Custom Power

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ELECTRIC POWER RESEARCH INSTITUTE

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

Editorial Advisor: Brent Barker

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

Please include the code number on your mailing label with correspondence concerning subscriptions.

Cover: Semiconductor switches, such as this gate-turnoff thyristor, are at the heart of power electronic controllers that can substantially improve service quality on distribution systems.

EPRI JOURNAL

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Power Quality Database

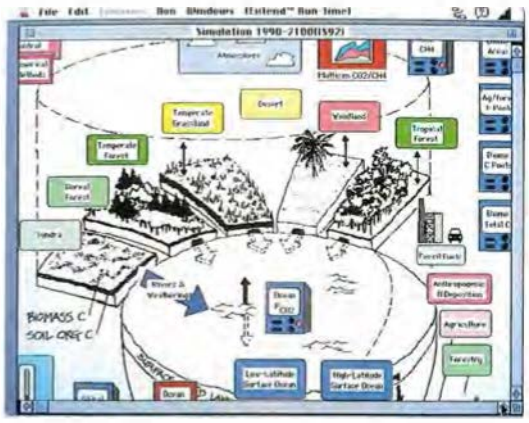
Not only are power quality disturbances an annoyance to utility customers, but they can cost a considerable amount of money in downtime and lost products. A Microsoft Windows–based CD-ROM, EPRI's Power Quality Database helps utility engineers pinpoint the route of a given problem and resolve it swiftly, regardless of whether the problem stems from a utility's distribution system or from the equipment within a customer's facility. PQ Database is a comprehensive resource that contains data from actual customer case studies, from power quality monitoring of utility distribution systems, and from tests of equipment at EPRI's Power Electronics Applications Center. Users can query the software for help in navigating through the data. They can also customize the database by adding information from their own utility.

For more information, contact Sid Bhatt, (415) 855-8751.
To order, call the EPRI Distribution Center, (510) 934-4212.

GLOCO, Version 2.0

Many proposals to mitigate climate change involve altering the global carbon cycle—that is, the movement and storage of carbon among the world's oceans, terrestrial systems, and atmosphere. But predicting the likely effectiveness of various mitigation strategies requires complex modeling that typically must be performed on expensive mainframe computer systems. With the Global Carbon Cycle Model, GLOCO, users can run such simulations on their desktop computers—both Macintosh and IBM-compatible machines. Whether a utility is considering reducing its carbon emissions, sponsoring reforestation, or employing a combination of mitigation strategies, GLOCO's simulations indicate how atmospheric levels of carbon will be affected. This enhanced version contains up-to-date scientific information and computational improvements.

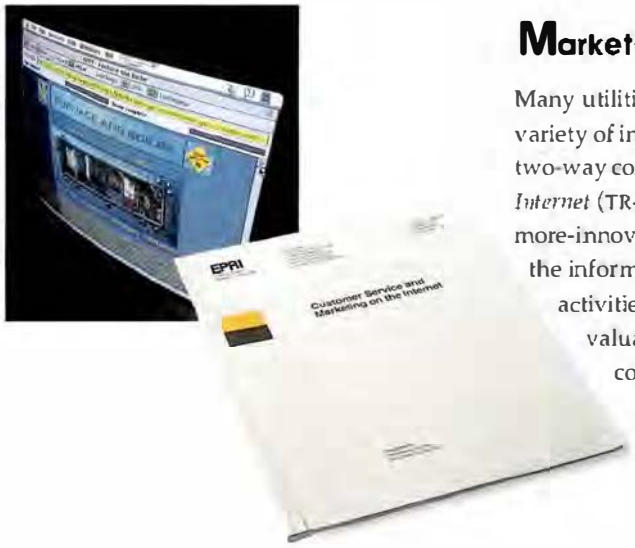
For more information, contact Robert Goldstein, (415) 855-2593.
To order, call the EPRI Distribution Center, (510) 934-4212.



STATCOM

With industry deregulation comes the inevitable need for the transmission network to handle an increasing number of electricity transfers, including significantly more bulk power transactions. How will the existing network manage the extra load? STATCOM, a static synchronous compensator developed jointly by EPRI, the Tennessee Valley Authority, and Westinghouse, is one system designed specifically to help. Employing advanced solid-state electronic switches, STATCOM regulates voltage at subcycle speed—much faster than conventional technologies for voltage regulation. The system provides continuous control, increases transmission capacity, and helps mitigate power disturbances before they reach sensitive customer equipment. What's more, installation and maintenance costs are significantly lower than those associated with conventional equipment; TVA saved $10 million with STATCOM by avoiding the need to install a new transformer bank.

For more information, contact Abdel-Aty Edris, (415) 855-2311. To order, call Westinghouse at (407) 281-2300.



San Diego Gas & Electric (http://www.sdge.com)

Marketing on the Internet

Many utilities have already tapped the Internet as a resource for disseminating a variety of information to their customers. But the Internet's true potential lies in two-way communications. This report, *Customer Service and Marketing on the Internet* (TR-105664), is a good starting point for utilities interested in offering more-innovative on-line services. It explains, in lay terms, how utilities can use the information superhighway for valuable customer service and marketing activities. For example, utilities can use two-way communications to gather valuable market research data, schedule service appointments, and conduct on-line analyses to demonstrate how a new electrotechnology can meet specific needs.

For more information, contact Paul Meagher, (415) 855-2420.
To order, call the EPRI Distribution Center, (510) 934-4212.

Radiation Handbook

Now there is an easily understandable resource covering the health risks of radiation for nuclear power plant workers and their families. *Radiation at Nuclear Power Plants: What Do We Know About Health Risks?* (TR-104630) is simple and concise, with technical terms defined in footnotes. The handbook was designed specifically to answer a variety of questions frequently asked by nuclear plant workers and their families. It is intended to give workers the knowledge they need to make informed decisions about their work. The text includes an explanation of radiation sources, both natural and man-made; facts about occupational radiation exposure; and information on the health effects of such exposure.

For more information, contact Chris Wood, (415) 855-2379.
To order, call the EPRI Distribution Center, (510) 934-4212.

Improving the Diagnosis and Treatment of Electrical Burns

Electrical shock ranks among the most devastating of all injuries: outright electrocution is a leading cause of death in some jobs, while survivors of severe electrical burns may undergo progressive tissue loss and often are unable to return to work. To improve the diagnosis and treatment of electrical burns, EPRI has sponsored research by Dr. Raphael C. Lee and his colleagues at the University of Chicago for several years. Recently, important progress has been achieved on several fronts.

Historically it was believed that the main cause of injury in electrical burns was the heating of tissue by the passage of current. The Chicago team first challenged this assumption by demonstrating that much of the damage resulted instead from the opening and enlargement of pores in cell membranes due to high-intensity electric fields. This process of electroporation allows important ions to flow freely through the membrane, eventually resulting in cell death. A paper presenting evidence that this can occur even in the absence of thermal damage won the 1995 Lindberg Award of the American Burn Association.

These cell membrane micrographs show (from left to right) a healthy surface, damage from pore formation following electrical trauma, and pore sealing after treatment with P-188.

On the basis of this new understanding of electrical burns, Dr. Lee and his colleagues postulated a fundamentally new type of treatment in which a surfactant already used for other medical purposes—Poloxamer 188 (P-188)—is administered to injured tissue to seal the membrane pores. The effectiveness of P-188 in this application has now been confirmed in both cell-culture and animal studies, and the U.S. Food and Drug Administration has given approval to begin clinical trials of the treatment.

An important component of these phase 1 trials, which are expected to begin shortly, will be to monitor the tissue response of electrical burn patients in real time. Such monitoring has been made possible by the development of a small high-resolution camera whose images can track the presence of a gamma-ray-emitting tracer that accumulates in injured tissue. New software has also been developed that permits more-precise, three-dimensional characterization of the injured area on the basis of visual inspection. In addition, enhanced techniques using magnetic resonance imaging are being explored as a way of identifying the extent of tissue damage.

To determine whether P-188 could also be used to treat conventional burns, experiments have been conducted in collaboration with Dr. Mehmet Toner at the Shriners Burns Institute and Massachusetts General Hospital. These cell-culture experiments showed that P-188 does retard ion leakage through thermally injured cell membranes and increases the rate of cell survival observed 24 hours after heat damage. The results of these studies indicate that P-188 can promote both the morphological and the functional viability of cells following heat injury. This information is expected to lead to the development of new therapies for conventional burns and to help in the design of even more effective surfactants for sealing membrane pores.

Another area of concern has been the neuropsychological and psychiatric abnormalities (such as memory loss, attention disorder, and irritability) that have contributed to the inability of some patients to return to work after receiving electrical burns—especially if high voltage and loss of consciousness were involved. In particular, many similarities have been noted between the problems experienced by these patients and the problems of blast victims, leading to speculation that the acoustic shock wave associated with an electrical arc may cause injury to the central nervous system.

On the basis of prior experience with blast injuries and head trauma survivors, the Chicago researchers have used single-photon-emission computed tomography techniques to look for impaired blood flow in the brains of electrical burn patients. They found that the majority of patients studied did in fact show such abnormalities, particularly in the midbrain area, which is related to sensory input, emotion, and long-term memory. This discovery both provides new evidence of a physical cause for the survivors' psychological symptoms and suggests the need for considering blast effects in developing safe electrical work practices.

"These results are very exciting, and we look forward to

Burn-charting software is a state-of-the-art diagnostic tool used at the University of Chicago to calculate the severity of a patient's injury and the percentage of body surface involved.

starting clinical trials as soon as funding permits," says EPRI project manager Ron Wyzga. "We've had a problem getting cofunding from private pharmaceutical companies, however, because P-188 is an 'orphan drug'—that is, a drug that's already available inexpensively for other purposes—which would make it difficult for a company to recoup its research investment. On the other hand, if the program is successful, its entire cost could be recouped through the savings realized by having a single worker return to work six months earlier after an electrical injury. And the added potential for revolutionizing the treatment of conventional burns means that this research could produce very widespread benefits for the public. I foresee the day when, because of this research, first-aid kits will contain new medications for treating both electrical and thermal burns."

■ *For more information, contact Ron Wyzga, (415) 8552577.*

Mercury Emissions From Vegetation

A basic assumption of efforts to reduce mercury pollution in the environment has been that, once deposited on the ground, mercury is unlikely to be reemitted to the atmosphere. This assumption recently received a setback when researchers at Oak Ridge National Laboratory discovered that plants and soils emit mercury into the air at rates that could significantly affect its atmospheric concentration.

Previous EPRI-sponsored research revealed that much of the mercury contamination found in remote lakes and streams results from atmospheric deposition and that the residence time of mercury in the atmosphere is long enough to disperse it far away from any industrial sources. Now, working with EPRI funding, Steven Lindberg and his colleagues at ORNL have measured mercury emissions of up to 100 ng/m^2 over forests and up to 7.5 ng/m^2 over soils. Further work must be done before these figures can be scaled up to calculate the global impact, but they are likely to increase current estimates of terrestrial sources of atmospheric mercury substantially.

The ORNL scientists conducted their original research with plants grown in laboratory chambers and then confirmed their findings through field measurements. Making such measurements had not been possible before the researchers developed a highly sensitive new sampling technique.

"It appears that plants transpire mercury in amounts that depend on the ambient concentration in surrounding air," says EPRI project manager Don Porcella. "That makes estimating the overall impact of these emissions very difficult. This discovery also calls into question the accuracy of current mercury source calculations and atmospheric transport and transformation models."

■ *For more information, contact Don Porcella, (415) 8552723.*

Custom Power: Optimizing Distribution Services

by John Douglas

THE STORY IN BRIEF Power disturbances that once would barely have been noticed may now produce costly malfunctions in critical customer equipment. Fortunately, a new generation of power electronic controllers is becoming available for use on distribution systems, which will enable utilities to provide premium-quality electricity to customers with sensitive loads. The first of these controllers, called Custom Power devices, are now entering utility service, providing a cost-effective alternative to the power-conditioning equipment previously installed on customers' premises. Eventually, the integration of Custom Power controllers with distribution automation equipment will help create distribution systems that are optimized from both the utility's and the customer's point of view.

Power line disturbances—such as voltage spikes, sags, and outages—cost electric utility customers billions of dollars each year. A primary reason is that minor power disruptions, which once would have been noticed only as a momentary flickering of the lights, may now interrupt whole automated factory assembly lines because of sensitive electronic controllers or make all the computer screens in an office go blank at once. Even one cycle of outage or two cycles of a 25% voltage dip can cause unprotected microprocessors to malfunction.

About 90% of outages affecting customers originate on the utility distribution system and are due to causes such as lightning and line faults. As a result, the ability to provide premium-quality power is becoming a distinct competitive advantage as utilities face increasing competition through deregulation of retail markets. Up to now, many customers with sensitive loads have installed their own uninterruptible power supply (UPS) to provide ride-through capability, but these battery-dependent devices are often expensive and energy inefficient, and they require maintenance that may exceed the owner's available in-house resources. Installing a UPS may also be difficult on some customer premises because of severe space constraints or changing facility requirements. In addition, a recent EPRI survey revealed that the majority of industrial and commercial customers would prefer a utility-provided solution to power quality problems.

Most of today's distribution system controller equipment—such as mechanical reclosers, which require six cycles to react to a line fault—is not fast enough to provide the virtually instantaneous switching needed to keep sensitive equipment operating properly. Fortunately, a new generation of power electronic controllers coming into use on distribution systems will enable utilities to provide premium-quality electricity to customers with sensitive loads. Through the use of these Custom Power devices, utilities will be able to provide their customers with a costeffective alternative to installing their own powerconditioning equipment.

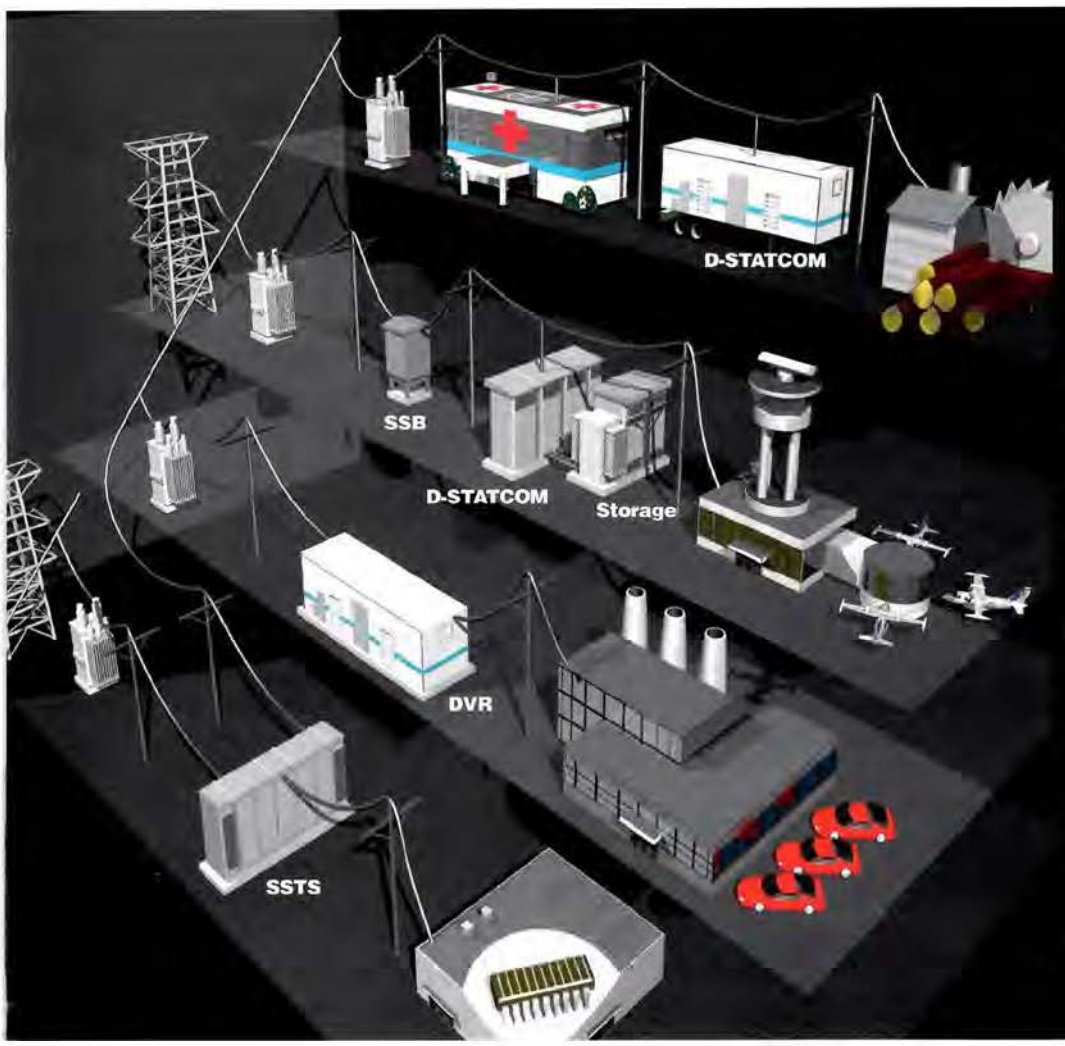
"First, EPRI pioneered the use of power electronic controllers to create the Flexible AC Transmission System, called FACTS, which enables utilities to maximize the use of their present high-voltage networks," says Karl Stahlkopf, EPRI's vice president for power delivery. "Now the cost of power electronics has declined enough for us to begin using such controllers to improve service for individual distribution system customers. With utility demonstrations just getting under way, I would say Custom Power is at about the same stage of development that FACTS reached some five years ago—but I expect even faster market penetration because of pressing demand and the rapid development of the technology involved."

First, the switches

The first Custom Power devices to enter utility service are two basic kinds of distribution system switches. The solid-state breaker (SSB) offers fast isolation of line faults and can be used in conjunction with other Custom Power devices to provide a variety of innovative applications. The solid-state transfer switch (SSTS) provides uninterrupted power to a customer by quickly transferring a load from a faulted feeder to an independent unfaulted feeder. In addition to being much faster than their mechanical counterparts, both of these switches can be used repeatedly with no degradation of performance.

The primary function of the SSB is to interrupt fault currents quickly enough to prevent them from affecting service on adjacent feeders. Since an ordinary thyristor (sometimes called an SCR, for silicon-controlled rectifier) does not have the ability to turn off until the line current goes to zero, a solid-state breaker requires a gate-turnoff thyristor (GTO) in order to stop current flow at subcycle speed. With EPRI sponsorship, Westinghouse Electric Corporation has developed a 13.8-kV SSB that can react to faults in as little as one-quarter

SOLID-STATE BREAKER When a fault occurs on a distribution feeder, conventional circuit breakers cannot react fast enough to prevent fault currents from affecting other lines connected to the same bus. An SSB quickly isolates the faulted line and limits fault current, thus protecting sensitive loads—such as a semiconductor manufacturing plant—on adjacent feeders.



CUSTOM POWER DEVICES **A new generation of power electronic controllers becoming available for use on distribution systems will enhance power delivery.**

A distribution static compensator (D-STATCOM) protects the rest of a distribution system from voltage irregularities caused by a nonlinear load.

A solid-state breaker (SSB) disconnects a feeder in a fraction of a cycle, preventing the spread of power disturbances. Coupling an SSB with a D-STATCOM and energy storage can provide full voltage support to a critical load during outages.

A dynamic voltage restorer (DVR) restores the quality of power delivered to a sensitive load when voltage sags, swells, or transients occur on a feeder.

A solid-state transfer switch (SSTS) provides uninterruptible power to a customer by switching between two independent feeders.

of a cycle, using a combination of SCR and GTO technology. (For background information on thyristor development, see the sidebar on page 12.)

During ordinary operation of this SSB, current flows through the GTO and out onto a distribution feeder. When a fault occurs on the line, the GTO shuts off and the SCR in parallel with it turns on, sending the power through a current-limiting reactor. This action immediately protects other feeders upstream on the distribution system and allows a preset amount of current to continue flowing onto the faulted feeder while protection devices downstream from the SSB attempt to clear the fault. If the fault remains after a specified period of time, usually a few cycles, the SCR also shuts off, isolating the feeder.

Demonstration of the new Westinghouse SSB began in 1995 at Public Service Electric and Gas Company, where it is being tested to control a capacitor bank on a line that serves a customer with a sensitive load. Westinghouse envisions eventually using multiple SSBs to control power flow throughout a Custom Power park, which would offer industrial and commercial tenants enhanced levels of electricity service. A variety of other Custom Power devices would be incorporated as needed. Some of these devices are being developed by SureTech LLC, an R&D alliance formed by EPRI and Westinghouse.

The electronic solid-state transfer switch is designed to replace the mechanical autotransfer gear currently used to switch major industrial and commercial facilities from one feeder to another—a process that typically takes 2 to 10 seconds. An SSTS can also provide large customers with a cost-effective alternative to in-house uninterruptible power supply systems. The first utility demonstration of an SSTS began in September 1995 at Baltimore Gas and Electric Company's Front Street complex, with EPRI participation. This 15-kV-class switch is now being marketed under the trade name PowerDigm by Silicon Power Networks, a partnership between BGE and Silicon Power Corporation, which manufactures both the device and the power semiconductors used in it.

In its simplest configuration, PowerDigm consists of two SCR thyristor switches connected back-to-back, which direct power flow from two feeders to a load. During normal operation, the switch connected to the primary feeder is kept closed and the switch on the secondary feeder is kept open. If a voltage sag or outage occurs on the primary line, the switch for the secondary feeder turns on, immediately forcing the first switch to shut off and transferring the load within a quarter cycle. In the event of a voltage swell or surge, the transfer takes about half a cycle because the primary SCR switch must be allowed time to shut off at the next zero-current point. A more complex configuration of PowerDigm, one that is designed to handle loads larger than about 4 MVA, employs three thyristor switches; these switches normally draw some power from both feeders—transferring the entire load to one feeder

only if a problem develops on the other.

