and Tools (RP3578-1)	$432,500 18 months	British Columbia Hydro & Power Authority/ *D. Maratukulam*
Integrated Control, Protection, and Data Acquisition (RP3599-1)	$464,700 30 months	ECC/*J. Melcher*
Substation Asset Management (RP3653-1)	$97,000 6 months	Sargent & Lundy/*J. Porter*
Energy Management System Technical Advisor Services (RP3654-3)	$117,800 12 months	ECC/*G. Cauley*
Distribution Automation/Demand-Side Management Demonstration (RP3674-3)	$1,045,500 29 months	Florida Power Corp./ *B. Blair*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Distribution Automation/Demand-Side Management Demonstration (RP3674-4)	$2,700,000 26 months	Georgia Power Co./ *B. Blair*
Implementation of Intelligent Systems in the Puget Power Control Center (RP3708-3)	$76,200 4 months	University of Washington/ *D. Sobajic*
Phase-Angle Measurements for Real-Time Western Systems Coordinating Council Monitoring and Control (RP3717-1)	$820,000 39 months	Virginia Polytechnic Institute and State University/ *R. Adapa*
Advanced Static VAR Compensator for Distribution Applications (RP3797-5)	$353,600 21 months	PSM Technologies Corp./ *H. Mehta*
Aging of Cables for Extruded Transmission Cable Application (RP7919-3)	$330,900 64 months	BICC Cablers Corp./ *B. Bernstein*
Transmission Cable End-of-Life Criteria (RP7924-1)	$3,040,500 53 months	Power Technologies/ *J. Shimshock*
Environment		
Ash Structural Fill for Site Demonstration (RP2422-22)	$774,300 119 months	JTM Industries/*D. Golden*
Effect of Coal Quality and Blending on the Operation of Furnaces Fitted With Low-NO_x Combustion Systems (RP2916-28)	$288,300 29 months	PowerGen PLC/*J. Stallings*
Review of Health Dose-Response Information Suitable for Incorporation Into Externality Studies (RP3253-2)	$59,900 7 months	University of Illinois/ *R. Wyzga*
Lake Quality and Mercury in Fish (RP3297-3)	$100,000 15 months	ESEERCO/*D. Porcella*
Vegetation/Ecosystem Modeling and Analysis (RP3316-4)	$174,800 16 months	Marine Biological Laboratory/*L. Pitelka*
Vegetation/Ecosystem Modeling and Analysis (RP3316-5)	$73,400 16 months	University of Lund/ *L. Pitelka*
ASTER Support for the Plume Rise and Downwash Modeling Project (RP3527-5)	$83,700 11 months	National Center for Atmospheric Research/ *C. Hakkarinen*
Demonstration of Total Environmental and Efficiency Management Technologies (RP3571-1)	$2,850,000 63 months	New York State Electric & Gas Corp./*R. Rhudy*
Reduction of NO_x Emissions for a Gas-Fired Boiler (RP3631-2)	$327,500 28 months	Louisiana Power & Light Co./*K. Zammit*
Organic Containment and Removal at Havana Site (RP9015-2)	$96,100 5 months	Tetra Tech/*D. McIntosh*
Characterization of the Distribution of Nonaqueous-Phase Liquids in an Aquifer Before Implementation of an In Situ Recovery System (RP9015-9)	$127,900 8 months	Atlantic Environmental Services/*I. Murarka*
Characterization of PCBs in Groundwater (RP9015-10)	$128,100 10 months	Meta Environmental/ *I. Murarka*
Wet Stacks Design Guide (RP9017-1)	$276,200 8 months	Burns & McDonnell Engineering Co./*R. Rhudy*
Construction of a Research Site for Assessing the Chemical Treatment of Coal to Control Leachate (RP9021-2)	$140,100 10 months	Pennsylvania Power & Light Co./*I. Murarka*
Utilization of Coal Combustion By-Products in Agriculture and Land Reclamation (RP9023-1)	$426,800 59 months	Southern Company Services/*J. Goodrich-Mahoney*
Management Tools for Pollution Prevention (RP9030-1)	$617,000 36 months	Decision Focus/ *M. McLearn*
Southern Oxidant Study (RP9031-1)	$5,652,200 66 months	University Corp. for Atmospheric Research/*D. Hansen*
Ash Structural Fill for Site Demonstration (RP9035-1)	$774,300 119 months	JTM Industries/*D. Golden*
Autoclaved Cellular Concrete Mobile Pilot Plant (RP9040-5)	$868,700 25 months	North American Cellular Concrete Co./*D. Golden*