Four additional utility installations of PowerDigm are scheduled to begin over the next year with EPRI funding provided through tailored collaboration, and several more are expected. These commercial units will have a continuous current rating of 600 amperes.

"The availability of solid-state breakers and transfer switches is fundamental to the Custom Power effort," says project manager Dave Richardson. "They are so much faster than their mechanical counterparts that fundamentally new ways can be considered for using them to isolate faults and to prevent most customers on a distribution system from being affected by voltage transients originating on adjacent feeders. I also expect to see more industrial parks use some combination of these switches with dual feeders and other Custom Power devices to offer premium-grade power to customers with critical loads."

DVR: protecting sensitive loads

Another Custom Power device now entering utility service is the dynamic voltage restorer (DVR), a solid-state controller that protects a critical load from power line disturbances other than outages. Connected in series with the primary distribution feeder providing power to a sensitive load, it compensates for momentary voltage sags, swells, transients, and harmonics by exchanging real and reactive power with the line. The first installation of a DVR—a 2-MVA unit manufactured by Westinghouse—is scheduled to take place this year on the Duke Power Company system near Anderson, South Carolina. The unit is being used to provide premium-quality service on a 12-kV line to a highly voltage-sensitive customer. Another installation of a 2-MVA unit is planned for the distribution system of Powercor Australia, Ltd., near Stanhope, Victoria. This DVR will maintain power quality on a 22-kV line that serves a large dairy food processing plant with a 6-MVA load.

SSTS

A DVR consists of a dc-ac power inverter based on insulated gate bipolar transistor (IGBT) technology, which is connected in series to a distribution line through a set of three single-phase injection transformers. When a voltage disturbance occurs on the incoming distribution feeder, the DVR restores the quality of the voltage waveform to the load by injecting a voltage into the feeder that compensates for the problem in real time. The dc side of the inverter is connected to a dc link that provides a regulated dc voltage source, which the IGBT switches convert into a synchronous ac voltage of controllable amplitude, phase angle, and frequency. For example, during a voltage sag, the DVR supplies a compensating voltage in phase with that on the line to make up the difference. When a switching transient somewhere on the distribution system creates harmonics in the line voltage, the DVR can generate complex waveforms in a fraction of a cycle to cancel them out. If desired, the DVR can also limit fault currents by injecting a voltage that leads the line current in phase by 90 degrees, increasing the apparent line impedance.

The Westinghouse DVR is available in ratings from 2 to 10 MVA for installation indoors, outdoors, or in a portable trailer. A rechargeable energy storage system, such as a large capacitor bank or batteries, can

SOLID-STATE TRANSFER SWITCH To protect critical loads from power outages, many customers use a battery-dependent uninterruptible power supply. In some circumstances, a cost-effective alternative is to use an SSTS to switch a load between two independent feeders, as Baltimore Gas and Electric is doing at its headquarters building.

DYNAMIC VOLTAGE RESTORER When voltage disturbances occur on a distribution line, they may cause sensitive electronic equipment to malfunction. A DVR can protect a customer with such equipment—for example, an automobile manufacturing plant.

also be connected to the dc terminal of the DVR to provide additional power to ride through deep sags. The response time to begin voltage regulation is less than 1 millisecond. Even without additional energy storage, a DVR tested at EPRI's Waltz Mill laboratory has demonstrated its ability to restore line voltage during a 25% sag for 5 seconds—a far longer duration than would ordinarily be expected in utility service.

"With EPRI's help, we will be able to increase our customer's productivity as well as increase our value to the customer," says Steven Whisenant, manager of system power quality at Duke Power, speaking of the utility's DVR installation. And Australia's minister for housing and regional development, Brian Howe, sees the DVR demonstration there as part of a long-term effort to improve the productivity of central Victoria's food processing industry. Across the region, he says, "lost production associated with short-term power disturbances is estmated at $10 million a year. If we extrapolate the benefits of DVR across Australia and to many other industries, the savings will be enormous."

D-STATCOM: cleaning up power pollution

A technology that provides a function complementary to that of the DVR is the distribution static compensator (D-STATCOM), which protects the distribution system from power "pollution" caused by the disturbing effects of certain customer loads. In a typical application, it would be placed between the feeder and a heavy, fluctuating load, whose operation would otherwise produce voltage sags, swells, and harmonics that could adversely affect other customers' power quality. For this purpose, the D-STATCOM replaces conventional equipment like load-tap changing transformers, voltage regulators, and switched capacitors. In addition, the D-STATCOM can be used with a solidstate breaker and an energy storage subsystem to support the downstream load during the operation of a feeder breaker or another upstream power interruption.

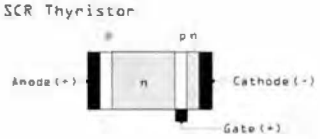
Like the DVR, the D-STATCOM consists of an IGBT-based dc-ac power inverter. In contrast to the DVR, however, the D-STATCOM is connected in shunt (rather than in series) to a distribution feeder through a coupling transformer that matches the inverter ac output voltage to the distribution system voltage. In this configuration, the D-STATCOM exchanges only reactive power with the line and provides voltage regulation and power factor correction to the load by injecting current that is in quadrature with the distribution feeder voltage. If an energy storage subsystem is added, the D-STATCOM can also supply real power to the load once the solidstate breaker has disconnected the load from the feeder during an upstream power disturbance. Harmonic currents required by nonlinear loads can also be provided by the D-STATCOM.

The first D-STATCOM to enter utility ser-

Thyristor Evolution

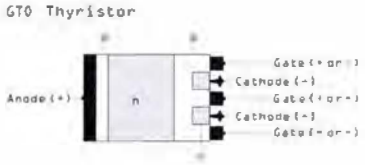
Underlying the development of power electronic controllers for both transmission voltage and distribution voltage applications has been the steady development of thyristor technology. New fabrication techniques have steadily lowered the cost and increased the power-carrying capacity of thyristors. But in addition, fundamentally new designs for these semiconductor switches keep punctuating such gradual evolution with sudden revolutionary bursts of activity. Now, another fundamental change appears to be taking place, which may lead to a new generation of thyristors and further widen the horizon of applications.

By themselves, the large, pure crystals of silicon from which solid-state electronic devices are created do not conduct electricity very well. To make silicon conductive, it is doped with small amounts of other elements, which either give or take away electrons from the crystal lattice. An *n*-type semiconductor has been doped with phosphorus or another element that donates free electrons to the silicon crystal. A *p*-type semiconductor has been doped with boron or some other element that takes electrons away from silicon atoms in the crystal, creating positively charged holes that move through the lattice.



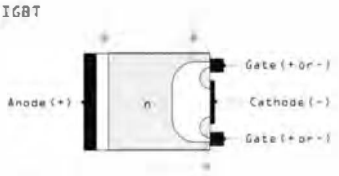
The junction between layers of *n*-type and *p*-type materials will conduct electricity only when the electrons and holes are brought together from opposite sides, as when a positive voltage is applied on the *p*-side of the junction and a negative voltage is applied on the *n*-side. A conventional thyristor (a silicon-controlled rectifier, or SCR) is constructed from four layers of doped silicon in a *p-n-p-n* configuration. An SCR can be turned on at any point in the positive cycle of alternating current by imposing a positive voltage on the embedded *p*-layer (the gate), which forces holes to the junctions between the gate and its neighboring *n*-layers. Once the SCR is conducting, however, it cannot be turned off until the current goes below the holding current—for example at the end of each half cycle, at the current zero crossing.

In a gate-turnoff (GTO) thyristor, current flow is interrupted by rearranging the device configuration so that gate connections are interdigitated between multiple cathodes at one end of the device. Each cathode is connected to a small *n*-region embedded in the adjacent *p*-layer, so that applying a negative voltage to the gate connections draws current away from the cathodes, causing the GTO to turn off. The disadvantage of this design is that it requires a relatively large gate current, resulting in commensurate power loss and heat buildup.

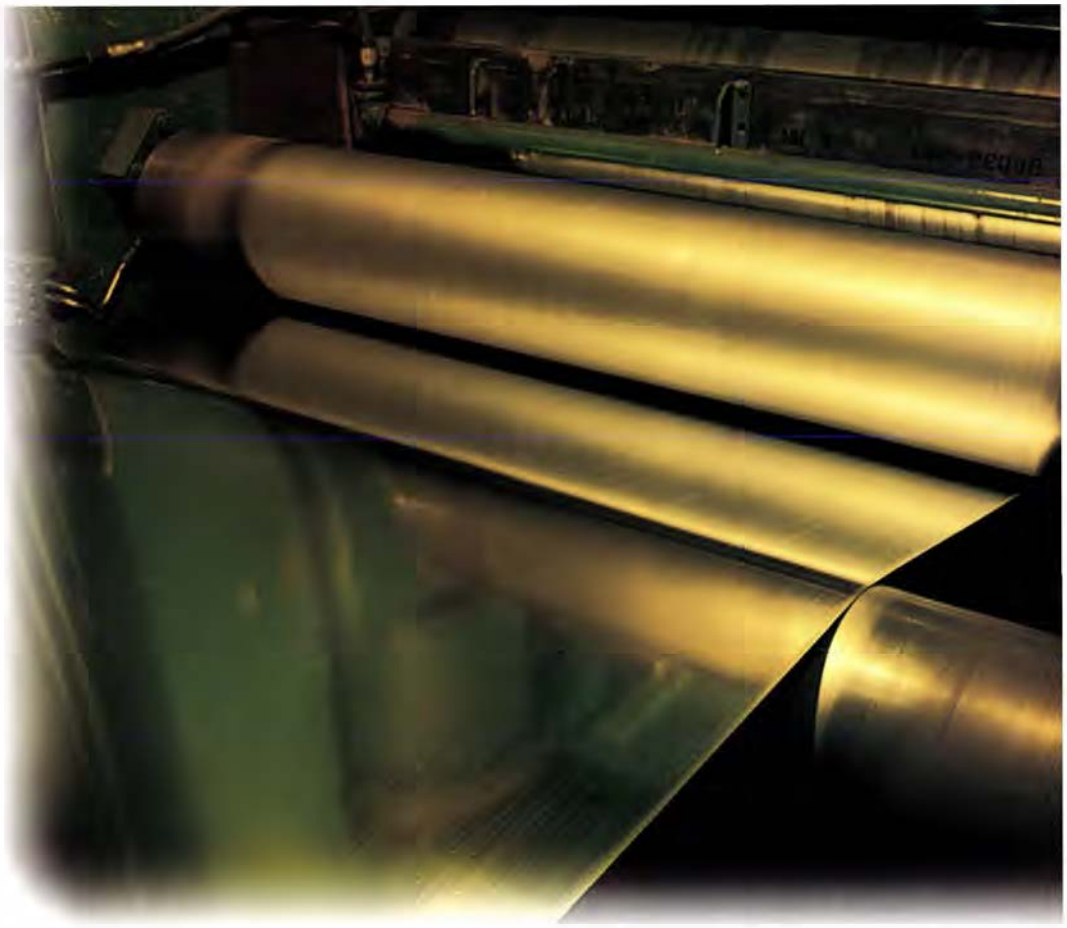


One way to get around this disadvantage is to use an insulated gate bipolar transistor (IGBT). The gate for this device is created from a thin region of metal oxide semiconductor (MOS) material deposited on top of the much larger, three-layer silicon structure below. By applying a positive voltage to this gate, a temporary *n*-channel is created in the top *p*-layer of the transistor, allowing current to begin flowing through the device. Very little current flows through the gate itself, giving the IGBT lower losses than the GTO. However, the three-layer structure of the IGBT does not have the latching capability of a four-layer thyristor, which limits its current-carrying capability and power rating. At present, IGBT stacks are considered to be competitive with GTOs up to capacities of about 10 MVA, which includes Custom Power controllers but not FACTS devices.

For several years, engineers have also been looking for a way to use MOS gates to control high-power thyristors—combining the



rapid response of the IGBT with the superior current-carrying capability of the SCR. At first, attention focused on a design called the MOS-controlled thyristor, which provided the low-power gate for both turnon and turnoff, theoretically giving great flexibility. Recently a new design has been developed that uses a MOS gate for turnoff only, providing greater ease of fabrication. Called the MOS-turnoff (MTO) thyristor, it is expected to replace the GTO because of its low-current gate-turnoff capability and potentially lower cost. EPRI is beginning to sponsor development of an advanced MTO for use in utility power system controllers. □



DISTRIBUTION STATIC COMPENSATOR
Large, nonlinear loads—like those involved in electric steelmaking processes—can cause power surges and harmonics that propagate along a distribution line. A D-STATCOM injects a current at the proper phase angle to compensate for such disturbances before they can affect other customers.

vice will be installed this year at the Adams Lake sawmill of International Forest Products (Interfor) in British Columbia, with EPRI participation. Manufactured by Westinghouse, this ±2-MVAR D-STATCOM will prevent what would otherwise be unacceptable levels of flicker affecting more than 800 other customers along a 30-km, 25-kV distribution feeder of BC Hydro. This Custom Power demonstration was prompted by the installation of a large, whole-log chipper driven by three 400-hp electric motors. In addition to mitigating harmonics generated by the sawmill motor drives, the D-STATCOM will also provide real-time voltage regulation during sags and swells that result from log carriage startup and braking operations. The alternative to this Custom Power solution would have been either to build a new distribution line into the area, at a higher capital cost, or to install diesel drives on the chipper, with a higher operating cost and adverse environmental implications.


D-STATCOM

Westinghouse is now offering the D-STATCOM product commercially as part of its new Custom Power SureSine product line. According to Neil Woodley, marketing manager of Custom Power products for Westinghouse, "These new power electronics-based products promise to change the way power distribution systems are designed and operated to achieve the high power quality demanded by today's sophisticated process customers."

"The demonstrations of DVR and D-STATCOM show that Custom Power offers a cost-effective way to eliminate power quality problems affecting distribution system customers," according to project manager Ashok Sundaram. "Utilities can begin to use these devices now, in their current configurations, and I anticipate that future installations involving the addition of energy storage subsystems will show even more advantages of the Custom Power approach over the use of an uninterruptible power supply on the customer's premises."

IntelliVAr: low-cost compensation

For applications requiring smaller amounts of reactive power compensation (i.e., in the range of −50 to +750 kVAR), a low-cost product has been developed under the sponsorship of EPRI and the National Rural Electric Cooperative Association (NRECA). A typical use would be to provide voltage support or power factor correction on the long, heavily loaded distribution lines that are common in many rural areas. This advanced static VAR compensator is small enough to be mounted on a utility pole and can be shunt-connected directly to a distribution line without the need for a coupling transformer. It is manufactured under the trade name IntelliVAr by Power Quality Systems, Inc.

IntelliVAr is designed to mitigate frequent, nonoutage power line disturbances that typically last a few cycles and are not amenable to correction by ordinary capacitor banks. The compensator responds to changing load conditions within a single cycle. Conventional thyristors are used to control internal capacitors and reactors for continuously variable compensation in either a voltage regulation mode or a power factor correction mode. A data link is provided to allow changing of control set points and remote selection of operating mode.

Next Steps

In addition to the Custom Power controllers now entering utility service, two other devices currently under development are scheduled for demonstration over the next few years. The transportable battery energy storage system (TBESS) will contribute to power quality while adding new distributed resource capabilities. The pole-mounted dynamic voltage restorer (PM-DVR) will open up new opportunities for applying voltage sag mitigation technology to utility distribution systems.

During previous EPRI-sponsored work at Southern California Edison Company's Chino battery energy storage facility, researchers found that in addition to supplying on-peak service with energy stored off-peak, battery plants offer dynamic operating benefits. They can provide spinning reserve, emergency VAR supply, and power quality improvements through fast response to changing load conditions or voltage irregularities. Such advantages would be multiplied if battery plants could be transported easily to locations experiencing rapid load growth or power quality problems.

In response to this need, EPRI has collaborated with the U.S. Department of Energy in a program to produce the TBESS—a battery plant composed of modules that can be transported on flatbed trailers. The full TBESS is rated at 1–2 MW and has a 1-hour discharge capability and a ramp rate of less than 4 milliseconds. Individual modules have ratings of 125–250 kW, with a maximum footprint of only 700 square feet. The aim of the joint EPRI-DOE project is to accelerate the commercialization of such transportable battery systems and to determine their potential benefits.

The first installation of a TBESS is scheduled for June 1997 on the distribution system of the Salt River Project, and EPRI is seeking host utilities for additional units. The TBESS is expected to have a mature cost of about $500/kW, with a payback period of about two years, assuming a 1¢/kWh premium for power quality improvements for customers with sensitive loads. In areas of modest load growth, where use of the TBESS could enable a utility to defer building new distribution facilities, additional cost deferral and operating benefits of about $75/kW annually would be expected.

Creating a dynamic voltage restorer that could be mounted on a utility pole head would greatly increase the opportunities to use this promising technology for selective feeder power quality improvement. In addition to offering premium power quality service to customers, the PM-DVR may enable some utilities to defer capital expenses for capacity expansion—for example, the cost of reconductoring at $25,000 per mile.

The development of a PM-DVR by Westinghouse Electric Corporation is just getting under way, with delivery of the first prototype to a host utility scheduled for 1998. The first PM-DVR is expected to have a rating of 300 kVA, for use on a 15-kV-class distribution system. Its primary function will be to protect sensitive customer loads from voltage sags, transients, and harmonics; its response time will be one-half cycle or less. Although the PM-DVR will be based on technology already proven in other Custom Power devices, considerable development work will be needed to meet the weight, size, cost, and environmental constraints of pole mounting. □

Utility demonstration of IntelliVAr is scheduled to begin in mid-1996 at Oglethorpe Power Company, in Georgia, under EPRI-NRECA sponsorship. The compensator will be used to mitigate flicker caused by a sawmill.

"The key reason NRECA wished to develop an advanced static VAR compensator with EPRI was to have a cost-effective way of compensating long, single-phase rural feeders with heavy-duty motors connected to them," according to Martin Gordon, the association's senior program manager for energy R&D. "We are pleased with the way IntelliVAr achieves this. It can be mounted on a pole and connected for either single-phase or three-phase function. It is also virtually maintenance free and easy to install, and it has an autostart system that requires no human intervention."

Toward distribution optimization

Ultimately, the success of any new distribution system technology will be determined by how well its application is integrated with a utility's business strategy to reduce overall costs and increase customer satisfaction. The term now frequently used to describe such broad technological integration is *distribution optimization*, as distinguished from the more narrow concept of distribution automation. In the next few years, Custom Power technology is likely to play a major role in facilitating the system productivity improvements and service enhancements needed for distribution optimization.

Traditionally, distribution automation has referred to the application of new technologies to convert existing control functions—such as feeder deployment switching and load balancing—to automatic operation. For example, improved system monitoring and remote control capability can be used to reconfigure distribution circuits in real time to balance load throughout a system and thus make the best use of available capacity. By contrast, distribution optimization inherently involves integrating a wider range of technologies and developing fundamentally new strategies for their use.

IntelliVAr

Consider, for example, how a utility might optimize its response to the problem of outages caused by summer storms. Today, the first notification of such an outage often comes as a phone call from a customer. A "trouble truck" may then be sent out to the general area of the outage to locate its cause and assess damage. Finally, performing the actual repairs may necessitate the dispatch of a more fully equipped maintenance crew.

A far more efficient, cost-effective response could be mounted by combining several new technologies. Even before the storm hits a utility's service territory, maintenance personnel can watch its approach by means of EPRI's National Lightning Detection Network, satellite imaging technologies, and next-generation weather radar. With this information, feeders can be resectionalized remotely, control equipment settings can be readjusted, and repair crews can be dispatched in anticipation of likely damage. Then, as lightning strikes and wind-related faults begin to occur, Custom Power devices can provide a virtually instantaneous response to protect sensitive customers and limit the spread of disturbances through the network. This response would be even more effective if the Custom Power devices were also used to control energy storage systems or dispersed generation units—such as small combustion turbines or solar photovoltaic units—to supply power to a distribution system "island" of critical customers. Advanced monitoring, fault detection, and communications technologies also play a key role in facilitating this optimized reaction to a common utility problem.

"For years the industry has dabbled with technologies to automate individual functions of the power distribution system, with only incremental success," declares Wade Malcolm, director of EPRI's Distribution Business Unit. "Now, this concept of localized automation has evolved into a much more inclusive approach to optimizing the whole distribution system by integrating multiple technologies and keeping the customer's needs foremost in mind. The Custom Power controllers now under development are critical to this effort because of their ability to create new options for meeting customer needs in a newly competitive industry." ■

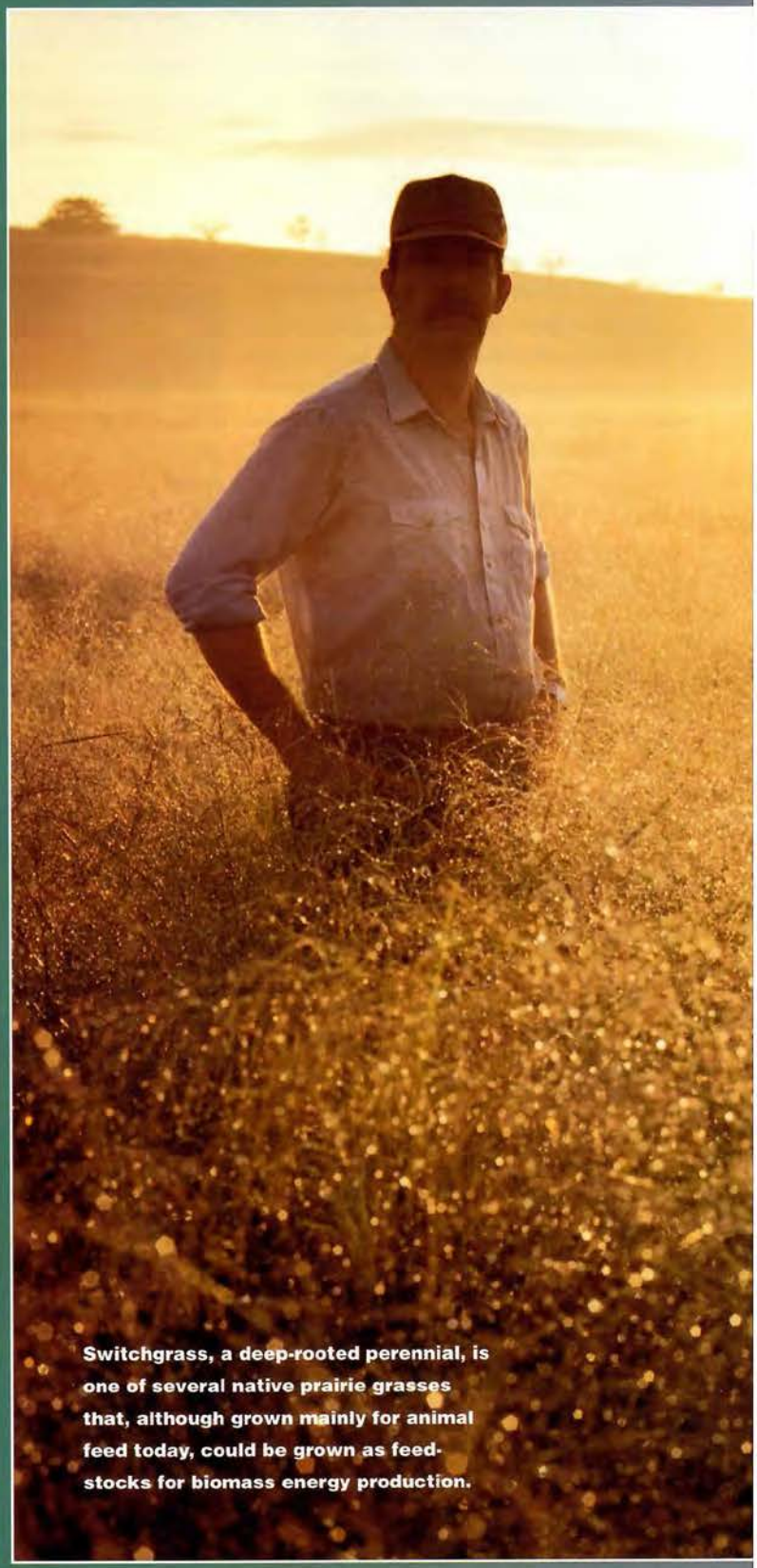
INTELLIVAR A frequent problem on long rural feeders is the occurrence of nonoutage voltage disturbances that are not amenable to correction by ordinary capacitor banks. IntelliVAr can mitigate such disturbances caused by end-of-feeder loads like sawmills.

Background information for this article was provided by Wade Malcolm, Ashok Sundaram, and David Richardson of the Power Delivery Group's Distribution Business Unit.

Harvesting the

by Taylor Moore

THE STORY IN BRIEF More than half a dozen electric utilities are involved in ongoing efforts to evaluate and develop the potential for biomass feedstocks—including wood, wood waste, and various herbaceous crops like alfalfa—as a renewable energy resource for power generation. The growing interest in biomass power stems from its promise for addressing emerging concerns on several fronts. For example, low-cost waste biomass available from customers can be used as a supplemental fuel in existing fossil power plants, reducing fuel costs and pollutant emissions. Significant use of biofuels could also help utilities forge closer relationships with customers that produce agricultural or wood products. For the longer term, biomass-fueled generating systems promise an effective and economically feasible approach to reducing the contribution of fossil-fuel-based generation to emissions of the greenhouse gas carbon dioxide.



Switchgrass, a deep-rooted perennial, is one of several native prairie grasses that, although grown mainly for animal feed today, could be grown as feedstocks for biomass energy production.

Wayne Gretz, NREL

Benefits of Biomass

Green plants are a natural storage medium for solar energy, absorbing it as they convert nutrients and water into food for people, feed for animals, and fiber. America's farmers, among the most productive in the world, are also harvesting solar energy from plants for its value as fuel. Some grow soybeans that are used to produce so-called biodiesel, which in turn fuels farm machinery. About 5% of the country's corn crop is currently converted into about a billion gallons a year of ethanol, used as an additive to make gasoline cleaner burning. Both on and off the farm, the homes of some 2 million Americans are heated with wood.

In the not-too-distant future, electric utilities conceivably could obtain a significant fraction of the carbon-based fuel required for power generation from renewable energy crops, thereby decreasing the use of such nonrenewable fossil carbon fuels as coal and gas. Crops like fast-growing trees and grasses could even become a major renewable energy resource for electricity generation, according to EPRI experts. Enough wood waste and agricultural residues to fuel as much as 10,000 MW of generating capacity are already available. And with large-scale production of dedicated biomass feedstocks on currently underused farmland, the potential exists for plant material to fuel more than 50,000 MW of generating capacity over the next two to three decades, EPRI experts estimate.

Biomass today accounts for about 3.2% of total U.S. energy production, mostly athermal energy produced from wood and wood waste and used directly by the pulp and paper industry. "We get almost as much total energy from biomass as we do from hydroelectric dams," notes Jim Birk, manager of EPRI's Renewables & Hydro Business Unit. The amount of grid-connected generating capacity fueled by biomass feedstocks—most of which is operated by lumber mills, wood processors, and pulp and paper companies at some 1000 locations—has grown from 200 MW to over 7000 MW in the past decade and a half, largely as a result of incentives enacted with the 1978 Public Utility Regulatory Policies Act.

If perennial herbaceous and woody crops were grown as dedicated biomass energy feedstocks, the potential fraction of total energy demand—including demand for transportation fuel and for electricity generation—that could be met by biomass might be 10 times greater, experts believe. "There is potential over the long term for a large amount of biomass to fuel a substantial fraction of total generating capacity," says Evan Hughes, EPRI's team leader for biomass power in the Generation Group. "But to get there, you have to grow energy crops to have enough biomass feedstock available."

Jane Turnbull, EPRI's manager for biomass resources, notes, "The development of biomass energy production on a large scale will result in a major shift in land use throughout rural America, with significant socioeconomic implications and environmental effects. Moreover, the large-scale use of biomass in integrated systems will depend on the establishment of reliable infrastructures that link the production of feedstock with its use in power generation."

Pilot projects involving thousands of acres of plantings as biomass feedstocks for either existing or new generating fa-

cilities are being evaluated with support from the U.S. Department of Energy, the U.S. Department of Agriculture, and EPRI. Studies of proposed projects are helping to define the characteristics of biomass production systems and related infrastructures in various regions of the country, identify ways to reduce costs, and validate principles of landscape ecology and agricultural economics as promoted by the National Biofuels Roundtable, a group that EPRI helped form.

Benefits of biomass

The production of crops for energy on a significant scale could help revitalize many parts of rural America by attracting energy industries. Since transporting crops is expensive, biomass power plants and fuel companies are likely to be located within 50 miles of where feedstocks are grown, bringing new jobs as well as the economic benefit of increased agricultural production. Biomass-fueled generating capacity totaling 50,000 MW could represent a new agricultural market worth as much as $12 billion a year in U.S. farm-sector income.

But if even a fraction of the potential for biomass energy production is to be realized, the unique economics of energy crops for power generation must be better understood and strategically developed in order to compete with cheap, abundant, and naturally occurring fossil fuels.

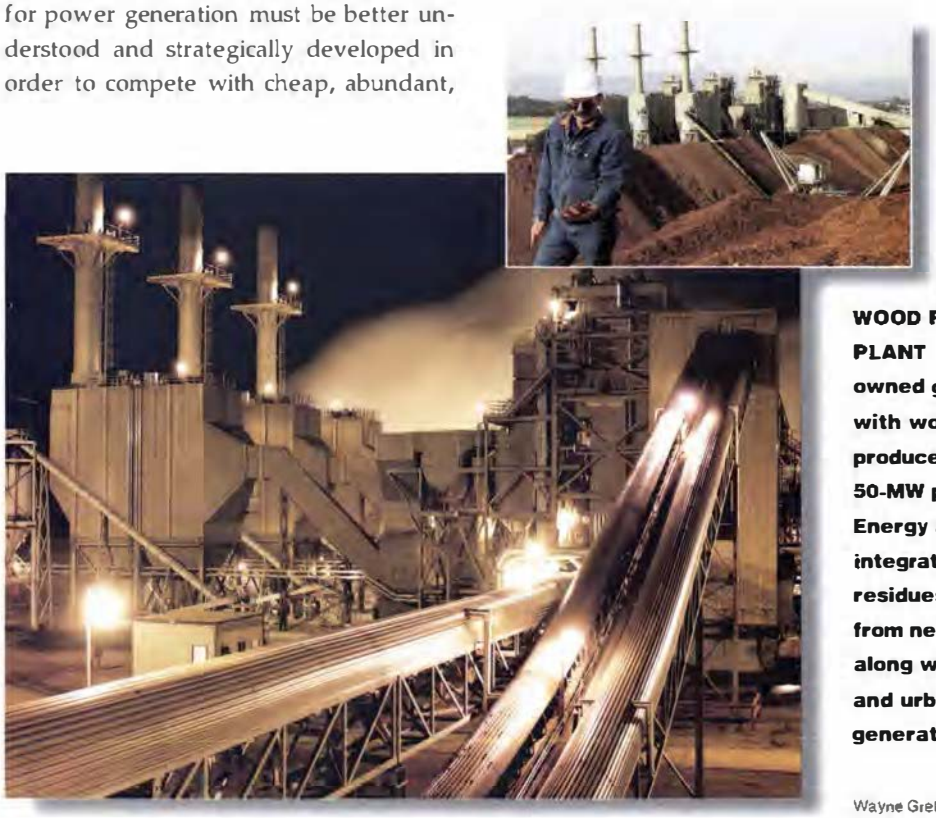
Evaluated strictly as a fuel for generating electricity, biomass is more costly than fossil fuels. Moreover, few utilities currently need additional baseload generating capacity (which is how most biomass facilities would operate). Some utilities have even opted to leave to other companies the building of such capacity when it is needed, limiting the near-term market for new plants fueled by biomass.

With biomass, however, the economics of agricultural production and waste disposal intersect with the economics of power generation. As Birk notes, "The current interest that some major utilities have in biomass and their vision for it in the longer term go beyond a simple picture of using biomass for fuel. Biomass can offer near-term business advantages as well as more-strategic, long-term value. The coproducts and other benefits, such as emissions offsets, waste reduction, and local economic growth, that can accrue from biomass projects are key elements in their overall appeal to utilities."

Unlike some renewables-based generating systems (e.g., solar photovoltaics) that require costly advanced technology, biomass fuels can be used to generate electricity with the same type of equipment and power plants that now burn fossil fuels. Thus, there is an opportunity for the phased introduction of biomass into the mix of utility generating resources, at first as a supplemental fuel in existing fossil power plants and eventually in advanced generating systems optimized to run perhaps entirely on biomass fuel.

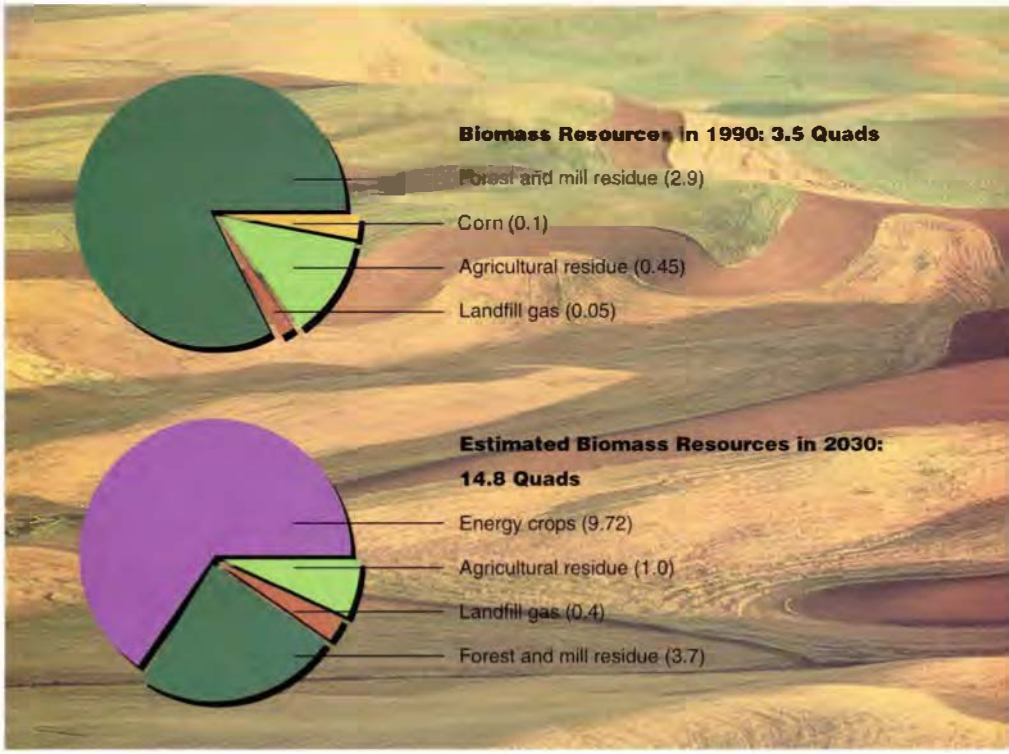
Even at a time when low-cost, natural-gas-fired combined-cycle generation poses seemingly unbeatable cost competition among sources of electricity generation, biomass power is enjoying a wave of interest among some electric utilities. This is happening because, although biomass-fired electricity generation is currently uneconomic, in some cases it is only marginally so. The value of coproducts like animal feed, ethanol, and pulp—and the potential ancillary benefits of biomass use, including its value as a local waste disposal solution, as a catalyst for economic development, and in maintaining customer satisfaction—can make specific biomass projects economically attractive.

"Waste disposal is often a problem for utility customers, so some utilities have investigated using biomass fuel as a customer service," notes Turnbull. "If the waste is solid, rather than the customer's having to truck it to a municipal landfill and pay the disposal costs, the utility will combust it, offsetting the cost of that heat content from coal. If the waste is liquid, it may be



WOOD FUELS CALIFORNIA POWER PLANT **In addition to a few utility-owned generating plants that are fueled with wood, some independent power producers are using wood biomass. The 50-MW plant of Wheelabrator Shasta Energy at Anderson, California, is an integrated operation that uses logging residues, tree chips, and mill wastes from nearby forest products companies, along with some agricultural prunings and urban wastes, to fire three steam generating units.**

Wayne Gretz, NREL



CROPS COULD PROVIDE BIGGER SLICE OF BIOMASS ENERGY **Most of the energy obtained from biomass today is in the form of thermal energy and is used directly by the pulp and paper industry. In addition, about 5% of the nation's corn crop is converted into ethanol, which is used as a gasoline additive. But according to the National Biofuels Roundtable, the percentage of total energy supply obtained from biomass resources could be increased substantially if crops like alfalfa and switchgrass and fast-growing trees like willows were grown as dedicated biomass feedstocks. The roundtable's projection of potential biomass use by 2030 assumes energy crop production on 30 million to 81 million hectares (74 million to 200 million acres).**

used to irrigate and fertilize energy crops being grown nearby. Often a waste problem can be turned into a win-win-win scenario for a utility, its customers, and the community." (This applies to municipal and industrial wastes as well, and EPRI is working with several utilities that are cofiring some of these nonbiomass wastes.)

The key near-term utility benefits of using biomass fuels as a supplement for cofiring in existing boilers are that they produce negligible emissions of sulfur oxides and may yield a greater-than-proportional (by energy content) reduction in emissions of nitrogen oxides. These results are now being confirmed in a series of EPRI-supported tests with several utilities.

Building on a decade of R&D interest

Reflecting the interest of member utilities in biomass power, EPRI has been involved in various assessments and studies of wood-fired generating systems and other biomass energy technologies for more than a decade. The Institute expanded its research thrust in 1989, undertaking a survey of biomass fuels and technologies as well as tests (in the Dakotas, Minnesota, and Wisconsin) of growing hybrid poplar trees as energy crops. In 1992, EPRI joined the Tennessee Valley Authority in a major systematic engineering and economic evaluation of biomass and waste fuels; this effort has evolved into a test program for cofiring wood and wood wastes and now involves several utilities.

Also in the early nineties, a systematic biomass resource assessment was launched to examine the overall potential for energy crops as dedicated feedstocks and to assess the associated environmental impacts and social and economic benefits. As part of this effort, EPRI and the National Audubon Society collaborated, with support from DOE, in establishing the National Biofuels Roundtable in 1992 to help build consensus on guiding the development of a sustainable biomass energy resource. According to the roundtable, a transition to a more sustainable energy economy that includes the development of domestic biomass energy resources would reduce both the risks of dependence on fossil fuels and the potential risks associated with global climate change related to increasing fossil fuel combustion.

The roundtable says that energy crops offer great promise for providing fuels both for transportation and for generating electricity. Moreover, environmental damage from energy crop production can be avoided if such crops are included in the general mix of agricultural production in an informed manner. In fact, according to the roundtable, significant environmental and ecological benefits could accrue from the development of a fully sustainable biomass energy resource. These include improved wildlife habitat, maintenance of biodiversity, improved soil qualities, and reduced erosion. On the other hand, the large-scale conversion of forests, grasslands, and wetlands to new energy crop production could have negative impacts if not thoughtfully managed.

The roundtable has found that there is plenty of idle or underused cropland available to support increased biomass feedstock production. Much of the more than 14 million hectares (35 million acres) of cropland set aside under the U.S. Department of Agriculture's Conservation Reserve Program could be suitable and could be made available for energy crops. And the USDA's projections for the year 2030 suggest that a total of 30 million to 81 million hectares (74 million to 200 million acres) of land in this country could be used to produce energy crops.

EPRI's projection of a potential 50,000 MW of biomass-fueled generating capacity assumes the use of at least 20 million hectares (49 million acres) of cropland, yielding at least 12 dry tons of biomass per hectare (about 5 tons per acre) per year. The projected production costs for this biomass would be close to the upper range of recent natural gas prices, provided that its

higher-value coproducts can be marketed. The assumed yields, although not yet obtained with all types of biomass, are already being exceeded with certain crops in some regions.

There appears to be wide agreement that yields for key crops of interest as biomass feedstocks could be increased significantly. EPRI is taking a leadership role in sponsoring research aimed at improving productivity and lowering costs for energy crops and at improving scientific understanding of the potential environmental and ecological consequences of using them, notes Turnbull. Recent studies cofunded with the U.S. Forest Service and the forest industry indicate that the measurement of leaf respiration efficiency makes it possible to select and clonally propagate various species of trees to achieve yields three times greater than those of conventionally selected species. In a current EPRI project, researchers are learning how to genetically engineer certain poplar species to make them resistant to pests.

Taking a close look at cofiring

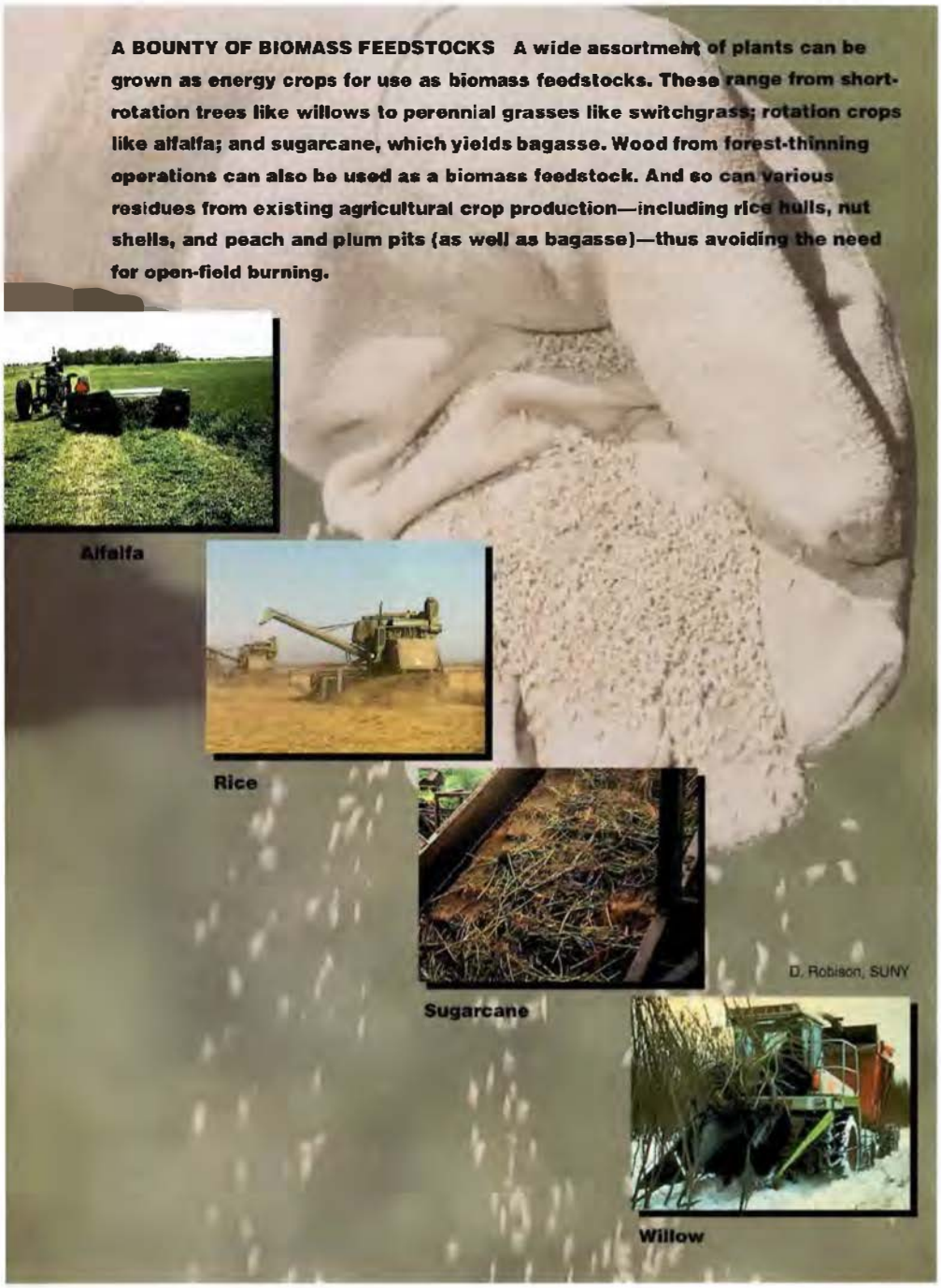
The utility use of biomass resources that has the best near-term prospects is the cofiring of wood wastes or agricultural residues in existing coal-fired power plants. Particularly suitable for this application are cyclone boilers, which require minimal modifications for feeding and mixing the biomass fuel with coal. In addition, there are cofiring opportunities with very old stoker boilers. New York State Electric & Gas Corporation has cofired waste wood and other alternative fuels at two of its stoker plants for nearly a decade. Two small (15-MW) stoker units of Northern States Power Company have been cofired with up to 200,000 tons of wood a year, making it the main fuel at these units.