Project	Funding/ Duration	Contractor/EPRI Project Manager
SO_2 Advanced Retrofit Demonstration Project: Homer City Unit 3 FGD Retrofit (RP9041-1)	$351,000 18 months	Radian Corp./*C. Dene*
Development of New Industrial Ashalloy Materials Using Fly Ash Cenospheres (RP9047-2)	$73,900 12 months	University of Wisconsin, Milwaukee/*D. Golden*

Exploratory & Applied Research

Project	Funding/ Duration	Contractor/EPRI Project Manager
Fuzzy Logic Startup and Optimal Load Following for Large Steam Turbine Systems (RP8004-25)	$165,100 18 months	General Electric Co./ *J. Weiss*
Nested-Epsilon Decomposition for Parallel Computation (RP8017-3)	$74,400 12 months	Santa Clara University/ *P. Hirsch*
Solution of Three-Dimensional Fluid Flow Problems on Unstructured Meshes (RP8018-1)	$210,700 26 months	University of Pittsburgh/ *L. Agee*
Gas and Solid Velocity Profiles in Circulating Fluid Beds Induced by Directed Solid Mass Streams (RP8022-8)	$241,500 24 months	Swiss Federal Institute of Technology/*S. Alpert*
Intelligent Control Through Use of Neural Networks (RP8030-7)	$100,000 29 months	University of Missouri, Rolla/*S. Yunker*
Small-Punch Testing for Irradiation Embrittlement (RP8046-3)	$80,100 9 months	Failure Analysis Associates/*R. Viswanathan*
Comprehensive R&D Program on Electroseparations (RP8060-1)	$126,000 11 months	Martin Marietta Energy Systems/*A. Amarnath*
Preparation and Performance of Platinized Ebonex and Other Metallized Ebonex Electrodes (RP8060-2)	$106,200 24 months	University of Southampton/*A. Amarnath*
Indirect Electrochemistry Using Ionomer-Coated Electrodes (RP8060-6)	$86,800 12 months	North Carolina State University/*R. Weaver*
Copper Gallium Diselenide Solar Cells (RP8063-1)	$134,700 12 months	University of South Florida/*T. Peterson*
Turbine Steam Chemistry and Corrosion: Experimental Turbine Tests (RP9003-5)	$233,000 24 months	Oxidation Systems/ *B. Dooley*

Generation & Storage

Project	Funding/ Duration	Contractor/EPRI Project Manager
Model-Based Diagnostics and Prognosis (RP1864-13)	$118,800 30 months	General Electric Co./ *R. Colsher*
Emulation of Siemens Man-Machine Interface (RP3152-18)	$622,200 28 months	TRAX Corp./*R. Fray*
Preliminary Research and Design for Whole-Tree-Energy™ Plant (RP3407-11)	$140,500 8 months	Bechtel Group/*J. Berning*
Hot Gas Cleanup for Wood-Fired Combustor (RP3407-15)	$150,000 42 months	Power Generating/ *E. Hughes*
Oil-Fired Gas Turbine Selective Catalytic Reduction Pilot Demonstration (RP3449-1)	$1,264,000 44 months	Maui Electric Co./ *H. Schreiber*
Solar Two (RP3551-1)	$750,000 18 months	Southern California Edison Co./*E. DeMeo*
Demonstration of Total Environmental and Efficiency Management Technologies (RP3572-1)	$1,500,000 63 months	New York State Electric & Gas Corp./*E. Petrill*
Biomass Resource Assessment for Wood Cofiring (RP3576-1)	$300,000 26 months	University of Tennessee/ *E. Hughes*
Advanced Weather Technologies for Electric Utility Applications (RP3682-1)	$450,000 33 months	National Severe Storms Laboratory/*D. Morris*
SOAPP (State-of-the-Art Power Plant) Workstation Repowering Modules (RP3683-1)	$776,700 27 months	Sargent & Lundy/*S. Pace*
Northport Station Automation Demonstration (RP3690-2)	$180,200 35 months	Long Island Lighting Co./ *D. Broske*
Enhanced Boiler Maintenance Workstation User Interface and Functionality (RP3720-1)	$476,200 30 months	Karta Technology/*R. Tilley*