In recent years, EPRI has cosponsored extensive studies of wood cofiring at TVA power plants. Results from these studies and other utility cofiring experiences, compiled for EPRI by Foster Wheeler Environmental, address such issues as fuel chemistry and the size and dryness of particles that can be cofired in cyclone and pulverized-coal (PC) boilers. The results cover sampling and analysis of more than 50 sources of wood in the TVA area, cold flow tests and storage tests, and full-scale combustion tests at TVA power plants, including a series of test runs in a 250-MW cyclone boiler. The maximum biomass fraction cofired was 20% by mass (9% by heat content).

Do the test results indicate good reason to cofire biomass or waste fuels? "That depends on the motivating factors, a utility's wood supply-cost curve, and the specific power plant being considered," says EPRI's Hughes. "Cofiring options offer very low capital costs—$100 to $200 per kilowatt generated from the cofired wood—compared with the cost of building new capacity that is dedicated to firing wood. Cofiring costs may be even lower for cyclone boilers if the fuel is already in small particles and is not too wet, preferably having a moisture content well below the 45–50% typical of green wood."

Continues Hughes, "If such fuel can be delivered to the power plant at a price that is 25–40¢ per million Btu [approximately per gigajoule] below the price of coal, the fuel savings plus a minor credit for offsetting sulfur dioxide emissions can be enough to cover the capital cost and

Wayne Gretz, NREL



A BOUNTY OF BIOMASS FEEDSTOCKS **A wide assortment of plants can be grown as energy crops for use as biomass feedstocks. These range from short-rotation trees like willows to perennial grasses like switchgrass; rotation crops like alfalfa; and sugarcane, which yields bagasse. Wood from forest-thinning operations can also be used as a biomass feedstock. And so can various residues from existing agricultural crop production—including rice hulls, nut shells, and peach and plum pits (as well as bagasse)—thus avoiding the need for open-field burning.**

PLANTING PROFITS DOWN ON THE FIBER FARM **In DOE-sponsored work over the past 15 years, Oak Ridge National Laboratory researchers have tested more than 100 species of trees to identify those best suited for use as energy crops. Today, tree farms using agricultural production methods yield three to eight times as much wood per acre as do natural forests. An example of such an operation is the James River Corporation's Lower Columbia Fiber Farm in Oregon, where hardwood trees are grown for pulp and paper production. Over the next 15 years, improved breeding and genetic engineering could make it possible to boost biomass yields from tree farms by an additional 50%.**

Wayne Gretz, NREL

Disease- and pest-resistant hybrid cottonwoods are bred in a nursery.

At the Lower Columbia Fiber Farm, a feller-buncher harvesting machine cuts trees and lays them in bunches for later chipping.

break even. When combined with other motivating factors, such as helping customers with a waste disposal problem or preempting potential competitors from using the waste as generating fuel, there can be good reason to cofire wood in low-cost situations."

EPRI studies confirm that the lowest-cost opportunities are to use cyclone boilers to cofire wood in the range of 1–10% (possibly as high as 15%) by heat content and to use PC boilers to cofire wood at low levels, in the range of 1–3% by heat. Cofiring at higher levels in PC boilers can entail not only higher costs for biomass fuel preparation, especially if the fuel must be dried, but the added cost of a separate feed system to deliver wood to the boiler. Among newer coal-fired power plants, fluidized-bed units are designed with the flexibility to fire biomass and waste fuels. Cofiring biomass in these units entails some additional costs for biomass storage, handling, and feeding systems.

An intriguing prospective benefit of biomass cofiring is the possible reduction of NO_x emissions at coal-fired plants. Wood contains less fuel nitrogen than coal does, and the moisture in wood serves to cool the coal combustion process, reducing the formation of thermal NO_x. Laboratory tests suggest that cofiring wood as a reburn fuel—downstream from the primary combustion zone—actually destroys thermal NO_x. If this approach proves feasible for reducing the cost of NO_x emissions control at existing cyclone or PC boilers, the cost savings may be several times the fuel savings from biomass cofiring, bringing the overall cost to well below the break-even point.

In laboratory combustion tests conducted for EPRI and DOE at the University of Utah, wood performed as well as natural gas and coal as a reburn fuel. The results suggest that a wood reburn system in a full-size cyclone boiler might reduce NO_x by 50%; reductions of 30–40% might be possible in a full-size PC boiler. EPRI and DOE are now interpreting the test results. TVA and EPRI, meanwhile, are using computer modeling to investigate whether a cyclone boiler can be equipped with a wood injection system that can mix the reburn fuel well enough to achieve NO_x reductions like those observed in the laboratory tests.

"Even if it pans out that wood reburn gives substantial NO_x reduction, whether such an approach really saves money will depend on a case-by-case assessment and on what else might have to be done at a plant to control NO_x," says Hughes. "If using wood as a reburn fuel lets you avoid other capital expense for NO_x control, it could be a big winner."

Exploring integrated biomass systems

Some utilities are taking preliminary steps beyond simple cofiring of waste biomass in existing power plants. They are exploring in greater depth the economics and engineering of integrated biomass power systems specifically designed to use a dedicated feedstock grown as an energy crop. A key feature envisioned for these integrated systems is the reduction of fuel costs, either by obtaining some valuable coproduct or other benefit from the primary crops or by blending the crops with some other readily available and economical waste biomass.

Some two dozen proposals for project feasibility studies aimed at demonstrating integrated biomass power systems were made by utilities and other companies in 1993 in response to a DOE solicitation. Ten were selected by DOE for cofunding. EPRI collaborated with DOE's National Renewable Energy Laboratory (NREL) in reviewing the proposals and in cofunding feasibility studies for the six projects that involved member utilities (see sidebar). EPRI staff worked with the project teams as their priorities and approaches evolved over the past couple of years. Three or four of the 10 proposals that were originally selected may receive additional DOE cofunding this spring to advance to detailed design and permitting.

Studies Highlight Variety of Feedstocks and Technologies

The half dozen recent biomass project feasibility studies in which EPRI was involved span quite a range of biology, geography, and technology.

A project in Iowa would make low-cost boiler modifications to IES Utilities' 726-MW coal-fired Ottumwa power plant to convert about 5% of its capacity to the cofiring of switchgrass and other forage crops. Between 12,000 and 16,000 hectares (30,000 and 40,000 acres) would be used to grow the perennial, deep-rooted switchgrass.

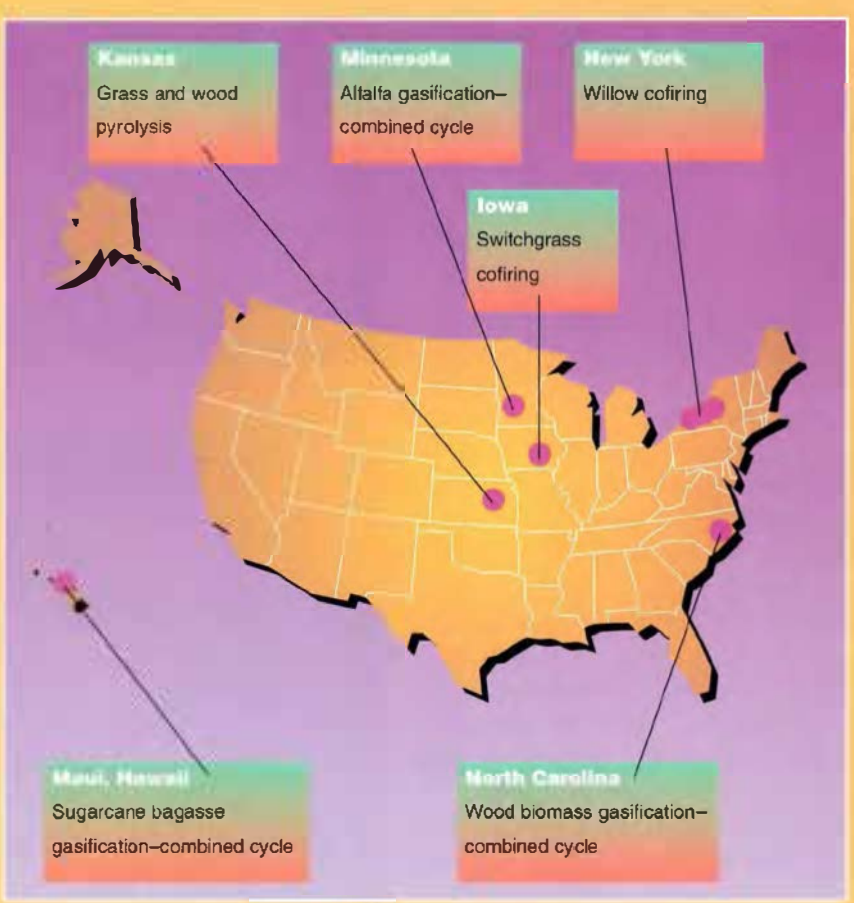
In western New York, biomass resources within a 50-mile radius of each of four power plants were evaluated for the potential to support cofiring. It was found that the waste biomass available from forest-thinning operations is sufficient to cofire at least 165 MW, about 10% of the plants' total generating capacity of 1610 MW. The study also investigated the eventual planting of over 6000 hectares (15,000 acres) of willow trees—a short-rotation woody crop—to provide a significant portion of the feedstock for cofiring. Niagara Mohawk Power Corporation and New York State Electric & Gas Corporation joined researchers at the State University of New York's College of Environmental Science and Forestry at Syracuse in leading the willow-cofiring assessment.

Another project would involve building a fast-pyrolysis unit in Holton, Kansas, to convert 100 tons per day of warm-season grasses, including switchgrass, and some wood wastes into a fuel oil for a 3.5-MW generating unit. In addition, the pyrolysis unit would produce a medium-Btu gas that could be used for process heat and in producing charcoal as a coproduct.

Three of the project proposals featured biomass gasification–combined-cycle (BGCC) generation. One investigated growing a variety of sugarcane or another crop to feed a proposed 65-MW BGCC unit at a Hawaii sugar mill. At least 1600 hectares (4000 acres) otherwise slated to be removed from production would be kept in use to produce bagasse feedstock for gasification.

A proposed Minnesota project would organize sufficient additional production of alfalfa in the vicinity of Granite Falls to fuel a 75-MW BGCC system. The system would feature an air-blown gasification approach (RENUGAS) developed by the Institute of Gas Technology. The alfalfa, produced on about 74,000 hectares (183,000 acres), would also yield over 320,000 tons a year of high-value, high-protein animal feed for sale. Northern States Power Company, facing a state legislature mandate to have 125 MW of biomass-fired generation under contract by 2002, initially led the project, but the Minnesota Valley Alfalfa Producers Cooperative now spearheads it.

In North Carolina, Weyerhaeuser evaluated atmospheric and pressurized gasification technologies for use in BGCC systems at its New Bern pulp mill to generate salable excess electricity from 1000 tons of lignocellulosic biomass per day. The project also evaluated the integrated coproduction of ethanol using a simultaneous saccharification and fermentation process being commercialized by Amoco and the National Renewable Energy Laboratory. □



Last year, EPRI published a synthesis of the lessons learned in the feasibility studies—a synthesis that outlines the vital business and economic considerations involved in developing integrated biomass power systems as strategic utility investments. The evaluations show that cofiring waste wood or energy crops in existing power plants can be a good way for utilities to gain experience in using biomass resources while also reducing both pollutant emissions and the marginal cost of fuel.

The feasibility studies examined biomass systems proposed in various parts of the country that would use a broad range of feedstocks: willow, alfalfa, varieties of sugarcane, switchgrass and other native prairie grasses, short-rotation trees (such as poplar, eucalyptus, and silver maple), and wood wastes. Conversion technologies that were assessed included three biomass gasification–combined-cycle (BGCC) options, a fast-pyrolysis technology, and cofiring in existing PC boilers.

BGCC is the advanced technology of choice, according to DOE and the U.S. Environmental Protection Agency. DOE has been particularly interested in developing the potential for low-cost gasification systems to produce a low-Btu biogas that can be fired in combustion turbines in a high-efficiency combined cycle. This type of biomass power generation theoretically promises a heat rate as low as 8500 Btu per kilowatthour (or a thermal efficiency as high as 40%). But it requires cleanup of the alkali salt-laden biogas before it enters a gas turbine.

A project supported by DOE is under way at the 50-MW wood-fired McNeil generating station in Burlington, Vermont, where an indirect wood gasification system developed by Battelle Memorial Institute is being demonstrated. After the gasifier and a gas cleanup system are built and tested, the biogas will be fired in a small gas turbine, adding 15 MW to the plant's overall capacity.

Costs of biomass generating systems

The capital costs of the BGCC systems examined in the feasibility studies ranged from $1200 to $1800 per kilowatt of capac-

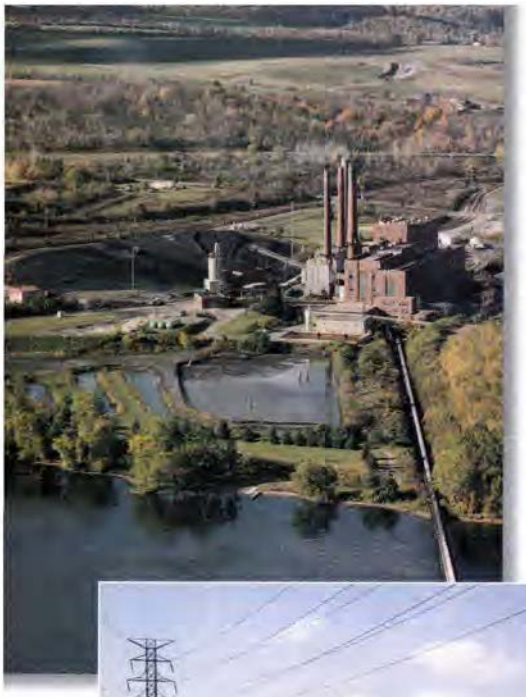
UTILITY-CUSTOMER PARTNERSHIPS CAN MAKE BIOMASS A WINNER

Some utilities have found opportunities to use biomass resources as part of strategic alliances with customers that produce wood, wood waste, or agricultural residues requiring disposal or with customers that can use industrial steam from biomass-fired cogeneration. Such alliances can yield win-win solutions, disposing of industrial or agricultural wastes for customers while producing electricity and other benefits for utilities.

In Washington state, the Snohomish County Public Utility District provided the capital for a 38-MW cogeneration unit at Kimberly-Clark Corporation's Everett paper plant. The unit burns wood waste from area lumber mills, producing steam for Kimberly-Clark and electricity for the utility.

In the mid-1980s, Minnesota Power converted two 30-MW oil-fired units at its Hibbard plant in Duluth to fire mainly mill wastes to raise steam that is sold to a paper plant adjacent to the site. The utility is considering resuming power generation at one of the units.

In Mobile, Alabama, Southern Electric International (a Southern Company subsidiary) purchased a 100-MW cogeneration unit that burns wood waste, coal, and crop residues from the former owner, Scott Paper; steam from the plant is sold to Kimberly-Clark, which recently acquired Scott Paper.



NYSEG's Greenidge station

TVA's Allen plant

COFIRING: A TRIED AND TESTED NEAR-TERM BIOMASS OPTION **A few utilities have cofired wood and wood waste in coal-fired boilers for several years. Cofiring waste biomass with fossil fuels can reduce both marginal fuel costs and pollutant emissions. EPRI-TVA tests in a 250-MW cyclone boiler at the utility's Allen plant produced a wealth of technical data for optimizing wood cofiring in fossil plants. These and other cosponsored utility tests have identified the best, lowest-cost cofiring opportunities. Meanwhile, some utilities are evaluating cofiring in pulverized-coal plants that are larger and of more-recent vintage than the units used up to now. New York State Electric & Gas is planning to cofire wood from local mills (at 10–15%, by heat content) in a 108-MW PC boiler at its Greenidge plant near Dresden, New York, beginning later this year.**

ity—comparable to the cost of new coal-fired capacity with flue gas desulfurization and particulate emissions control, but up to three times the cost of new gas-fired combined-cycle capacity. The feasibility studies found, however, that if the capital costs of BGCC systems can be reduced by 20% as the technology matures, they could generate electricity at a cost that is within the range of current system generating costs for some utilities.

Today's actual cost of producing biomass fuels from dedicated crops is estimated to be between $1.95 and $3.50 per million Btu (per gigajoule). The fuel costs projected in the six member utility feasibility studies ranged from $1.35 to $2.65 per million Btu. In comparison, natural gas currently costs electric utilities $1.25 to $2.25 per million Btu, and coal, $0.90 to $1.35.

"Although energy crops grown today expressly for generating electricity are not competitive with natural gas or coal, agronomists and agricultural engineers agree that crop production costs can be reduced significantly through increased yields and improved harvesting and production systems," says EPRI's Turnbull. The use of a mix of energy crops together with wood or other waste biomass could also improve the economics of biomass fuels, as could higher future fossil fuel prices.

A key lesson from EPRI's evaluation of the feasibility studies of proposed biomass power projects, says Turnbull, is that although much of the existing analysis of biomass energy is at the aggregate or macroeconomic level, specific projects are virtually unique. Thus the feasibility of each project being considered for investment will be determined by feedstock and capital costs as well as operating characteristics that are intrinsic to specific systems and markets.

To help researchers evaluate and compare the economics of specific biomass power systems, EPRI developed a software program called the Biomass Energy System Initial Evaluator (BESIE), which was released in 1995. Used in EPRI's analysis of the six feasibility studies, BESIE can be applied to calculate the 20-year levelized cost of electricity for various biomass systems. EPRI has also produced a spreadsheet computer program—BIOPOWER—that includes comparative data on biomass and waste fuel conversion technologies.

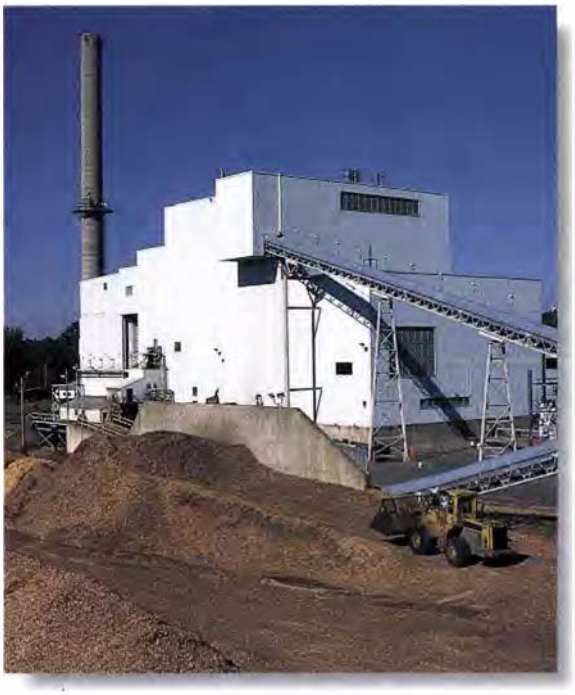
Not all the feasibility studies took into account the value of environmental benefits, such as reducing SO_x or NO_x emissions. Those that did, however, found that the value of such benefits measurably improved a project's economics. The same was true when the value of offsetting fossil carbon emissions was considered. A New York cofiring project took into account a $1 per ton offset for CO_2, based on a valuation by that state's utility regulators. A proposed alfalfa gasification project in Minnesota included the effect of that state's CO_2 offset of $5.99 to $13.60 per ton. Projects proposed in Hawaii and Iowa included consideration of a tax credit for closed-loop biomass systems—now 1.6¢ per kilowatthour generated from biomass—as provided under the Energy Policy Act of 1992. In the case of the Iowa study, the closed-loop biomass credit reduced the effective cost of the feedstock (switchgrass) enough to economically justify proceeding with the project, according to Turnbull.

Coproducts, covalues key to viability

The value of the coproducts and corollary benefits associated with biomass power systems can currently make the difference in a particular system's economic viability, according to EPRI's analysis of the project feasibility studies. The tangible coproducts with explicit monetary value in the studies ranged from animal feed from alfalfa leaves in Minnesota to ethanol and pulp in North Carolina, ethanol from cane in Hawaii, charcoal from pyrolysis char in Kansas, and willow cuttings in New York for use as planting stock. In some cases, however—the ethanol coproduction schemes in the North Carolina and Hawaii projects and the charcoal in the Kansas study—the coproducts were not found to have sufficient current market value to make the overall projects competitive without substantial subsidy.

Covalues, although more difficult to cal-

culate in monetary terms, clearly provide indirect benefits: creating local jobs (almost 300 in New York and nearly 200 in Minnesota); providing unique service to valued customers; remediating soil (as would be the case for growing crops in atrazine-contaminated soils in Kansas); and disposing of or using green waste, water effluent, and sludges—key factors in the Hawaii, North Carolina, and New York project studies.