Integrated Energy Systems

Project	Funding/ Duration	Contractor/EPRI Project Manager
Power Quality Market Assessment (RP3273-10)	$86,000 4 months	CRS Sirrine Engineers/ *V. Longo*
Assessment of Emissions Trading Based on Experience With the 1990 Clean Air Act Amendments (RP3306-7)	$689,900 33 months	National Economic Research Associates/ *R. Patrick*
Value of Climate Change Impacts on Water Resources (RP3676-2)	$180,000 17 months	RCG/Hagler, Bailly/ *T. Wilson*
Impacts of Climate Change on the Timber Market (RP3676-4)	$85,900 20 months	Yale University/*T. Wilson*
Options Transaction System Experiment Design (RP7581-1)	$99,500 6 months	National Economic Research Associates/ *R. Siddiqi*
Integration of Fuel Burn With Other EPRI Fuel Models (RP7604-1)	$77,100 15 months	Applied Decision Analysis/ *R. Goldberg*
Strategic Asset Management Case Study (RP7678-1)	$175,900 5 months	Strategic Decisions Group/ *L. Rubin*
Retail Market Management Research at Public Service of Oklahoma (RP7802-1)	$124,996 8 months	Laurits R. Christensen Associates/*R. Siddiqi*
Development of an Industrial Real-Time Pricing Experiment: Baltimore Gas & Electric (RP7802-2)	$90,000 6 months	Tabors, Caramanis and Associates/*R. Siddiqi*

Nuclear Power

Project	Funding/ Duration	Contractor/EPRI Project Manager
Westinghouse Owners Group Generic License Renewal Program (RP3075-9)	$500,000 14 months	Westinghouse Electric Corp./*J. Carey*
Application of Abnormal Conditions and Events Methodologies to Instrumentation and Control Upgrades (RP3352-6)	$396,900 15 months	TRW/*R. Torok*
Comprehensive Approach to Safety-Grade System Replacements (RP3549-3)	$866,000 20 months	Westinghouse Electric Corp./*J. Naseri*
Post-irradiation Evaluation of Fuel From Hatch BWR (RP3564-1)	$821,000 28 months	General Electric Co./ *S. Yagnik*
CHECWORKS Demonstration (RP3776-1)	$145,200 16 months	Altos Engineering Applications/*R. Mahini*
Electrochemical Potential Test Program at Millstone 2 (RPS416-9)	$85,300 10 months	Babcock & Wilcox Co./ *P. Millett*
Titanium Dioxide Injection at Point Beach 2 (RPS416-10)	$80,000 10 months	NWT Corp./*P. Paine*
MULTEQ Database Support (RPS510-2)	$90,700 24 months	NWT Corp./*P. Paine*
Evaluation of Stress Corrosion Cracking Inhibitors for Steam Generators (RPS510-6)	$165,900 13 months	Babcock & Wilcox Co./ *P. Paine*
Film Analysis of Alloy 600 (RPS512-1)	$97,900 33 months	Rockwell International Corp./*A. McIlree*
Analysis of Intergranular Attack/Stress Corrosion Cracking by Analytical Transmission Electron Microscopy (RPS512-2)	$70,700 8 months	Battelle Memorial Institute/ *A. McIlree*
Electrochemistry and Chemistry in a Heated Crevice (RPS520-8)	$148,700 15 months	Rockwell International Corp./*P. Millett*
Acid/Base Titrations in High-Temperature Aqueous Systems (RPS522-4)	$60,100 12 months	Pennsylvania State University/*P. Millett*
Neural Network Methods for Automation of Steam Generator Eddy-Current Nondestructive Evaluation (RPS530-8)	$65,500 19 months	North Carolina State University/*M. Behravesh*
Thermally Enhanced Eddy-Current Testing (RPS530-9)	$75,700 7 months	Foster-Miller/*M. Behravesh*
PWR Steam Generator Tube Fretting and Fatigue Wear Characteristics (RPS542-1)	$159,900 12 months	Siemens/*G. Srikantiah*
Large-Eddy Simulation of Turbulent Fields in Steam Generators (RPS545-1)	$199,400 24 months	Texas Engineering Experiment Station/*G. Srikantiah*
Plugging Limits for Outside-Diameter Stress Corrosion Cracking at Tube-Support Plate Intersections (RPS550-5)	$437,200 12 months	Westinghouse Electric Corp./*D. Steininger*
Best-Estimate Calculations of Fission-Product Release During a Main Steam Line Break With Steam Generator Tube Leakage (RPS550-11)	$141,600 16 months	Science Applications International Corp./ *D. Steininger*
Relationship of Radiation-Induced Segregation and Microstructural Changes to Irradiation-Assisted Stress Corrosion Cracking (RPX103-30)	$205,000 32 months	Battelle Memorial Institute/ *L. Nelson*