VERMONT HOSTS BIOMASS GASIFICATION DEMONSTRATION **The gasification of biomass to fuel a combined-cycle combustion turbine is considered the advanced technology of choice because of its potential high efficiency. A DOE project to demonstrate an indirect gasification technology developed by Battelle Memorial Institute is under way at the 50-MW wood-fired McNeil station in Burlington, Vermont. The McNeil plant now burns up to 500,000 tons a year of wood from local suppliers in an existing stoker-fired boiler. Once the Battelle gasification unit and a gas cleanup system are built and tested, low-Btu biogas will be fired in a 15-MW combustion turbine to be installed for combined-cycle operation.**

Hedge for a greenhouse gambit

Unlike systems that burn fossil forms of carbon and thereby continually add to the total atmospheric loading of CO_2, biomass-based energy systems in effect recycle carbon in a closed loop between its emission from biomass combustion and its subsequent sequestration in new plant material. Thus the ultimate long-term value of biomass systems may be as a hedge against potential future, and much higher, costs of reducing CO_2 emissions from fossil fuel combustion.

Since some fossil fuels are inevitably used in growing crops, it is somewhat simplistic to say that biomass energy systems are CO_2 neutral—that they add no net CO_2 to the atmosphere. But the recent project feasibility studies and related EPRI analysis indicate that the fossil fuel emissions associated with biomass production would amount to only 5–10% of the carbon emissions from fossil fuel combustion offset by the biomass.

Scientists and others who are advising policymakers on the risks of global climate change say that the use of biomass-derived fuels for transportation and electricity generation is potentially the most promising approach to reducing greenhouse gas emissions from energy use. The displacement of one megawatt of coal-fired generating capacity by biomass feedstock offsets about 6000 tons of CO_2 a year. Moreover, EPRI results show that the cost of avoiding fossil CO_2 emissions by using biomass, even in a PC boiler firing 15% biomass by heat, would be low: less than $5 per ton of carbon, compared with $50 or even $100–$200 per ton of carbon for some other CO_2 reduction options, such as fuel switching or direct emissions control.

Because of this strategic, long-term benefit, biomass is drawing increasing attention from many electric utilities, despite pressures to focus strictly on the economic bottom line, notes Turnbull. "The 88 utilities that have signed the Climate Challenge with DOE to commit to reduce CO_2 emissions in the future are considering various ways to reduce their use of coal. Several companies see the potential for offsetting fossil CO_2 emissions as a key motivation for their interest in biomass," she adds.

Utilities taking meaningful steps

As a result of its growing involvement with utilities and others in studies of the potential of biomass resources, EPRI concludes that it makes sense for utilities to take meaningful steps now to evaluate biomass resources and understand better the related business opportunities. Utility-directed R&D funding for biomass at EPRI has gone up recently relative to funding for other emerging renewables-based technologies. "Power producers, responding to customer interests, environmental concerns, and bottom-line demands, are moving toward inherently sustainable biomass energy resources," says EPRI's Birk. Many utilities are cofunding biomass cofiring, and others are cofunding biomass resource assessments. Concludes Birk, "In a competitive environment, proactive power producers are becoming actively involved in assessing biomass resources and opportunities, despite their general disinclination toward the development of renewables. It's simply a prudent business position." ■

Further reading

BESIE: A First-Stage Evaluator for Biomass Energy Systems. Final report for RP4062-2, prepared by the Department of Applied Economics, University of Minnesota. December 1995. EPRI AP-105788.

Making Biopower Work for Utilities: A Rationale for Near-Term Investment in Integrated Biomass Power Systems. Final report for RP3407. December 1995. EPRI TR-105854.

Performance and Cost of an IV@SDIG Biomass Gasification–Combined-Cycle System. Final report for RP3407-30, prepared by Stone & Webster Engineering Company. August 1995. EPRI TR-105356.

Benefits and Detriments of Deploying Genetically Engineered Woody Biomass Crops. Final report for RP3407, prepared by Bruce Hajssig Company. April 1995. EPRI TR-104896.

100-MWe Whole Tree Energy™ Power Plant Feasibility Study. Final report for RP3407-11, prepared by Bechtel Corporation. January 1995. EPRI TR-104819.

Turnbull, J. H. "Developing an Integrated Approach to Biomass Energy Systems in the United States." *Biomass and Bioenergy*, Vol. 6, No. 1/2 (1994), pp 151–158.

A "How-to" Primer for Biomass Resource Development. Final report for RP3407-19. December 1993. EPRI TR-103439.

Background information for this article was provided by Jim Birk, Evan Hughes, and Jane Turnbull of the Generation Group's Renewables & Hydro Business Unit.

honoring EPRI Achievement

EPRI's latest technical leadership awards honor staff who have demonstrated great creativity in applying new scientific and technological ideas for the benefit of the Institute's members and their customers.

by Deborah Clark

EPRI's Awards of Excellence are presented each year to recognize individual staff members and teams who have made exemplary business and technical contributions that promote the discovery, development, and delivery of technological innovations. In addition to awards for increasing EPRI's operational efficiency and promoting closer relationships with utilities, a number of awards—highlighted in the following

Front, Iveson, Vojdani; *back*, Cauley, Becker

Gerry Cauley, Ali Vojdani, Peter Hirsch, Bob Iveson, Dave Becker

Real-Time Information Networks

Under the Federal Energy Regulatory Commission's proposed rules on open access, transmission service and tariff information must be publicly posted on real-time information networks, or RINs. These networks will act as a type of reservation system that power marketers and wholesale transmission customers can consult to learn about and purchase available transmission services.

This EPRI team is helping facilitate an industry effort to design and develop RINs in time for the implementation of open transmission access, expected later this year. Key to EPRI's assuming this role was a presentation at a FERC conference last July by

pages—were given specifically for technical leadership.

In remarks at the annual Institute recognition program earlier this year, EPRI president Dick Balzhiser emphasized the dedication and commitment to excellence of the award recipients, noting that they "have shown unusual personal involvement in the development, support, and completion of a successful work—a work that has a strong potential impact for the success of EPRI and the delivery of value to customers."

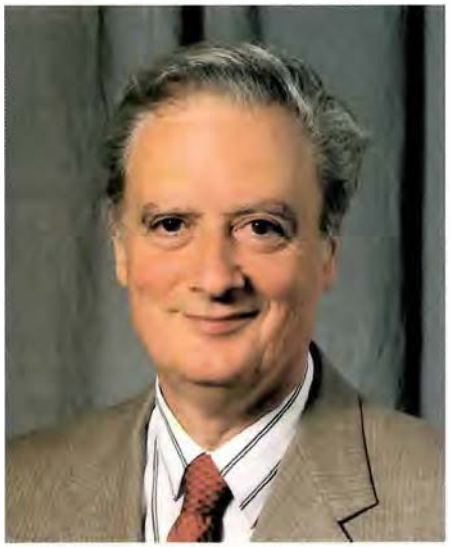
Kurt Yeager, executive vice president and chief operating officer, expanded on the importance of such dedication at a time when competitive pressures are calling into question the value of R&D. "No undertaking matters more to our society's future than our investment in research," he said. "And no commitment matters more to our technical and economic leadership in the world. Discovery, innovation, and research—the world of ideas—need to be widely and fully understood as the underpinnings of our future, of both smart business decisions and profoundly important societal decisions." The following individuals have taken on what Yeager called "the responsibility to persist in carrying the message of research's value into industry, government, and society."

innovation Awards

team leader Gerry Cauley, who described an EPRI-developed communications protocol for real-time data exchange between control centers, power pools, and utility business centers.

The EPRI team has resolved some very tough issues of RIN architecture, communications standards, performance, and functionality. In the end, a bold decision was made to rely on the public Internet as the basis for RINs in the early implementation phases.

Hirsch



Mukesh Khattar

All-Electric Space-Conditioning and Refrigeration System

Working with OG&E Electric Services, Mukesh Khattar helped convince Wal-Mart, a major national chain, to implement an innovative combination of electric technologies at its new environmental demonstration SuperCenter in Moore, Oklahoma, which could serve as a model for future Wal-Mart stores. The resulting system features more-comprehensive integration than conventional systems, coordinating the store's space-conditioning, refrigeration, water-heating, dehumidification, ventilation, and indoor air quality needs.

The store's centerpiece is an electric heat pump space-conditioning and refrigeration system that uses a water loop for heat recovery and has a novel dual-path design for controlling and conditioning ventilation air. The system also features a nonozone-depleting refrigerant, used in a relatively small amount.

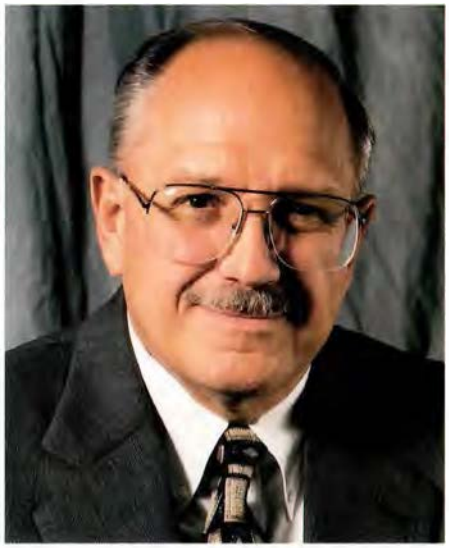
Khattar forged a unique partnership with Wal-Mart to fast-track the project, induce manufacturers to supply the equipment (with warranties), and keep all objectives intact throughout the design process. The result is an efficient, fully integrated system that is expected to yield significant savings in energy costs.

John Gisclon

Containment Leak Testing Requirements

In connection with EPRI's nuclear safety and reliability assessment target, John Gisclon successfully led an effort to support the industry in achieving significant reductions in the frequency of performing containment leakage rate tests required by the Nuclear Regulatory Commission. Gisclon used risk analysis techniques to demonstrate that the incremental risk associated with lengthening the time between containment leakage rate tests is very low. This work also supported NRC initiatives to revise regulations in this area.

Less-frequent testing will save a significant number of critical-path outage days, yielding estimated savings of about $600 million across the industry. The work also sets an important precedent in demonstrating that risk-based considerations can be effectively used to promote more cost-effective regulations without compromising safety. This opens the door for further risk-based applications to improve the economics of nuclear plants.



EPRI Achievement Awards

honoring innovation

Carl Hiller

Electric Resistance Space and Water Heating

Electric resistance space heating and water heating have traditionally made a significant contribution to residential and commercial electricity revenues. However, standards proposed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and regulations proposed by the Department of Energy threatened to block the use of these technologies, whose ability to meet desired energy efficiency goals was questioned.

Carl Hiller has been a leader in the industry's effort to preserve electric resistance space and water heating as options for electric utility customers. Hiller studied the technical issues involved and developed analyses supporting electric resistance technologies as economical choices for residential and commercial buildings. In response to analysis tools, seminars, and consulting advice presented by EPRI, DOE has temporarily withdrawn its proposed regulations, and ASHRAE is revising its proposed standards in order to reflect Hiller's findings.

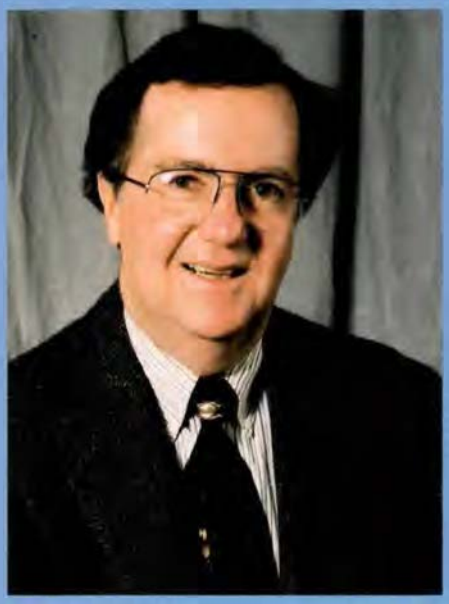
Stan Pace

SOAPP WorkStation

In EPRI-sponsored work with Sargent & Lundy, Stan Pace directed the development of a powerful PC software package for engineers that enables conceptual design and analysis of advanced power plants from a desktop computer.

This award-winning CD-ROM-based, multimedia software—the State-of-the-Art Power Plant (SOAPP™) WorkStation and its related technology modules—combines the latest cost and performance data from equipment vendors with leading-edge design and engineering knowledge. SOAPP users, both specialists and nonspecialists, can quickly screen, analyze, and visualize alternative plant configurations for specific projects.

The first series of SOAPP products focuses on gas turbine and combined-cycle power plants. A related module on the repowering of existing fossil plants is scheduled for release the middle of this year. Future technology modules are expected to extend coverage to other conventional and advanced plant options.



Larry Carmichael

Real-Time Pricing Controller

Through real-time pricing (RTP) programs, some utilities offer customers hourly based rates that reflect the time-varying cost of generating and transmitting electricity. Typically these rates are forecast a day in advance, but they can be forecast as little as one hour ahead. Larry Carmichael has been instrumental in the development of a controller that responds automatically to RTP rates and helps customers optimize their energy use.

Carmichael took the concept of a price-responding energy management system through basic research and prototype testing, negotiated an innovative licensing agreement with the developer, and assisted with the product's commercial introduction. The RTP Controller is now being marketed by Honeywell and is meeting with considerable success.

The prototype system, introduced at the Marriott Marquis Hotel in New York City, saved the customer $100,000 in first-year energy costs. The RTP Controller has also been installed at the World Financial Center in New York and at a McCormick/Schilling spice manufacturing plant and an AT&T office building in Baltimore.

Ishwar Murarka

Coburning MGP Site Remediation Wastes

The disposal of coal tar residues and contaminated soils from former manufactured gas plant (MGP) sites has been a difficult problem for utilities that inherited those sites. Ishwar Murarka was instrumental in providing the Edison Electric Institute with information to support its development of a strategy acceptable to the Environmental Protection Agency for the coburning of MGP site remediation wastes in utility coal-fired boilers.

The EEI strategy entails blending the contaminated solids with coal to render them nonhazardous. The EPA's endorsement of coburning has paved the way for utilities to test this relatively low cost strategy in their own boilers.

Murarka conceived and managed projects that demonstrated the technical soundness and cost-effectiveness of coburning. All R&D results indicate that the destruction of organic contaminants is complete and that use of the coburning process will pose no significant threat to the environment.

New Markets for Heat Pumps

by John Douglas

Small enough to fit in a utility closet and requiring no outdoor components, the Insider heat pump was chosen for the 275 apartment units in the Dominion Tower high-rise complex being built adjacent to Atlanta's upscale shopping district.

The Story in Brief EPRI has worked closely with major equipment manufacturers to help develop residential and commercial heat pumps with features that allow the units to compete strongly in a growing range of applications and climates. As efficiency levels for advanced heat pumps continue to increase, EPRI has launched a new initiative to focus on other concerns—such as reliability, noise, and comfort—that may be even more important in customer purchase decisions. The initiative includes a training and certification program aimed at increasing the skills of installation and maintenance technicians. The Institute is also continuing its leadership in the development of environmentally friendly refrigerants and in the design of heat pump units that can use these new materials at high efficiency.

Versatile, efficient, and reliable, the electric heat pump is a comfort provider for all seasons. Compared with the most common alternative—separate furnace and air conditioner units—it can also help customers reduce their energy bills while giving utilities a powerful tool for load shaping and strategic load growth.

Even so, after a period of spectacular growth during the oil embargo and gas moratorium era of the 1970s and early 1980s, the heat pump share of the heating market for new homes has dropped from 29% to 24% over the last decade, as gas furnaces have again asserted their dominance. Meanwhile, the use of heat pumps for commercial buildings has never gained the acceptance that heat pump use in the residential market has. Finally, climate constraints continue to restrict the popularity of heat pumps in many northern regions of the country.

For each of these market issues, collaborative research involving EPRI, individual electric utilities, and manufacturers is making heat pumps increasingly attractive and is opening important new residential markets. Innovative designs are providing more options to meet the varied needs of commercial buildings. And improving the infrastructure to support ground-source units is extending the range of heat pumps further north, into harsher climates.

Steadily increasing efficiencies have allowed heat pumps to compete more effectively with gas units in terms of energy costs. But energy costs are only part of the marketing challenge; customers are often motivated even more strongly by other concerns—such as reliability, noise, and comfort—in making purchase decisions. To address such customer concerns, EPRI recently launched the Heat Pump Initiative. This initiative focuses on determining customer preferences and translating them into specific heat pump performance targets. Another thrust of the initiative is to develop a national training and certification program for heat pump technicians, since many customer complaints about heat pump performance result from improper installation or maintenance by inadequately trained technicians.

"We have been conducting research on heat pumps for more than 15 years, helping increase their acceptability and achieve a wider market share," says Mort Blatt, manager of EPRI's Residential and Commercial Business Units. "Initially, we helped counter claims that heat pumps weren't reliable; then we worked with manufacturers to develop advanced technologies to make them more widely competitive. Now we are placing greater emphasis on meeting specific customer needs. The result, I believe, will be a new period of substantial expansion of the heat pump market—which today has annual sales of about 1 million units."

Residential market

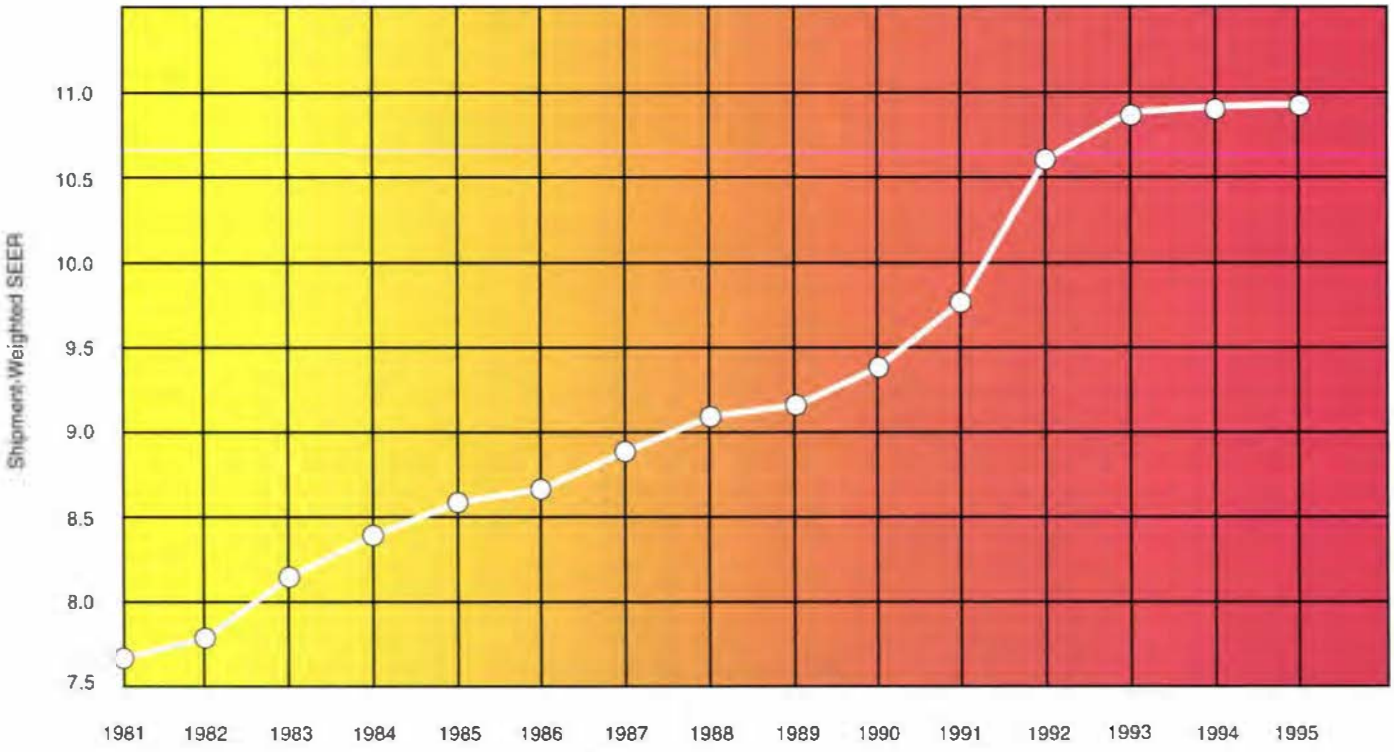
Heat pumps are already well established in the residential market, with more than 8 million installed in American homes. EPRI helped drive technology advances in this market by sponsoring the development of the Powermiser, an innovative high-efficiency unit that serves both space-conditioning and water-heating needs. Introduced on the market by Nordyne in 1992, the Powermiser enabled families to reduce their energy bills by 20–40% by combining space heating, air conditioning, and water heating in a single highly efficient appliance. According to an analysis done for Public Service Electric and Gas Company, such savings led to a payback period of three to four years for Powermiser installation.

Although work to increase the efficiency of conventional air-source units continues, recent research has concentrated on developing products for new residential markets. One such market is manufactured homes, whose sales are increasing rapidly as families seek low-cost, flexible alternatives to conventionally built houses. A leading candidate to meet this demand is the Insider, a self-contained heat pump that fits entirely inside the utility closet of a manufactured home. Because it has no outdoor section, the Insider can be installed at the factory before the home is transported to a dealership or homesite.

EPRI, the Rural Electric Research Program of the National Rural Electric Cooperative Association, and Consolidated Technology Corporation, which manufactures the Insider, have recently collaborated to make the technology more efficient, quieter, and easier to install. Historically, few heat pumps have been sold for use in manufactured homes, and the availability of the improved Insider is expected to accelerate the penetration of heat pumps into this important niche market. Already, this product has been chosen for installation in the 300 manufactured dwellings that will be used to house security guards at the Atlanta Olympic Games in 1996. And at least one home supply company is beginning to carry the Insider in its retail stores as a retrofit option for the conventional heating units that are common in existing manufactured homes. The Insider is also being marketed by Carrier Corporation as the All-In-One unit, sold under the Bryant brand name.