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

Radio-Frequency Drying of Latex Adhesive on Carpet
TR-102546 Final Report (RP2782-5); $200
Contractor: Georgia Institute of Technology
EPRI Project Manager: A. Amarnath

Windows on the Future: Using Scenarios to Envision the Impact of Future Uncertainties on Utility Markets
TR-102567 Final Report (RP2788-67); $200
Contractor: Strategic Decisions Group
EPRI Project Manager: H. Courtright

Drivers of Electricity Growth and the Role of Utility Demand-Side Management
TR-102639 Final Report (RP2863-1); $200
Contractors: Barakat & Chamberlin, Inc.; Regional Economic Research, Inc.
EPRI Project Managers: P. Meagher P. Hummel

A Comparative Demonstration of Alternative Milk Cooling
TR-102686 Final Report (RP2782-4); $200
Contractors: University of Wisconsin, River Falls; National Food & Energy Council, Inc.
EPRI Project Managers: A. Amarnath, O. Zimmerman

Electroconductive (Ohmic) Heating for Continuous Sterilization of Solid-Liquid Food Mixtures
TR-102688 Final Report (RP2782-4); $200
Contractors: Ohio State University Research Foundation; National Food & Energy Council, Inc.
EPRI Project Managers: A. Amarnath, O. Zimmerman

Demand-Side Management Program Evaluation and the EPA Conservation Verification Protocols
TR-103103 Final Report (RP3269-21); $200
Contractor: Quantum Consulting, Inc.
EPRI Project Manager: P. Hummel

ELECTRICAL SYSTEMS

Protective Relay Workstation Applications of Digital Simulator for Protective Relay Studies: System Requirement Specifications
TR-102781 Interim Report (RP3192-1); $5000
Contractor: Texas A&M University
EPRI Project Manager: M. Wilhelm

ENVIRONMENT

Magnetite-Based Magnetoreceptors in Animals: Structural, Behavioral, and Biophysical Studies
TR-102008 Interim Report (RP2965-8); $200
Contractor: California Institute of Technology Division of Geological and Planetary Sciences
EPRI Project Manager: C. Rafferty

Technical and Feasibility Assessment of Combined SO_2/NO_x Processes, Vol. 1: Process Evaluation
TR-102820-V1 Final Report (RP3004-1); $2500
Contractors: Sargent & Lundy; Radian Corp.
EPRI Project Managers: E. Cichanowicz, P. Radcliffe

Dry Sorbent Injection SO_2 Control Technology Review
TR-102866 Final Report (RP982-47); $2000
Contractor: Energy Technology Consultants, Inc.
EPRI Project Manager: R. Rhudy

Proceedings: Tenth Particulate Control Symposium and Fifth International Conference on Electrostatic Precipitation, Vols. 1 and 2
TR-103048-V1, TR-103048-V2 Proceedings; $250 each volume
Contractor: Southern Research Institute
EPRI Project Managers: R. Chang, R. Altman

Investigation of High-Volume Fly Ash Concrete Systems
TR-103151 Final Report (RP3176-6); $200
Contractors: Radian Canada, Inc.; Canada Centre for Mineral and Energy Technology
EPRI Project Manager: D. Golden

Hazard Identification of Commercially Available Biocides to Control Zebra Mussels and Asiatic Clams
TR-103175 Final Report; $200
Contractor: Syracuse Research Corp.
EPRI Project Manager: J. Mattice

Index of Sampling and Analytical Methods for Multimedia Monitoring
TR-103186 Final Report (RP2933-1); $200
Contractor: Radian Corp.
EPRI Project Managers: W. Chow, B. Nott

Small Animal Electric and Magnetic Field Exposure Systems
TR-103194 Final Report (RP2965-3); $200
Contractor: Electric Research and Management, Inc.
EPRI Project Manager: C. Rafferty

PCTRANS: A PC-Based System for Simulating Groundwater Flow and Transport Using EFLOW, ETRANS, and ETUBE Modules—Version 1.0, Computer Code Manual
TR-103201 Computer Code Manual (RP3217-2); $200
Contractor: HydroGeoLogic, Inc.
EPRI Project Manager: D. McIntosh

ROAM™ Version 1.0: Remedial Options Assessment Model—User's Manual and Technical Reference
TR-103202 Interim Report (RP2879-2); $200
Contractor: Tetra Tech, Inc.
EPRI Project Manager: I. Murarka