EPRI is also sponsoring the ongoing development of an improved heat pump water heater to replace less-efficient electric resistance heaters. Compact and lightweight, this advanced water heater will automatically switch from heat pump mode to electric resistance mode when the ambient air temperature drops below about 35°F. The unit will have an overall efficiency much higher than the efficiency of resistance heating, and it is expected to be popular in southern climates.

Another major challenge in the residential market has been to develop a heat pump that offers enhanced comfort and greater flexibility in system sizing for northern climates. Because the ground remains considerably warmer than the air



Source: Air-Conditioning and Refrigeration Institute.

EFFICIENCY RISING Steadily increasing efficiencies have allowed heat pumps to compete more effectively with gas-fired units in terms of energy costs. Shown here are seasonal energy efficiency ratios (SEERs) for unitary air-source heat pumps.

Unit	Manufacturer	Use Sector	Type	Primary Application	Special Features
Powermiser	Nordyne	Residential	Air source	Combined space conditioning and water heating	High-efficiency, multiple functions
Insider	Consolidated Technology	Residential	Air source	Manufactured homes, multifamily housing	Compact, self-contained, factory-installable
All-In-One	Carrier (Bryant)	Residential	Air source	Manufactured homes, multifamily housing	Compact, self-contained, factory-installable
Premier AT	WaterFurnace	Residential	Water/ground source	Homes in northern climates	Two-speed operation for efficiency and better unit sizing
Water-source heat pump	Trane	Residential and commercial	Water loop and ground-coupled	Office buildings, schools, homes	High efficiency, programmable internal heat transfer, easy to retrofit
L Series	Lennox	Commercial	Air source	High-performance building space conditioning	High efficiency, good low-temperature performance, easy maintenance
ClimaDry	ClimateMaster	Commercial	Water/ground source	Space conditioning and dehumidification for large stores, schools, and other institutions	Integrated multifunction unit, controllable ventilation air for indoor air quality, "green" refrigerant
Dual-fuel heat pump	Lennox, York, Carrier, Trane	Commercial	Air source	Buildings in mid to northern climates	Single-package rooftop unit, efficient in cold weather, easy to retrofit, "green" refrigerant

during winter months, geothermal heat pumps—which use buried coils to provide a heat source—are the preferred choice. The problem has been that most ground-source heat pumps (GSHPs) are sized to meet the winter heating load, which can result in oversizing for the summer cooling load.

A solution to this problem is provided by the Premier AT Series two-speed GSHPs, developed by WaterFurnace International under the sponsorship of EPRI and Mississippi Power Company. This product is designed to operate at low speed 70–90% of the time and at high speed only during extreme weather. Such a two-speed capability makes the Premier AT unit 30–50% more efficient than other GSHPs currently on the market. It also provides greater precision in sizing, since the high-speed capacity can be chosen to provide adequate peak heating while the low-speed capacity provides a better match to the smaller cooling load typical of northern climates. The two-speed operation is automatically controlled by a microprocessor and a multistage electronic thermostat. The availability of low-speed operation also improves customer comfort by reducing fluctuations in temperature and humidity.

A continuing challenge that faces supporters of GSHPs is the lack of an extensive infrastructure to support the installation and maintenance of these pumps. To solve this problem, EPRI is cooperating with the Geothermal Heat Pump Consortium, which is promoting field demonstrations, working to lower installation costs, and developing new training materials for technicians.

A general difficulty in the residential heat pump market has been that overall system performance is only as good as the integrity of the system's air distribution assembly. Leaky ductwork, in particular, can waste about 20% of a typical house's heating and cooling energy. Sometimes this is the result of improper installation, and better technician training will eventually help. In addition, EPRI has developed an aerosol that deposits particles directly at the site of a leak and can seal openings up to a quarter-inch wide. Applied with an easily portable unit in less than half the time of repairs by traditional methods, the aerosol is expected to be commercialized later this year.

"Many utilities are seeing rapid growth in their residential heating market, which provides a new chance to increase heat pump sales," says EPRI's Terry Statt, manager for residential systems. "Opportunities are particularly great in the retrofit market, as homeowners realize the advantages of replacing their conventional heating and cooling units with more-efficient heat pumps."

TAILORED FOR NEED **EPRI has been involved in the development and commercialization of a wide variety of heat pumps tailored to specific space-conditioning needs.**

Commercial sector

The heating, ventilating, and air conditioning (HVAC) requirements of commercial buildings pose special problems for engineers. A large office building, for example, may need simultaneous cooling at its core and heating around its periphery. Even when outdoor temperatures dip into the 35–45°F range, HVAC equipment may have to provide cooling to part of a building. Occupancy patterns are also very different from those of homes, with a sharp usage

peak during work hours. In addition, unlike residences, commercial buildings require the introduction of large amounts of outdoor air and continuous internal circulation. This can lead to excess humidity in hot, humid climates and can result in unnecessarily high power consumption. Comfort can also be a problem with conventional heating systems, which may first overheat an office and then cycle off, blowing cool air onto the occupants. Finally, HVAC operators in commercial buildings must make allowances for widely varying occupancy rates and for utility bills that may include demand charges and time-of-day energy rates.

Heat pumps can provide superior solutions to each of these challenges, but selecting the right heat pump for a particular commercial application depends on a number of site-specific considerations. The most popular heat pump in commercial buildings uses outdoor air as a heat source and is most efficient in warmer climates. Water-loop heat pump (WLHP) systems can recover the heat from the core of a large building and use it to warm perimeter offices. And GSHPs provide the most efficient heating systems available. Nevertheless, only about 100,000 heat pump units are installed in commercial buildings each year, compared with more than 750,000 air conditioners. Further market penetration will depend on a number of factors, particularly the development of new heat pumps to meet niche market needs and the availability of higher-efficiency heat pumps that will enable commercial customers to lower peak demand and decrease their overall HVAC costs.

Already, EPRI has helped develop the technology now used in the most efficient line of air-source heat pumps available for commercial buildings. Manufactured by Lennox Industries and first offered in January 1995, this L Series line of products had first-year sales so much higher than expected that demand continues to outpace supply. "The L Series heat pump was engineered by Lennox to provide the highest efficiency on the market at a very competitive price," says EPRI's Wayne Krill, manager of commercial equipment development. "The product has had rapid success with national accounts and other customers who demand high-performance heating and cooling."

Heating/Cooling System	Operating Costs ($/yr)			
	Heating	Cooling	Water Heater	Total
Standard heat pump (12 SEER)	382	284	412[a]	1078
Standard gas furnace/air conditioner (80 AFUE/12 SEER)	363	284	165[b]	812
Condensing gas furnace/air conditioner (92 AFUE/12 SEER)	326	284	165[b]	775
Powermiser heat pump (12 SEER)	449	306	0[c]	755

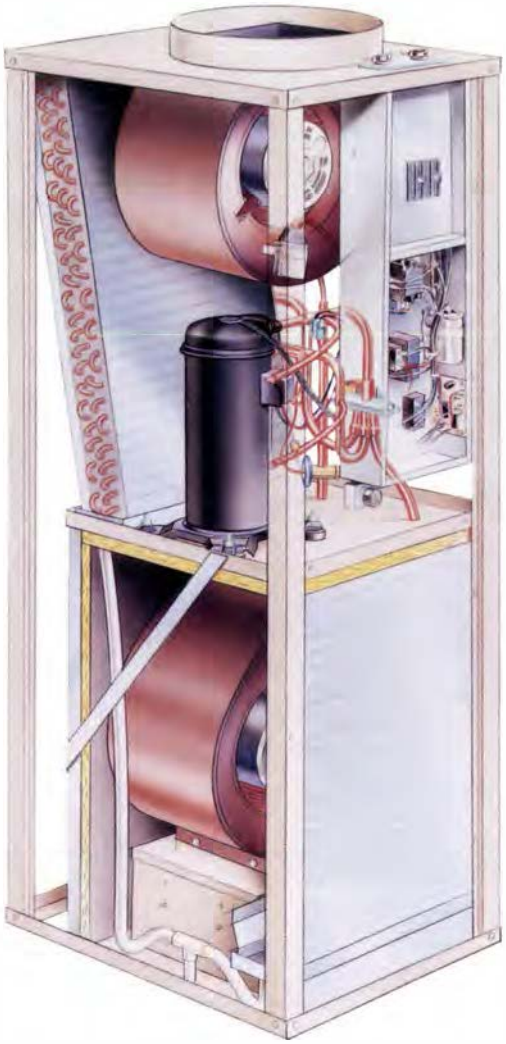
Note: SEER = seasonal energy efficiency ratio; AFUE = annual fuel utilization efficiency.
[a]Electric resistance water heater. [b]Gas water heater.
[c]The water-heating cost is included in the heating and cooling costs.

POWERMISER: DOING MORE FOR LESS
Special features can give equipment a distinct advantage in the marketplace. Because the Powermiser heat pump combines space conditioning and water heating in a single high-efficiency unit, it can offer the homeowner substantial energy savings over other equipment. The table compares annual operating costs for serving the needs of a typical 1800-square-foot home in North Carolina. The Powermiser has a lower purchase price than the high-efficiency gas furnace system.

In addition to their exceptional efficiency, the L Series heat pumps offer improved comfort and enhanced defrost and low-temperature performance. They were also designed for easier maintenance, a response to the results of a 1992 survey of building owners and contractors. A hinged access panel, for example, makes electrical and refrigeration components more readily accessible, and onboard diagnostics can identify over 80 specific servicing needs.

Another commercial HVAC option is the WLHP, which has lower installation costs than central plant HVAC units and offers much greater operating flexibility. Several major office buildings, such as the 76-story Columbia Seafirst Center in Seattle, use WLHP systems. Typically, individual heat pumps in each thermal zone (for example, an office suite) are connected to a pipe loop in which water is circulated throughout the building. Each heat pump adds heat to or removes heat from the loop, depending on whether cooling or heating is required in that zone. Since the heat pumps do the heating or cooling and loop temperatures are held between 60°F and 90°F, it is possible to use a low-cost two-pipe system with uninsulated piping. The system also includes a boiler and a cooling tower to help maintain loop temperature. The large amount of heat recovery within a building contributes to overall efficiency, so that some WLHPs seldom need to use supplemental heating from the boiler. In some cases, the boiler can be replaced altogether by using a ground-source water loop—an idea successfully employed, for example, at Stockton State College in New Jersey.

To further increase the attractiveness of WLHPs in the commercial HVAC market, EPRI has developed the concept of a "floating loop," which uses intelligent controls to optimize energy consumption and reduce operating costs. Incorporating such controls into existing heat pump systems is expected to result in annual energy sav-



SELF-CONTAINED, FACTORY-INSTALLED
Designed specifically for manufactured homes, the All-In-One heat pump is compact and quiet and requires no outdoor section. While the units are generally closet-installed at the factory before homes are transported to their sites, the All-In-One is also available as a replacement unit for older manufactured homes.

ings of 10-30%. These energy savings are expected to increase market share for electricity and to influence conversions from chiller-boiler systems when the chiller needs replacement.

The commercial development of a standalone control unit ready for retrofit was recently announced by GC Controls of Green, New York, under the name SmartLoop 2000. This product, which is expected to cost about the same as typical electromechanical controls, can be used with WLHP units in both large and small buildings. SmartLoop's proprietary control algorithms provide optimum cycling, boiler and cooling-tower operation, and variable loop-temperature management. The first two prototypes are being installed at a Stamford, Connecticut, office building and a San Diego Gas & Electric Company customer site; four to eight more sites are to be added later this year. SmartLoop 2000 is expected to be commercialized soon by a major WLHP supplier, through a strategic alliance with GC Controls.

Where humidity is a problem, a dual-path heat pump—which handles the ventilation and recirculation airstreams separately—may provide the best solution. A new product of this type, built by ClimateMaster Corporation and based on an EPRI design concept, has recently been installed in the Wal-Mart SuperCenter in Moore, Oklahoma. Called the ClimaDry heat pump, this system provides independent control of ventilation air and greater efficiency in handling the higher dehumidification requirements imposed by new air quality standards designed to ensure the health and comfort of commercial building occupants.

Conventional heat pumps and air conditioners increase dehumidification by using an oversized cooler and then reheating the air to compensate for the extra cooling. Under part-load conditions, when the compressor is off, these units can bring humid ventilation air into the space. A dual-path system provides a more cost-effective solution by removing excess moisture from the fresh air before mixing it with the return air. In the Wal-Mart application, the ClimaDry system provides even greater efficiency by integrating space conditioning with refrigeration and water heating. As a result, Wal-Mart expects to spend nearly $60,000 a year less in energy costs at the Moore SuperCenter than if it used conventional refrigeration, HVAC, and gas-fired desiccant dehumidification systems. In the future, the market for this type of heat pump will be expanded to include other types of buildings—such as schools, theaters, and convention halls—that require relatively large amounts of ventilation. ClimaDry is also the first heat pump for commercial applications that uses an environmentally friendly, or "green," refrigerant—one that will not harm the ozone layer of the earth's atmosphere.

Supplementing the ClimaDry system, which serves the SuperCenter's open sales area, is another new ClimateMaster water loop system that will provide space conditioning for offices and other parts of the building. The unusual aspect of this latter system is that its main serviceable components are located in an easily accessible rooftop unit. Rooftop units of this type

would also be attractive for use in schools and fast-food outlets, which generally have limited space inside for mechanical service equipment. This WLHP also uses nonozone-depleting refrigerants.

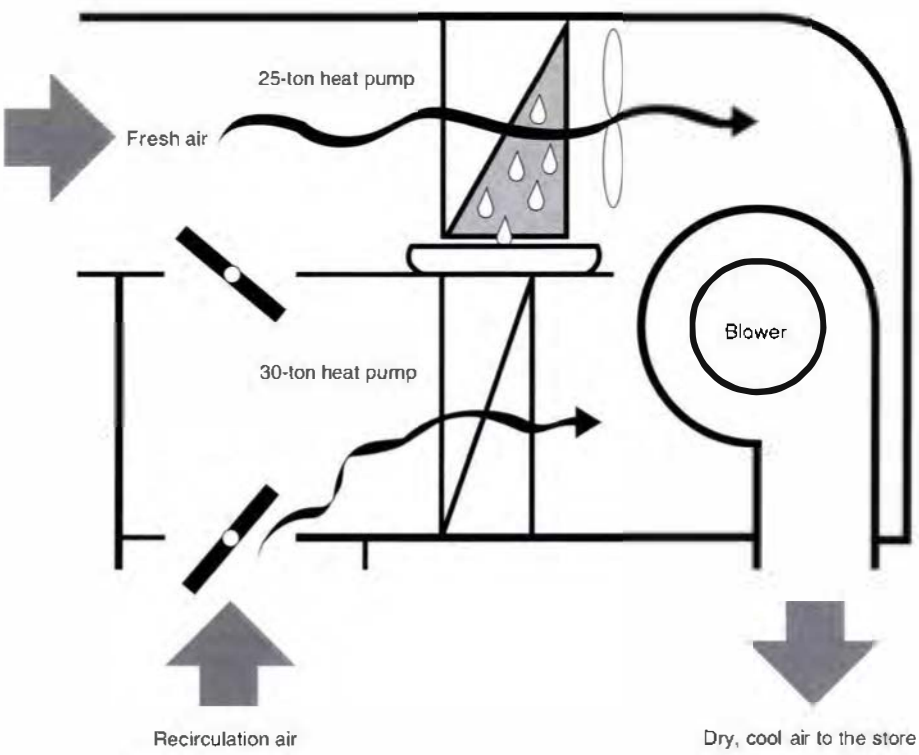
The development of a single-package dual-fuel heat pump (DFHP) designed for commercial establishments that face long, cold heating seasons has helped extend the heat pump market further north. The DFHP can help customers achieve the lowest possible winter heating costs by operating as a heat pump, a furnace, or both, depending on the severity of the weather. Like any air-to-air heat pump, a DFHP has a specific thermal balance temperature—the outdoor temperature below which the unit requires a supplemental heat source to meet a building's heating requirement. While a conventional heat pump uses an internal electric resistance backup to provide supplemental heat, the DFHP incorporates a gas furnace for this purpose.

When outdoor temperatures are above the thermal balance point, only the heat pump section of the DFHP is operated. Below this point, both the heat pump and the furnace are operated down to a break-even temperature, below which using the gas unit alone is more economical. In one typical application at a restaurant in Portland, Oregon, the use of a DFHP instead of a conventional gas furnace and air conditioner saved over $400 a year. Because of such savings, the DFHP is seen as a particularly good retrofit option for replacing aging rooftop gas-electric units, which make up a large fraction of the commercial sector's space-conditioning equipment. In climates where a DFHP is an appropriate choice, the heat pump side of the unit can satisfy 75–80% of the load, boosting growth in electricity sales.

EPRI field-tested the first rooftop DFHP, manufactured by Lennox Industries, in a broad range of applications, including restaurants and retail stores, and helped refine the design. The technology is now offered in a full line of products by three additional companies: York, Carrier, and Trane. "EPRI was centrally involved in the development and commercialization of the dual-fuel concept," says Blatt. "Without our early work, this entire line of sin-

WATER LOOP ADDS FLEXIBILITY **Water-loop heat pumps can provide operating flexibility in conditioning large office buildings, such as the Columbia Seafirst Center in Seattle. With this system, individual heat pumps are connected to a pipe loop in which water is circulated throughout the building. Each heat pump either adds heat to or removes heat from the loop, depending on whether cooling or heating is required in that thermal zone. On a cold day, for example, heat generated by a computer center in the interior of a building would help keep exterior offices comfortably warm.**

ClimaDry dual-path ventilation system



FIGHTING HUMIDITY AT WAL-MART

Wal-Mart dealt with dehumidification concerns at its new SuperCenter in Moore, Oklahoma, by installing the ClimaDry heat pump, an innovative high-volume, dual-path conditioning unit. The ClimaDry provides independent control of the building's ventilation and recirculation airstreams, allowing excess moisture to be removed from the fresh air component before it is mixed with cycled air. The system also integrates the space-conditioning function with refrigeration and water heating for substantial energy cost savings.

gle-package dual-fuel units would not be on the market today."

Later this year, EPRI will begin work on improving GSHPs used in commercial buildings. Part of this effort will focus on revising heat pump controls so that a ground-loop configuration can be combined with WLHPs in a large building. Already, in a separate project, a national database on GSHP experience in the commercial sector is being developed. This database will provide the foundation for an improved understanding of appropriate system sizing and configuration.

One promising idea now being demonstrated is a hybrid GSHP for general commercial application. In this type of unit, the ground loop is sized to meet winter heating needs, and a supplemental fluid cooler is used for the summer cooling load. The overall installed cost of such an arrangement can be lower than that of a ground loop sufficient to meet a building's entire year-round needs. A hybrid heat pump of this type has been installed in the Paragon Center of Allentown, Pennsylvania, through a tailored collaboration agreement between EPRI and Pennsylvania Power & Light Company, and performance monitoring is now in progress.

"Heat pumps available now can meet the needs of almost every commercial client," declares EPRI's Mukesh Khattar, manager for HVAC, refrigeration, and thermal storage. "EPRI and its industry partners are taking steps to ensure that heat pumps become a stronger contender in this critical market."

The EPRI Heat Pump Initiative

As electric utilities enter an era of increased competition and expanding opportunities, particularly in the residential market, there is a need to redefine heat pumps according to customer preferences. The

EPRI Heat Pump Initiative is responding to this need by identifying the remaining barriers to widespread customer acceptance. A planning workshop for the initiative, held in May 1995, established three top research priorities: identification of customer needs, development of better equipment for northern climates, and improvement of heat pump installation and maintenance.

Focus group research has already begun to provide a deeper understanding of residential and commercial customer preferences. The participants were selected from the customers of six sponsoring utilities—Entergy Corporation, Hoosier Energy Rural Electric Cooperative, Nevada Power Company, Omaha Public Power District, Southern Company Services, and the Tennessee Valley Authority. In the focus groups, the participants have engaged in lengthy discussions of their heating and cooling needs and their likes and dislikes. The results of these discussions will help guide further heat pump development efforts and assist utilities in planning their heat pump marketing efforts.

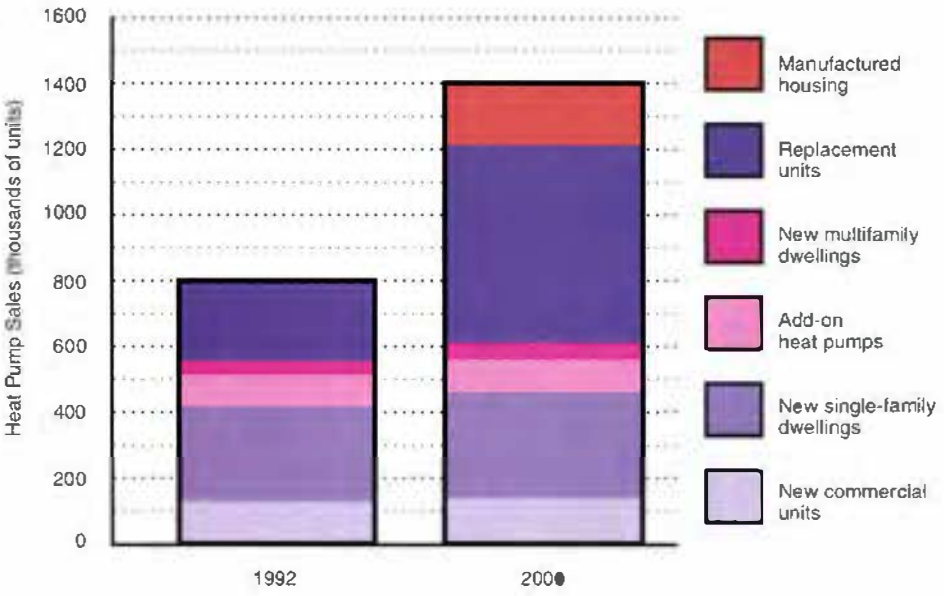
Advanced heat pump technology research is currently being directed toward developing an affordable heat pump that offers higher comfort levels and lower energy bills in the harshest northern climates. In one key project, EPRI is collaborating with Duke Power Company, Empire State Electric Energy Research Corporation, Northeast Utilities, Southern Company Services, and Carrier Corporation to introduce in 1998 a new generation of heat pumps that will deliver warmer air—closer to the temperature of a furnace—while operating at outdoor temperatures as low as −10°F. Already, manufacturing cost analyses have verified that compared with current models, the new heat pumps will entail only a modest first-cost premium.

Most often, when residential customers complain of improper heat pump performance, high bills, and lack of comfort, the reason is improper installation and maintenance—which can cause such problems as duct leakage and incorrect equipment sizing. Under current industry practice, the vast majority of HVAC technicians do not get formal training in heat pump technology. To overcome this deficiency, a national heat pump technician training and certification program has been launched by a broad group of utilities, manufacturers, and trade organizations, in cooperation with EPRI. The program, which is being launched in a one-year pilot effort, will produce three certified skill levels for technicians—apprentice, journeyman, and master. After the pilot project is completed in 1997, state and local governments will be asked to include heat pump testing as a licensing requirement for technicians.

In addition to these three top-priority research areas, the initiative calls for funding new projects to improve specific equipment design and features—for example, the development and testing of heat pumps that use new, environmentally safe refrigerants. EPRI's contributions in this area, including its pioneering work with the National Institute of Standards and Technology and others, have helped accelerate the development of first-generation refrigerants with zero ozone-depletion potential by more than two years. As part of the Heat Pump Initiative, EPRI's Residential and Commercial Business Units are working aggressively to develop heat pumps that use these refrigerants, while the Strategic R&D Business Unit continues to support basic research to identify and qualify second-generation refrigerants with characteristics that will lead to further improvements in electric heat pumps.

Other projects under the initiative will focus on conducting an education campaign to inform customers about the benefits of heat pumps and on developing a portfolio of electrical alternatives to resistance water heaters—including both dedicated heat pump water heaters and integrated heat pumps with year-round water-heating capability.

"Through this new initiative, EPRI will continue its leadership role in developing heat pump concepts that address customers' needs while reflecting the technological state of the art," concludes Blatt. "As a result, I expect manufacturers to offer an increasingly inclusive array of heat pumps that can compete effectively with fossil fuel alternatives, enabling electricity to retain and expand its share of both the residential and commercial space-conditioning and water-heating markets." ■



GROWTH IN THE MARKETPLACE
EPRI estimates that between 1992 and the year 2000, heat pump sales will nearly double to 1.4 million units a year, with particular growth in the replacement and manufactured-housing markets. The enhancement of customer and retailer acceptance—a primary goal of EPRI's Heat Pump Initiative—could increase the sales in 2000 by an additional 30%.

Background information for this article was provided by Mori Blatt, Terry Stalt, Mukesh Khattar, Carl Hiller, and Wayne Krill of the Customer Systems Group.

CONTRIBUTORS

Technical sources for Journal feature articles


MALCOLM


SUNDARAM


RICHARDSON


BIRK


HUGHES


TURNBULL


BLATT


STATT


KHATTAR

Custom Power: Optimizing Distribution Services (page 6) was written by science writer John Douglas with assistance from members of EPRI's Distribution Business Unit.

Wade Malcolm, director of the business unit, came to EPRI in 1988 as a loaned employee from Philadelphia Electric Company. In 1991, he officially joined the staff as manager of the Customer Systems Division's Power Electronics and Controls Program; he took on his current responsibilities in the Power Delivery Group in 1994. At Philadelphia Electric, Malcolm worked on communications systems development, distribution automation and control, and utility applications of robotics technology.

Ashok Sundaram joined the Institute in 1993 as a project manager specializing in power electronics and power quality. Earlier he was a senior engineer at Elgar Corporation, a design engineer at Behlman Electronics, and a project engineer at Crompton Greaves Ltd.

David Richardson is a project manager for dispersed energy systems planning and Custom Power applications. Before joining EPRI in 1993, he was director of electrical engineering at U.S. Windpower; during his seven-year tenure there, he was involved in electrical systems design and development for over 4000 wind turbines. Earlier Richardson was employed by Wulfsburg Electronics, King Radio, and Black & Veatch. ■

Harvesting the Benefits of Biomass (page 16) was written by Taylor Moore, *Journal* senior feature writer, with assistance from three staff members of the Generation Group's Renewables & Hydro Business Unit.

Jim Birk, business unit manager, came to EPRI in 1973 as a project manager for advanced battery development. He assumed increasing levels of responsibility in energy storage, ultimately overseeing research in hydropower and renewable technologies as well. Birk's earlier experience includes several years as a senior scientist with Rockwell International. During that time he spent a year on loan to Argonne National Laboratory, working on advanced battery technologies.

Evan Hughes, manager for renewable fuels, joined EPRI in 1978 after serving as manager of the Geothermal Energy Office of the California State Energy Commission. Earlier he was a senior member of the technical staff at SRI International, specializing in the analysis of energy, resources, and the environment.

Jane Turnbull, manager for integrated biomass systems, joined the EPRI staff in 1993 after 12 years with Pacific Gas and Electric Company. She had come to the Institute as a loaned employee the preceding year. Since 1990, Turnbull has been involved in California and national research programs to develop sustainable biomass energy systems using agricultural and wood wastes and dedicated energy crops. She participated in the establishment of the National Biofuels Roundtable in 1992. ■

New Markets for Heat Pumps (page 30) was written by John Douglas with technical guidance from members of the Customer Systems Group.

Morton Blatt is manager of the Residential and Commercial Business Units. Before joining the Institute in 1985, he was manager of end-use efficiency programs at Science Applications International Corporation. Earlier he worked for General Dynamics.

Terry Statt is a project manager specializing in advanced residential heat pumps and refrigeration equipment. Before joining EPRI in 1992, he was with the Department of Energy for nine years, directing research on non-ozone-depleting refrigerants. He has also worked as an engineer for Energy Applications, PRC Energy Analysis Company, Automation Industries, and Hittman Associates.

Mukesh Khattar, manager for HVAC, refrigeration, and thermal storage, came to EPRI in 1989 from the Florida Solar Energy Center in Cape Canaveral, where he specialized in advanced technologies for building energy systems. From 1981 to 1984, he taught mechanical engineering and solar energy courses at the Florida Institute of Technology. ■

SCE Evaluates Pulse-Jet Fabric Filter Options for Opacity Compliance

With EPRI assistance, Southern California Edison Company evaluated technologies for enabling its Mohave generating station to further control particulate emissions for the full range of current and probable future operating conditions. Two promising options were identified: replacing the existing electrostatic precipitators with conventional pulse-jet fabric filters (PJFFs) or supplementing the precipitators with Compact Hybrid Particulate Collector (COHPAC) PJFFs, which have about four times the air-to-cloth ratio of conventional PJFFs.

The Mohave plant burns a coal-water slurry and had no prior experience in using baghouses to collect the fly ash produced by the fuel. Earlier tests with a small filter showed that the fly ash might be difficult to collect. Since up to 1580 MW of generating capacity could be affected, it was important to SCE to ensure that conventional or COHPAC PJFFs would not present problems—such as short bag life or poor bag cleanability—that could lead to substantially higher operating and maintenance (O&M) costs.

To ensure that PJFFs would perform without problems for the Mohave coals and operating conditions, in 1994 SCE installed two of EPRI's 1-MW transportable pilot PJFFs in parallel at the generating station. The units were operated for 12 months to demonstrate conventional and COHPAC PJFF effectiveness and to provide design data and O&M information for full-scale application. Test conditions for the pilot units were designed to minimize the risk of early bag failure and potential plant derating associated with improper design and operation. The pilot results showed that both conventional and COHPAC PJFFs can be used effectively to control particulate emissions at Mohave.

"The testing of EPRI's pilot pulse-jet fabric filters at the Mohave generating station helped SCE confirm the ability of pulse jets to control particulate emissions and minimize the potential for unforeseen problems during full-scale application," says SCE's Brian Watts.

■ *For more information, contact Ramsay Chang, (415) 855-2535.*

Two transportable pilot-scale pulse-jet fabric filters were installed at the Mohave station.

Abandoned Lead Mine Helps Heat, Cool Missouri Town's New City Hall

Water from an abandoned lead mine is helping to provide low-cost heating and cooling for the new Park Hills, Missouri, city hall, thanks to a collaborative effort by Union Electric Company, EPRI, and the city. Each provided a third of the cost of a geothermal heating, ventilating, and air conditioning (HVAC) system that uses natural energy stored in the earth to heat or cool the building. Park Hills, with a population of around 8000, is located about 60 miles southwest of St. Louis.

The 8100-square-foot building houses the Park Hills city hall offices as well as the police, water, and sewer departments. It sits above an abandoned lead mine that contains about 70 billion gallons of water. Because the water has a temperature of 57–58°F year-round, it is an ideal source of geothermal heating and cooling. In winter, water pumped from a 120-foot-deep well circulates through a heat exchanger inside the building, where heat is transferred to a secondary water system to which nine water-loop heat pumps are connected. The heat pumps extract heat from the water to heat the building; the well water is returned to the mine through a second well. Whenever cooling is needed, the heat pump system operates in reverse to transfer heat from the building to the water in the mine.

"It's an innovative engineering solution to provide low-cost heating and cooling," says Milt Murry, a Union Electric engineer who was involved in the project. "Besides low cost,

another important feature is operating flexibility. For example, the police department may require air conditioning on a hot summer evening, since it is open 24 hours a day, while the city hall offices do not. The system can even provide simultaneous heating and cooling to different parts of the building."

The cost of the project was about $30,000 more than the cost of a conventional HVAC system for a building of the same size. But the additional cost is expected to be recovered through savings in energy costs. "The operating-cost savings of this geothermal system are about $8100 a year, and the system should pay for itself in a little over three years," Murry says. Union Electric engineers are continuing to monitor the performance of the geothermal system in the now-occupied building during extreme as well as normal weather conditions and to track the system's energy savings. The utility hopes to market the technology to other customers in the area at similar favorable sites.

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

Rochester Gas and Electric Lowers Magnetic Field Levels With EPRI's Net Current Control Device

A customer of Rochester Gas and Electric Corporation was concerned about higher-than-typical magnetic fields in her home, especially in her daughter's bedroom. The source of the magnetic fields: ground currents flowing on the home's water service pipe.

Against the backdrop of continuing public concern about possible health effects from exposure to electric and magnetic fields, EPRI is responding to the interest of member utilities and their customers in the development of field management and reduction options. Staff at RG&E were looking for an opportunity to demonstrate a product for managing magnetic fields when the utility was contacted by the residential customer requesting help in reducing indoor fields. Utility engineers determined that currents flowing back to the distribution transformer via water pipes were the primary source of the indoor magnetic fields. EPRI's Nationwide Survey of Residential Magnetic Field Sources, completed in 1993, identified such ground currents as one of the major sources of magnetic fields in homes.

An RG&E line worker installs the net current control device beneath a distribution transformer.

RG&E was aware that an EPRI contractor, Electric Research and Management, had recently developed a net current control (NCC) device designed to reduce residential ground currents. The NCC device employs a simple ferromagnetic core that, when installed on the service cable, induces voltage in each of the conductors. The induced voltage opposes the flow of net current along an alternative path, such as a water-pipe ground connection, and instead encourages the load current to return through the neutral conductor of the service cable.

RG&E proposed expanding the field testing of the device to include its residential customer. The device was subsequently installed on the customer's service pole, along with test equipment to monitor results. Current and magnetic field levels were measured in the customer's home and in neighboring homes before and after the installation. The customer also conducted indoor magnetic field surveys with a gaussmeter provided by the utility.

After the NCC device was installed on the customer's service pole, current levels on the water pipe were reduced by 96%, from about 2 amperes to 0.07 ampere. Peak magnetic field levels were reduced by 60%, from 12 milligauss to 4.5 milligauss, and average field levels were reduced by half, to 2 milligauss. RG&E engineers discovered that the remaining magnetic fields were primarily attributable to ground currents on the water pipes of adjacent homes.

As indicated by the RG&E field installation and other tests at EPRI's Power Delivery Center in Lenox, Massachusetts, the NCC device can virtually eliminate ground currents as a source of residential indoor magnetic fields. "The NCC equipment is quicker and a lot easier to install than alternative techniques for reducing residential magnetic fields," says Don Cushman, a retired RG&E engineer who was involved in the project with EPRI. The NCC device is available from Electric Research and Management, (412) 826-3222.

■ *For more information, contact Richard Lordan, (415) 855-2435.*

Applied Science and Technology

Advances in Weld Repair Technology

by Vis Viswanathan, Strategic R&D Business Unit

At present, nearly half of fossil-fired plants are over 25 years old, and more than half of nuclear plants are over 15 years old. Metal components in both types of units are aging from exposure to high temperatures and pressures, corrosion, and cycling strain. In today's competitive business climate, utilities prefer to maintain their old plants rather than build new ones. By extending component lifetime, utilities can maximize asset utilization while minimizing the need for new capital expenditures.

Welding can be a cost-effective way to repair and refurbish aging or damaged components and upgrade existing systems. In some instances, weld repair may provide the only economic approach for avoiding permanent plant shutdown. However, there are no standard guidelines on how to identify the best weld repair technologies for aging components or how to determine the length of time by which they will extend a particular component's life. Neither the procedures used in the past nor the results of completed repairs have been fully documented. In addition, extended outages may be required for proper repairs using conventional welding technologies; postweld heat treatment (PWHT), normally a code requirement for piping, can be particularly time-consuming.

Utilities are interested in weld repair, as evidenced by the fact that a March 1994 EPRI conference on welding technologies for fossil plants attracted more than 300 attendees. To advance the industry's weld repair capabilities, EPRI is directing major international collaborative efforts aimed at identifying optimal techniques and procedures for key components and at developing and qualifying technologies that eliminate the need for PWHT. Projects are being conducted to address two critical areas: stationary components in fossil plants and rotating components in both fossil and nuclear plants. These efforts are being cofunded by domestic and foreign utilities —including Electricité de France, ENEL (Italy), and Taiwan Electric Power—and are being administered through the Fossil Power Plants Business Unit of EPRI's Generation Group. The Strategic R&D Business Unit (SR&D) is providing technical leadership, with technical support from EPRI's Repair and Replacement Applications Center (RRAC) in Charlotte, North Carolina.

Complementary projects on advanced welding technologies are being funded by SR&D and the Nuclear Power Group (NPG). The focus of these projects is to develop and demonstrate automated and laser welding methods for addressing major repair priorities in fossil and nuclear plants.

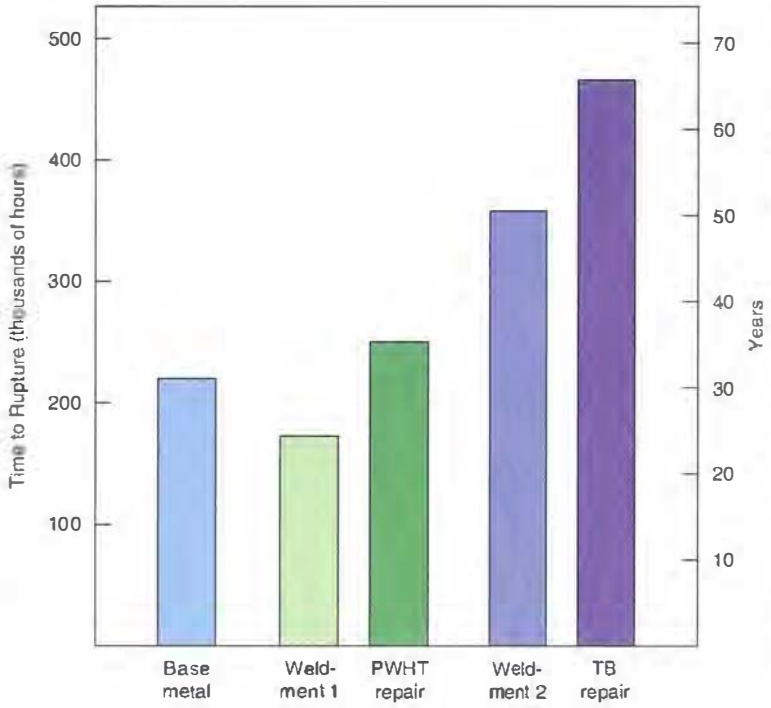
Stationary components

Many stationary components in fossil plants operate at high temperatures and pressures. Examples include header piping, reheat and main steam piping, and turbine casings, as well as ancillary components like lugs, thermowells, radiographic plugs, drains, and vents. Common damage mechanisms include creep, low-cycle/thermal fatigue, embrittlement, softening, and spheroidization. Component failure can lead to major shutdowns and may injure power plant personnel. To optimize the weld repair of aging stationary components, in 1992 EPRI initiated a tailored collaboration effort with 20 domestic and foreign utilities.

ABSTRACT *As steam generating plants age, metal components can be damaged as a result of temperature and pressure extremes, cycling, radiation, and many other factors. Utilities require proven weld repair technologies to extend the life of aging components, maximize the utilization of generation assets, and reduce failures, availability losses, and operating and maintenance costs. Decision makers and O&M personnel need to know the welding techniques best suited for a given situation, the proper procedures for implementing a cost-effective repair, and the lifetime extension expected to result. EPRI is collaborating with member utilities, manufacturers, and vendors to meet these needs. The thrusts of this work are to evaluate fundamental weldment properties and aging mechanisms, test the efficacy of existing weld repair methods for stationary and rotating components in fossil and nuclear plants, and develop repair guidelines and advanced welding technologies.*

Early work focused on characterizing the state of the art in weld repair. EPRI surveyed manufacturers, vendors, utilities, R&D organizations, and industry experts to gather methodological, cost, and performance data. On the basis of these data, preliminary guidelines were developed for performing weld repairs of aging piping and casings and for estimating the additional lifetime afforded by these procedures. These guidelines, which were recently distributed to the project's utility sponsors, include up-to-date information on a range of topics: damage mechanisms, life assessment methods and codes, inspection and testing, component evaluation, repair decision making, metallurgical analyses, damage excavation, repair methods and techniques, preheating, PWHT, consumables, materials specifications, welding management, weldability, and future R&D priorities.

Figure 1 On the basis of accelerated tests, estimates of remaining life at design conditions (1050°F and 5.8 ksi) were made for a 2.25Cr-1Mo base metal and two weldments removed from header service. (Prior service exposure was 244,000 hours at 1050°F.) Also tested were weld repairs performed on the ex-service weldments using shielded metal arc welding; the repair on one weldment included conventional postweld heat treatment (PWHT), whereas the repair on the other used temperbead (TB) techniques. (A service year was assumed to be 7000 operating hours.)



In ongoing work, the efficacy of current weld repair procedures is being tested, and the effects of service aging and weld repair on material integrity are being quantified. These studies are being conducted on slightly and severely degraded cast 2.25Cr-1Mo and 1Cr-1Mo-0.25V turbine casing materials and on wrought or forged 2.25Cr-1Mo and 1.25Cr-0.5Mo piping/header girth weldments. The properties of the base metals and of service-exposed weldments have been assessed through a matrix of mechanical and metallurgical tests. Following its characterization, each component material was repaired by using current industry practices for manual shielded metal arc welding (SMAW), gas-tungsten arc welding, or gas-metal arc welding. Also tested were temperbead techniques, which had been demonstrated in previous NPG work and which represent a promising alternative to PWHT. In these techniques, heat treatment (tempering) occurs during—rather than after—the welding process.

For 2.25Cr-1Mo header materials, EPRI work to date, combined with results from other worldwide studies, has already led to many significant conclusions. Characterization studies indicate that even material exposed to 1050°F for 240,000 hours shows no evidence of creep cavitation damage in the base metal. Also, cavitation has been observed only in nozzle welds and girth welds subjected to extraneous stresses. Both aging base metal and weld metal can be successfully repaired, with a projected life extension of 35 to 40 years. For weldments, successful weld repair requires excavation of all damaged areas, elimination of external sources of stress, and good weld repair practice. In terms of remaining life, fracture toughness, and tensile properties, the temperbead process yields results comparable to and sometimes exceeding those of SMAW repairs with PWHT—making a good case for the elimination of PWHT. Figure 1 shows life extension results for PWHT and temperbead repairs of two weldments removed from service.

For 1Cr-1Mo-0.25V turbine casing materials, SMAW temperbead repair offers better performance than PWHT repair in terms of heat-affected-zone toughness (Charpy impact). Tensile and creep property test results suggest that the industry-standard SMAW filler metal (E8018-B2) for this material overmatches the properties of the base metal by 20–30%, even at 1050°F. Filler metals with properties that more closely match those of the service-exposed base metal are being tested in ongoing efforts.

In an effort to encourage code organizations to relax PWHT requirements, temperbead test results are being provided to such organizations as the American Society of Mechanical Engineers (which oversees the Boiler and Pressure Vessel Code), the National Board of Boiler and Pressure Vessel Inspectors (which oversees the National Board Inspection Code), and the American Welding Society.

All materials property data, test results, recommendations, code changes, and revised life assessment methods will be incorporated in an updated version of the state-of-the-art guidelines for weld repairs of stationary components in fossil plants. On completion, the updated guidelines will be made available to all EPRI member utilities, providing a tool for cost-effectively extending the lifetime of key components, reducing O&M costs, and minimizing downtime for repairs.

Rotating components

In both fossil and nuclear plants, rotating components—rotors, disks, and blades—in high-, intermediate-, and low-pressure turbines are highly stressed. The causes of rotor failure in high- and intermediate-pressure turbines include creep damage,

temper embrittlement, and fatigue. Low-pressure rotors commonly experience fatigue and stress corrosion cracking at blade attachments. Nearly 200 high- and intermediate-pressure turbines will be at the end of their design life before the year 2000, and hundreds of millions of dollars in O&M costs could be saved if 10 to 20 years could be safely added to their lives. In 1995, EPRI initiated a three-year tailored collaboration project with 10 utilities, including 2 foreign companies, to identify effective weld repair procedures for rotating components.