EPRI Transport (ETRANS) Module for Flow and Transport of Solutes in the Subsurface: Version 1.0, Computer Code Manual
TR-103321 Final Report (RP3217-2); $200
Contractor: HydroGeoLogic, Inc.
EPRI Project Manager: D. McIntosh

The Potential Effects of Climate Change on the Native Vascular Flora of North America: A Preliminary Climate Envelopes Analysis
TR-103330 Final Report (RP3041-3); $200
Contractor: The Nature Conservancy
EPRI Project Manager: L. Pitelka

GENERATION & STORAGE

Cycling Operation of Fossil-Fueled Plants, Vol. 6: Evaluation and Strategy
GS-7219 Final Report (RP1184-36); $2000
Contractor: Daedalus Associates, Inc.
EPRI Project Manager: D. O'Connor

Materials Support for EPRI Fluidized-Bed Combustion Program, Vols. 1 and 2
TR-101804-V1, TR-101804-V2 Final Report (RP979-20); $200 each volume
Contractor: Battelle Columbus Division
EPRI Project Manager: B. Dooley

A Feasibility and Assessment Study for FT4000 Humid Air Turbine (HAT)
TR-102156 Final Report (RP3251-5); $200
Contractors: Fluor Daniel, Inc.; United Technologies, Turbo Power and Marine; Texaco, Inc.
EPRI Project Managers: J. McDaniel, A. Cohn

Carbonate Fuel Cells and Diesels as Distributed Generation Resources: Economic Assessment of Application Case Studies at Oglethorpe Power Corporation
TR-102163 Final Report (RP1677-24); $500
Contractor: Rumla, Inc.
EPRI Project Manager: D. Rastler

Modification and Operation of the EPRI Large-Scale Hot Gas Filter During the Grimethorpe Topping Cycle Experiment, Vols. 1 and 2
TR-102404-V1, TR-102404-V2 Final Report (RP1336-8); $200 for set
Contractor: British Coal Corp.
EPRI Project Manager: R. Brown

Scaling and Lateral Solid Mixing in Circulating Fluidized Beds
TR-102427 Final Report (RP979-21); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: T. Boyd

Assessment of the Benefits of Distributed Fuel Cell Generators in the Service Areas of Central & South West Services, Inc.
TR-102468 Final Report (RP1677-25); $1000
Contractor: Rumla, Inc.
EPRI Project Manager: D. Rastler

Distributed Generation Assessment Guidelines: A Market-Based Framework for Evaluating High-Value Applications—Vol. 1, Executive Summary
TR-102532-V1 Interim Report (RP1677-20); $5000
TR-102532-V2, TR-102532-V3, forthcoming
Contractor: Rumla, Inc.
EPRI Project Manager: D. Rastler

Engineering Development of Selective Agglomeration
TR-102708 Final Report (RP3118); $200
Contractors: Praxis Engineers, Inc.; Southern Electric International, Inc.; Southern Company Services, Inc.
EPRI Project Manager: B. Weber

Concurrent Front End Controller, Vols. 1 and 2
TR-102828 Final Report (RP2922-4); Vols. 1 and 2, $200 each volume
Contractor: Honeywell
EPRI Project Manager: J. Weiss

High-Reliability Condenser Application Study
TR-102922 Final Report (RP1689-14); $200
Contractor: Heat Exchanger Systems, Inc.
EPRI Project Manager: J. Tsou

Applications of Carbonate Fuel Cells to Electric Power Systems
TR-102931 Final Report (RP2221-36, RP1041-33); $500
Contractor: Fluor Daniel, Inc.
EPRI Project Managers: E. Gillis, J. McDaniel

Bus Transfer Criteria for Plant Electric Auxiliary Systems
TR-103185 Final Report (RP2626-1); $200
Contractor: General Electric Co.
EPRI Project Manager: J. Stein

Upgraded Low-Rank Coal User Guidelines
TR-103221 Final Report (RP1895-36); $200
Contractor: CQ Inc.
EPRI Project Manager: B. Weber

Engineering and Economic Evaluation of Integrated Gasification–Compressed-Air Storage With Humidification (IGCASH)
TR-103347 Final Report (RP2834-3); $200
Contractors: Bechtel Group, Inc.; Energy Storage & Power Consultants
EPRI Project Manager: A. Cohn

A "How-to" Primer for Biomass Resource Development
TR-103439 Final Report (RP3407-19); $200
EPRI Project Manager: J. Turnbull

NUCLEAR POWER

Ultrasonic Inspection of Nodular Cast Iron
NP-7522-M Final Report (RP2813-2); $200
NP-7522-SL Final Report; license required
Contractor: ABB Amdata, Inc.
EPRI Project Managers: M. Avioli, R. Williams

Interim On-Site Storage of Low-Level Waste, Vol. 3, Part 2: User's Manual and Lotus Spreadsheet for Estimating LLW Volumes and Activities
TR-100298-V3P2 Final Report (RP3800-3); $200
Contractor: D. W. James and Associates
EPRI Project Manager: C. Hornibrook

Interim On-Site Storage of Low-Level Waste, Vol. 4, Part 3: Waste Container Closures, Seals, and Gas Vents
TR-100298-V4P3 Final Report (RP3800-4); $200
Contractor: J. E. Cline & Associates, Inc.
EPRI Project Manager: C. Hornibrook

Instrumentation and Control (I&C) Maintenance Experience Reference
TR-100856 Final Report (RP2814-73); $7000
Contractor: ERIN Engineering and Research, Inc.
EPRI Project Manager: J. Jenco

The Knowledge-Based Technology Applications Center (KBTAC) Seminar Series, Vol. 2: Introduction to Knowledge-Based Systems for Utility Managers
TR-101740-V2 Final Report (RP3109-1); $200
Contractor: Kaman Sciences Corp.
EPRI Project Manager: C. Lin

Examination of Dissimilar Metal Welds in BWR and PWR Piping Systems
TR-102148 Application Report (RP3232-1); call for price
EPRI Project Manager: J. Lance

Instrument Performance Under Severe Accident Conditions: Ways to Acquire Information From Instrumentation Affected by an Accident
TR-102371 Final Report (RP3183-1); license required
Contractors: Grove Engineering, Inc.; CHAR, Inc.
EPRI Project Managers: S. Oh, J. Chao

Service Water System Repair/Replacement Guidelines: Planning and Implementation
TR-102410 Final Report (RP2939); $200
Contractor: EPRI NDE Center
EPRI Project Manager: W. Childs

Issues Related to the Inter-utility Transfer of Material
TR-102544 Final Report (RP3186); $200
EPRI Project Manager: F. Rosch

Nonstochastic Skin Effects From Discrete Radioactive Particles Emitting High-Energy Spectra Beta Rays
TR-102658 Final Report (RP3099-9); $200
Contractors: Texas A&M University; Battelle Pacific Northwest Laboratories; ENCORE Technical Resources, Inc.
EPRI Project Manager: C. Hornibrook

Prediction of Environmental Crack Growth in Nuclear Power Plant Components, Vols. 1–3
TR-102797 Final Report (RP2006-1, -8); Vols. 1–3, $200 each volume
Contractors: Westinghouse Electric Corp.; Framatome
EPRI Project Manager: J. Gilman

Severe Degradation of BWR Fuel Failures: Coolant Activity Analysis
TR-102799 Interim Report (RP2229-6); $200
Contractor: S. Levy, Inc.
EPRI Project Manager: O. Ozer

Biocidal Treatment for Control of Service Water System Microfouling
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Contractors: Betz Laboratories; Baltimore Gas & Electric Co.
EPRI Project Manager: M. Lapides

Evaluation Procedure for Service Level C and D Upper Shelf Toughness Criteria for Linde 80 Weld Material
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Contractor: Sartrex Corp.
EPRI Project Manager: R. Carter

Review of the Severe Accident Management Guidance Technical Basis Report (EPRI TR-101869)
TR-102867 Final Report (RP3051-1); license required
Contractor: Science Applications International Corp.
EPRI Project Managers: R. Oehlberg, S. Oh

Evaluation of Characterization Methods for Irradiated Waste Components
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Contractor: Sierra Nuclear Corp.
EPRI Project Manager: R. Lambert

ORAM™ User's Manual: Outage Risk Assessment and Management Integrated Software, Version 1.5 (DOS)
TR-102919 Computer Code Manual (RP3114-66; RP3333-10, -13; RP3531-1, -2); license required
Contractors: ERIN Engineering and Research, Inc.; Safety Management Services
EPRI Project Manager: P. Kalra

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TR-103042 Final Report (RPS409-15); $200
Contractor: Pedro Point Technology, Inc.
EPRI Project Manager: P. Millett

GOTHIC Containment Analysis Package, Version 3.4E, Vols. 1–5
TR-103053-V1 Final Report (RP3048-1); $200
TR-103053-V2–V5 Final Report; license required
Contractor: Numerical Applications, Inc.
EPRI Project Managers: A. Singh, M. Merilo, J. Kim

A Resource Guide to Nuclear Plant Life-Cycle Management
TR-103054 Final Report (RP2643-3, -35); $200
Contractor: Grove Engineering, Inc.
EPRI Project Manager: M. Lapides

Effect of Boric Acid on Intergranular Corrosion in Tube Support Plate Crevices
TR-103117 Final Report (RPS407-14); $200
Contractor: Commissariat à L'Energie Atomique
EPRI Project Managers: P. Paine, C. Shoemaker

EPRI MOV Performance Prediction Program: Friction Separate Effects Test Report
TR-103119 Topical Report (RP3433-13); $25,000
Contractor: Battelle
EPRI Project Manager: K. Wolfe

Use of Probabilistic Seismic Hazard Results: General Decision Making, the Charleston Earthquake Issue, and Severe Accident Evaluations
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Contractor: Risk Engineering, Inc.
EPRI Project Manager: C. Stepp

Proceedings: Second International Seminar on Subchannel Analysis
TR-103188 Proceedings; $200
EPRI Project Managers: L. Agee, G. Srikantiah

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Contractor: Anacapa Sciences, Inc.
EPRI Project Manager: J. Yasutake

Proceedings: 1993 EEI/UWASTE-EPRI-USCEA Spent-Fuel Storage Workshop II—Regulatory and Communications Strategies
TR-103253 Proceedings (RP3290-5); $200
Contractor: Energy Resources International, Inc.
EPRI Project Manager: R. Lambert

EPRI MOV Performance Prediction Program: Computation of Flow Fields in Gate Valves
TR-103254 Topical Report (RP3433-7); $10,000
Contractor: Continuum Dynamics, Inc.
EPRI Project Manager: K. Wolf

Hot Cell Examination of Extended Burnup Fuel From Calvert Cliffs-1, Vols. 1 and 2
TR-103302-V1, TR-103302-V2 Final Report (RP2905-2); license required
Contractor: ABB Combustion Engineering—Nuclear Fuel
EPRI Project Manager: O. Ozer

EPRI Guide to Managing Nuclear Utility Protective Clothing Programs: PCEVAL User's Manual
TR-103304 Final Report (RP2414-34); $200
Contractor: Right Angle Industries
EPRI Project Manager: C. Hornibrook

Reference Electrodes for Electrochemical Corrosion Potential Monitoring in PWR Secondary Systems
TR-103311 Final Report (RPS407-41); $200
Contractor: NWT Corp.
EPRI Project Managers: P. Millett, P. Paine

Sourcebook on Ion Exchange for Liquid Radwaste Treatment: Materials, Systems, and Operations
TR-103326 Final Report (RP2414-6); $200
Contractor: Puricons, Inc.
EPRI Project Manager: C. Hornibrook

Proceedings: 1992 EPRI Workshop on PWSCC of Alloy 600 in PWRs
TR-103345 Proceedings (RP3223-1); $1000
Contractor: Dominion Engineering, Inc.
EPRI Project Manager: R. Pathania

Modeling of BWR Water Chemistry and Thermal Hydraulics for Oxidizing Species Concentrations, Vols. 1–5
TR-103366-V1 Interim Report (RP2006-16, RP3133, RP3382-3); $1000
TR-103366-V2 V5, forthcoming
Contractors: Massachusetts Institute of Technology; S. Levy, Inc.
EPRI Project Managers: R. Pathania, B. Sun

MELTSPREAD-1 Computer Code for the Analysis of Transient Spreading and Cooling of High-Temperature Melts: Code Manual
TR-103413 Final Report (RP3047-2); license required
Contractor: Argonne National Laboratory
EPRI Project Managers: R. Sehgal, S. Oh

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Developer: TRAX Corp.
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EA Manager™: SO_2 Compliance and Emission Allowance Strategy Planning
Version 1.0 (PC-DOS)
Developer: Decision Focus, Inc.
EPRI Project Manager: Gordon Hester

FGD-RAM™: FGD Reliability, Availability, and Maintainability
Version 1.2 (PC-DOS)
Developer: ARINC Research Corp.
EPRI Project Manager: Chuck Dene

FOWL-GH™: Fossil Fuel Combustion Waste Leaching Code
Version 2.0 (PC-DOS)
Developer: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: Ishwar Murarka

GOTHIC: Generation of Thermal Hydraulic Information in Containments
Version 3.4E (PC-DOS)
Developer: Numerical Applications, Inc.
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LDAW: Load Data Analysis Workstation
Version 2.1.3 (PC-DOS)
Developer: Quantum Consulting
EPRI Project Manager: Rich Gillman

MANAGES™: Management and Evaluation of Groundwater Monitoring Data
Version 1.0 (PC-DOS)
Developer: Southern Company Services
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Version 1.5 (PC-DOS)
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PCTRANS
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EPRI Project Manager: Dave McIntosh

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Version MOD001 (PC-DOS)
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ROAM: Remedial Options Assessment Model
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EPRI Project Manager: Bill Reuland

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EPRI Project Manager: Rambabu Adapa

VDA™: Valve Diagnostic Advisor
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Rate Design in the 1990s
Phoenix, Arizona
Contact: Phyllis Firebaugh, (214) 556-9545

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NO_x Controls for Utility Boilers
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

12–13
Decision Analysis for Environmental Risk Management
Dallas, Texas
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16–20
Applications of Static Compensators and Other FACTS Power Flow Controllers
Madison, Wisconsin
Contact: Bill Long, (608) 262-2061

17–19
Fluidized-Bed Combustion for Power Generation
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

17–19
6th Predictive Maintenance Conference
Philadelphia, Pennsylvania
Contact: Lori Adams, (415) 855-8763

19–20
Improving Building Systems in Hot and Humid Climates
Arlington, Texas
Contact: Susan Swanson, (409) 862-2291

JUNE

1–2
Customer Value Deployment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

1–2
Workshop on Optimal BWR Iron Removal
Philadelphia, Pennsylvania
Contact: Barbara James or Gary Brobst, (707) 823-5237

1–3
Strategic Asset Management
Newport, Rhode Island
Contact: Angel Barrom, (415) 854-9000

2–3
Integrated DSM/T&D
Lake George, New York
Contact: Phyllis Firebaugh, (214) 556-9545

6–8
ISA POWID/EPRI Controls and Instrumentation Conference
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

27–29
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

29–July 1
Service Water Systems Reliability Improvement
St. Louis, Missouri
Contact: Susan Otto, (704) 547-6072

JULY

10–14
Mercury as a Global Pollutant
Whistler, British Columbia
Contact: Pam Turner, (415) 855-2010

11–13
PWR Secondary Water Chemistry Training and Optimization Workshop
San Antonio, Texas
Contact: Barbara James or Gary Brobst, (707) 823-5237

12–13
Needs-Driven Program Design
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24–26
International Conference on Low-Level Waste
Norfolk, Virginia
Contact: Linda Nelson, (415) 855-2127

26–29
ASME/EPRI Radwaste Workshop
Norfolk, Virginia
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AUGUST

2–4
Direct DSM Marketing
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

3–4
Nuclear Plant Performance Improvement Seminar
Charleston, South Carolina
Contact: Susan Otto, (704) 547-6072

9–12
Nondestructive Evaluation of Fossil Plants
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

17–19
Effects of Coal Quality on Power Plants
Charleston, South Carolina
Contact: Susan Bisetti, (415) 855-7919

24–26
4th International Symposium on Magnetic Bearings
Zurich, Switzerland
Contact: Tom McCloskey, (415) 855-2655

30–September 1
Cooling Towers and Advanced Cooling Systems
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

7–9
4th Conference on Cycle Chemistry in Fossil Plants
Atlanta, Georgia
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7–9
4th International Conference on Rotor Dynamics
Chicago, Illinois
Contact: Tom McCloskey, (415) 855-2655

8–9
Decision Analysis for Environmental Risk Management
Palo Alto, California
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14–15
11th Annual Operational Reactor Safety Engineering and Review Groups Workshop
Dallas, Texas
Contact: Denise O'Toole, (415) 855-2259

14–16
Fossil Plant Cycling
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

19–21
Fuel Supply Seminar
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

OCTOBER

3–6
Pollution Prevention Seminar
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

19–21
13th Conference on Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

24–27
Power Quality Applications, 1994
Amsterdam, Netherlands
Contact: Carrie Koeturius, (510) 525-1205

28
Municipal Wastewater and Energy Conference
New York, New York
Contact: Keith Carns, (314) 935-8598

NOVEMBER

28–December 1
Fuel Cell Seminar
San Diego, California
Contact: Ed Gillis, (415) 855-2542

DECEMBER

5–7
12th International Electric Vehicle Symposium
Anaheim, California
Contact: Pam Turner, (415) 855-2010

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