To prepare guidelines for the weld repair of rotating components, researchers are compiling methodological, cost, and performance data from surveys of manufacturers, vendors, utilities, R&D organizations, and industry experts. The principal goal of these guidelines is to identify safe, reliable, and technically sound weld repair practices. Topics being covered include materials specifications, damage mechanisms and defects, repair decision evaluations, mechanical repair techniques, defect removal and weld repair methods, PWHT methods, metallurgical and mechanical testing procedures, inspection methodologies, machining and rebtading techniques, life assessment practices, and insurance considerations.

In addition, a case history database is being compiled from a survey of EPRI members, other utilities, repair vendors, and original equipment manufacturers. The database will document utility experience from at least 20 nuclear turbine rotor, 20 fossil turbine rotor, and 20 steam path (blade) case histories. The focus is on repairs at key locations, including blade attachment, shaft, bore, keyway, and journal repairs. A literature review covering the past 15 years will also be included. This rotor repair database will be easy to use, interactive, and accessible via computer modem. It will help utilities optimize repair practices by enabling them to identify troublesome locations on components, evaluate the successes of past repair procedures, and contact utility personnel who have dealt with similar problems. If sufficient funding is available, information gathered in the development of the guidelines and the database will be used to create a repair decision-making framework for rotating components.

Figure 2 This advanced automated pipe-welding system developed by EPRI and Magnetech combines an orbital tracking mechanism for out-of-position welding and a commercially available power supply with a "fuzzy logic" control feature that greatly improves arc stability.

Advanced welding technology

In a collaboration complementary to the stationary components effort, SR&D and RRAC have been working with Magnetech and OTC/Diahen to develop an automated, orbital flux-core welding system. The work has focused on improving existing power supplies to facilitate out-of-position welding; coupling those supplies with orbital tracking mechanisms for carrying the welding torch and head assembly around a pipe; enhancing existing filler material; and developing and testing optimized temper bead techniques.

The result of these efforts is a fast, easy-to-use, affordable system that produces high-quality welds and can perform out-of-position welding (Figure 2). The system incorporates a new concept in welding power supplies called fuzzy logic, which allows for real-time correction of welding arc instabilities by continuously switching between constant-voltage and constant-current control. The new system is expected to be marketed by Magnetech under license from EPRI.

For steam generator tubes in nuclear plants, SR&D is supporting efforts by NPG to provide a permanent repair method as an alternative to tube plugging, tube sleeving, or replacement of the entire generator. SR&D has developed a rotating optical coupler for use with NPG-developed laser welding technology. The coupler connects a fixed fiber-optic monofilament cable from the Nd-YAG (yttrium-aluminum-garnet) laser welding system to a second cable that rotates within the laser tube itself. This device allows precise optical alignment of the laser system and the rotating weld head and cable assembly. Laser energy of over 2400 watts can be transmitted through the coupler, which incorporates a so-called safety fiber to monitor and limit damage by reflected light from the welding laser. The coupler may also prove suitable for the repair of heat exchanger tubing, control rod drive housings, and hard facings. This repair technology has been licensed to ABB Combustion Engineering.

R&D coordination and technology transfer

EPRI's welding support team—which consists of staff from SR&D, the Generation and Nuclear Power Groups, and RRAC—provides technical review and steering for all the Institute's welding R&D activities. The team also coordinates work that cuts across groups, and it addresses priority utility industry needs. For example, surveys are under way in two areas: one effort is quantifying welding costs and identifying welding-related areas where utilities

should target efforts to reduce costs and improve productivity; the other is comparing U.S. and European welding approaches in order to optimize weldment design for long-term, high-temperature performance.

In addition, the team works to enhance the transfer of EPRI results and products to member companies. The R&D activities discussed in this update promise to yield numerous benefits. The state-of-the-art weld repair guidelines for stationary fossil plant components will help utilities select and apply proven condition-assessment and repair methodologies. Already, the use of weld repair to extend the life of aging steel components by 35 to 40 years has been successfully demonstrated. Proving the efficacy of temperbead repair methods to code organizations is expected to lead to the relaxation of PWHT code requirements, thereby increasing the cost-effectiveness of repair activities.

The state-of-the-art guidelines for rotating fossil and nuclear plant components will provide a tool for assessing rotor, disk, and blade damage in steam turbines and selecting appropriate repair methodologies. The guidelines also will provide a one-stop source for assessing the capabilities, facilities, and repair experience of repair vendors and original equipment manufacturers. The complementary case history database will facilitate the evaluation of alternative approaches to specific repair problems.

In the area of advanced welding technologies, automated flux-core welding and temperbead repair techniques will provide improved, cost-effective welding processes for piping and headers.

Together, these efforts will enable the life of aging components to be extended, substantially reducing repair and maintenance costs for utilities.

New Computer Software

Orders for EPRI-developed software should be directed to the Electric Power Software Center, 11025 North Torrey Pines Road, La Jolla, California 92037, (800) 763-3772. EPRI members can receive, free of charge, software developed by the business units to which they subscribe. Others should contact EPRI's Licensing Office at (415) 855-2974.

COMMEND: Commercial End-Use Forecasting Model
Version 4.1 (PC-DOS)
Contractor: Regional Economics Research
Business Unit: Retail Market Tools & Services
EPRI Project Manager: Paul Meagher

Desk Book™: Residential End-Use Technologies
Version 2.0 (PC-DOS/Windows)
Contractor: Energy International, Inc.
Business Unit: Residential Technologies & Services
EPRI Project Manager: John Kesselring

DEW: Distribution Engineering Workstation
Version 1.0 (PC-DOS/Windows)
Contractors: BSG Alliance/IT, Inc.; Virginia Polytechnic Institute
Business Unit: Distribution
EPRI Project Manager: Harry Ng

DSManager: Demand-Side Management Analysis Software
Version 2.5 (PC-DOS)
Contractor: EPS Solutions
Business Unit: Retail Market Tools & Services
EPRI Project Manager: Perry Sioshanshi

EMFWorkstation: EPRI Electric and Magnetic Fields Workstation
Version 2.5 (PC-DOS)
Contractor: Enertech Consultants
Business Unit: Environmental & Health Sciences
EPRI Project Manager: Randall Takemoto-Hambleton

ERCAWS: EPRI Root Cause Advisory Workstation
Version 2.0 (PC-DOS)
Contractor: FPI International, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: Avtar Singh

FAULT: Fault Analysis and Underground Location Techniques
Version 1.0 (PC-DOS/Windows)
Contractor: Power Technologies, Inc.
Business Unit: Transmission
EPRI Project Manager: Don Von Dollen

FUELBURN
Version 2.0 (PC-DOS/Windows)
Contractor: Applied Decision Analysis
Business Unit: Utility Resource Planning & Management
EPRI Project Manager: Richard Goldberg

GLOCO™: Global Carbon Cycle Model
Version 2.1 (PC-DOS/Windows; Macintosh)
Contractor: Tetra Tech, Inc.
Business Unit: Environmental & Health Sciences
EPRI Project Manager: Robert Goldstein

INTURB: Informational Database for Gas Turbines
Version 4.0 (PC-DOS/Windows)
Contractor: Combustion Turbine Technologies Co.
Business Unit: Gas & New Coal Generation
EPRI Project Manager: Robert Frischmuth

IRP-Manager
Version 1.2.2 (PC-DOS)
Contractor: EPS Solutions
Business Unit: Retail Market Tools & Services
EPRI Project Manager: Perry Sioshansi

Life-Cycle Cost Management System
Version 1.0 (PC-DOS)
Contractor: Decision Focus Inc.
Business Unit: Environmental Control
EPRI Project Manager: Mary McLearn

LightPAD
Version 2.0 (PC-DOS)
Contractor: The Weidt Group
Business Unit: Commercial Technologies & Services
EPRI Project Manager: Karl Johnson

PMW: Plant Monitoring Workstation
Version 4.11 (PC-OS/2)
Contractor: Power Technologies, Inc.
Business Unit: Fossil Power Plants
EPRI Project Manager: John Bickley

PowerDOE™
Version R1.0 (PC-Windows)
Contractor: J. J. Hirsch & Associates
Business Unit: Commercial Technologies & Services
EPRI Project Manager: Karl Johnson

REEPS: Residential End-Use Energy Planning System
Version 2.2 (PC-DOS)
Contractor: Regional Economics Research
Business Unit: Retail Market Tools & Services
EPRI Project Manager: Paul Meagher

TRELSS: Transmission Reliability Evaluation for Large-Scale Systems
Version 3.0 (PC-DOS; RS6000-AIX)
Contractor: Southern Company Services
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: Ram Adapa

WINSQUG
Version R1.2 (PC-Windows)
Contractor: EQE International
Business Unit: Nuclear Power
EPRI Project Manager: Robert Kassawara

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. EPRI members that fund the business unit issuing a report can receive the report free of charge (or, in the case of bulk orders, for a nominal price). Domestic organizations not eligible for EPRI membership pay the listed price. Others should contact the Distribution Center for further information.

Two-page summaries of the reports announced here are available, free of charge, by fax. To receive a summary, call EPRI's Fax on Demand service (800-239-4655) from a touch-tone phone and follow the recorded instructions, using the fax identification number given in the report listing.

CUSTOMER SYSTEMS

Cool Storage Open Hydronic Systems Design Guide
TR-104906 Final Report (RP3280-3); $75
Contractors: Gatley & Associates, Inc.; Mackie Associates
Business Unit: Commercial Technologies & Services
EPRI Project Managers: M. Khattar, R. Wendland
Fax ID: 23386

Assessment of HVAC Installations in New Homes in Nevada Power Company's Service Territory
TR-105309 Final Report (WO3841-3); $200
Contractor: Proctor Engineering Group
Business Unit: Residential Technologies & Services
EPRI Project Manager: S. Kondepudi
Fax ID: 24091

New Construction HVAC Program Implementation Plan for Nevada Power Company
TR-105310 Final Report (WO3841-3); $200
Contractor: Proctor Engineering Group
Business Unit: Residential Technologies & Services
EPRI Project Manager: S. Kondepudi
Fax ID: 24093

Proceedings: Energy-Efficient Office Technology, 1994 (International Seminar)
TR-105549 Proceedings (WO2890-18); $200
Contractor: Policy Research Associates, Inc.
Business Unit: Commercial Technologies & Services
EPRI Project Managers: M. Blatt, J. Kesselring
Fax ID: 24419

Proceedings: Efficient Lighting, 1993 (Symposium for Utility Lighting and DSM Professionals)
TR-105963 Proceedings (RP3367-6); $200
Contractor: Policy Research Associates, Inc.
Business Unit: Commercial Technologies & Services
EPRI Project Manager: K. Johnson
Fax ID: 25059

ENVIRONMENT

Exposure to Electromagnetic Fields During Pregnancy and Associated Risks for Intrauterine Growth Retardation and Spontaneous Abortion
TR-105756 Final Report (RP2964-2); $200
Contractor: Department of Epidemiology and Public Health, Yale University School of Medicine
Business Unit: Environmental & Health Sciences
EPRI Project Manager: L. Kheifets
Fax ID: 24709

Kauai Endangered Seabird Study, Vols. 1 and 2
TR-105847-V1, TR-105847-V2 Final Report (WO3521-1, -2); $200 each volume
Contractors: Alaska Biological Research, Inc. (Vol. 1); Point Reyes Bird Observatory (Vol. 2)
Business Unit: Environmental & Health Sciences
EPRI Project Manager: M. Fraser
Fax ID: 24850

Development of the Residential Case-Specular Epidemiologic Investigation Method
TR-105900 Final Report (RP4305-1); $200
Contractor: Enertech Consultants
Business Unit: Environmental & Health Sciences
EPRI Project Manager: K. Ebi
Fax ID: 24942

GENERATION

Dis-Gen Advisor: Market-Based Guidelines for Evaluating Distributed Generation Investments for T&D Grid Support and Customer Energy Service Applications
TR-102532-V2 Final Report (RP1677-20, RP3897); license required
Business Unit: Gas & New Coal Generation
EPRI Project Manager: D. Rastler
Fax ID: 24572

Acoustic Emission Monitoring of High-Energy Steam Piping, Vol. 1: Guidelines for Hot Reheat Piping
TR-105265-V1 Final Report (RP1893-20); $10,000
Contractor: Pacific Gas and Electric Co.
Business Unit: Fossil Power Plants
EPRI Project Manager: R. Tilley
Fax ID: 24024

Results of 30-Day Petroleum Cofire Test at the Houston Lighting & Power W. A. Parish Station
TR-105491 Final Report (RP3920); $10,000
Contractors: Radian Corp.; Houston Lighting & Power Co.
Business Unit: Fossil Power Plants
EPRI Project Manager: D. O'Connor
Fax ID: 24331

Making Biopower Work for Utilities: A Rationale for Near-Term Investment in Integrated Biomass Power Systems
TR-105854 Final Report (RP3407); $10,000
Business Unit: Renewables & Hydro
EPRI Project Manager: J. Turnbull
Fax ID: 24866

Round-Robin Study of Methods for Trace Metal Analysis: Graphite Furnace Atomic Absorption Spectroscopy—Aluminum, Beryllium, and Thallium
TR-105910 Final Report (RP1851-1); $10,000
Contractor: TRW Inc.
Business Unit: Environmental Control
EPRI Project Manager: B. Nott
Fax ID: 24958

Coal Supply and Transportation Markets During Phase One: Change, Risk, and Opportunity
TR-105916 Final Report (RP4125-1); $10,000
Contractor: Fieldston Co., Inc.
Business Unit: Fossil Power Plants
EPRI Project Manager: J. Platt
Fax ID: 24968

NUCLEAR POWER

Guidelines and Criteria for Nuclear Piping and Support Evaluation and Design, Vol. 9: Guidance on Load Definition and Load Combinations
TR-101968-V9 Final Report (RP2967-2); $1000
Contractor: Duke Power Co.
Business Unit: Nuclear Power
EPRI Project Manager: H. Tang
Fax ID: 25400

Precipitation Kinetics, Thermal Stability, and Corrosion Properties of Alloy 718 and 718-Based Superalloys
TR-103971 Final Report (RP2181-9); $20,000
Contractor: University of Texas, Austin
Business Unit: Nuclear Power
EPRI Project Manager: L. Nelson
Fax ID: 21299

Effect of Nuclear Power Plant Decommissioning Costs on Plant Life Cycle Decisions
TR-104829 Final Report (RP3343-1); $3000
Contractors: Baltimore Gas and Electric Co.; ABZ, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 23248

Experience With Elevated pH at the Millstone Point-3 PWR
TR-105245 Final Report (RP2648-1); $20,000
Contractor: Westinghouse Electric Corp.
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
Fax ID: 23989

EPRI PWR Fuel Cladding Corrosion (PFCC) Model, Vol. 1: Theory and User's Manual
TR-105387-V1 Final Report (RP1250-25); license required
Contractor: S. Levy Inc.
Business Unit: Nuclear Power
EPRI Project Manager: B. Cheng
Fax ID: 24206

Interim On-Site Storage of Low-Level Waste Facility Design Options: Bulk Ion-Exchange Resin Storage
TR-105784 Final Report (RP3800-1); $10,000
Contractor: Sargent & Lundy
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24750

Monitoring and Inspection of Low-Level Radioactive Waste Stored at Nuclear Power Plants
TR-105785 Final Report (RP3800-12); $10,000
Contractors: Sargent & Lundy; ENCORE Technical Resources, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24752

Waste Forms for Extended Storage
TR-105787 Final Report (WO3800-20); $500
Contractor: R. Kohout & Associates, Ltd.
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24756

An Economic Analysis of BWR Control Rod Blade Management Strategies
TR-105812 Final Report (RP4035-1); $20,000
Contractor: Decision Focus Inc.
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
FaxID: 24795

Chromium Coatings to Reduce Radiation Buildup
TR-105813 Final Report (RP2758-2); $20,000
Contractor: CENTEC XXI
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
Fax ID: 24797

NOREM Applications Guidelines: Procedures for Gas Tungsten Arc and Plasma Transferred Arc Welding of NOREM Cobalt-Free Hardfacing Alloys
TR-105816 Final Report (RP1935-19), $10,000
Contractor: EPRI Repair and Replacement Applications Center
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
Fax ID: 24803

Mixed Waste Treatment Study
TR-105826 Final Report (WO3800-22); $10,000
Contractor: Duke Engineering & Services, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24817

Cost-Effective Liquid Processing Programs
TR-105859 Final Report (RP2414); $10,000
Contractor: CENTEC XXI
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24876

Quality Assurance Grading Criteria for Plant Systems and Components: Results From a Pilot Plant Project at Grand Gulf Nuclear Station
TR-105868 Final Report (RP3719-2); $5000
Contractor: Science Applications International Corp.
Business Unit: Nuclear Power
EPRI Project Manager: F. Rahn
Fax ID: 24890

Crack Growth and Microstructural Characterization of Alloy 600 Head Penetration Materials
TR-105958 Interim Report (RP3223-7), $1000
Contractor: Westinghouse Electric Corp.
Business Unit: Nuclear Power
EPRI Project Manager: R. Pathania
Fax ID: 25051

Proceedings: 1995 Radiation Field Control and Decontamination Seminar, Vols. 1 and 2
TR-106009-V1, TR-106009-V2 Proceedings (RP1935); $1000 for set
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
Fax ID: 25294

Cured-in-Place Piping for Structural and Pressure Boundary Integrity: Interim Report
TR-106013 Interim Report (WO3052-13, -14); $30,000
Contractors: ProtoPower Corp., Energy International, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: N. Hirota
FaxID: 25142

POWER DELIVERY

Active Cancellation of Transformer Noise, Vols. 1–3
TR-102924 Final Report (RP2744-1), $5000
Contractor: Angevine Acoustical Consultants, Inc.
Business Unit: Substations, System Operations & Storage
EPRI Project Managers: B. Damsky, G. Addis, S. Wright
Fax ID: 19503

Reaping the Benefits of RTP: Georgia Power's RTP Evaluation Case Study, Vols. 1 and 2
TR-105044 Final Report (RP7802-6, -8); $10,000
Contractor: Laurits R. Christensen Associates, Inc.
Business Unit: Utility Resource Planning & Management
EPRI Project Manager: C. Smyser
Fax ID: 23651

DRUMS Dynamic Feeder Rating for Pipe-Type Cable Systems
TR-105251 Final Report (RP7900-1); $5000
Contractor: Underground Systems, Inc.
Business Unit: Transmission
EPRI Project Managers: T. Rodenbaugh, F. Garcia
Fax ID: 23988

Effects of Transient Voltages on Power Semiconductor Devices
TR-105319 Final Report (RP3389-4); $5000
Business Unit: Distribution
EPRI Project Manager: A. Sundaram
Fax ID: 24107

Steady-State Voltage Monitoring and Control
TR-105393 Final Report (RP2473-70); $5000
Contractor: Massachusetts Institute of Technology
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: D. Maratukulam
Fax ID: 24214

Underground Cable Fault Location Reference Manual
TR-105502 Final Report (RP7913-3); $5000
Contractor: Power Technologies, Inc.
Business Unit: Transmission
EPRI Project Manager: D. Von Dollen
Fax ID: 24350

Superconducting Magnetic Energy Storage in Trapped Field Magnets of High-Temperature Superconductors
TR-105751 Final Report (RP7921); $5000
Contractor: University of Houston
Business Unit: Transmission
EPRI Project Managers: M. Rabinowitz, D. Von Dollen
Fax ID: 24702

Energy-Based Dynamic Security Assessment Tools for Maintaining Voltage Stability
TR-105796 Final Report (RP3103-4); $5000
Contractor: University of Wisconsin, Madison
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: P. Hirsch
FaxID: 24769

Intercontrol Center Communications Protocol (ICCP) Demonstration
TR-105800 Final Report (RP3830-1); $200
Contractor: ECC, Inc.
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: A. Vojdani
Fax ID: 24777

STRATEGIC R&D

Sensitive Landscape Features for Detecting Biotic Effects of Global Change
TR-105216 Final Report (RP8020-13), $200
Contractor: Applied Biomathematics
Business Unit: Strategic R&D
EPRI Project Managers: L. Pitelka, J. Maulbetsch
Fax ID: 23946

Control Room Crew Operations Research Project
TR-105280 Final Report (RP8013-4), $40,000
Contractors: Halliburton NUS; University of Maryland
Business Unit: Strategic R&D
EPRI Project Manager: A. Singh
FaxID: 24050

The Electricity-Society Connection: A Forum of the Electric Power Research Institute
TR-105485 Final Report (RP8013-18), $200
Contractors: Walter H. Esselman; Jack M. Hollander, Thomas R. Schneider
Business Unit: Strategic R&D
EPRI Project Manager: T. Schneider
Fax ID: 24322

The Origin and Properties of Unburned Carbon From Pulverized-Coal Combustion
TR-105743 Final Report (RP8005), $200
Contractor: Sandia National Laboratories
Business Unit: Strategic R&D
EPRI Project Manager: A. Mehta
Fax ID: 24690

Power System Control Valuation Methodology
TR-106031 Final Report (RP3436-9); $200
Contractor: GE Power Systems
Business Unit: Strategic R&D
EPRI Project Manager: V. Longo
Fax ID: 25174

EPRI Events

JUNE

24–26
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

JULY

11–12
EPRI Partnership for Industrial Competitiveness
Philadelphia, Pennsylvania
Contact: Bill Smith, (415) 855-2415

22–24
1996 International Low-Level-Waste Conference
New Orleans, Louisiana
Contact: Michele Samoulides, (415) 855-2127

24–26
ASME/EPRI Radwaste Workshop
New Orleans, Louisiana
Contact: Michele Samoulides, (415) 855-2127

25–26
Manufactured Distribution and Transmission Pole Structures
Denver, Colorado
Contact: Kathleen Lyons, (415) 855-2656

29–30
Turbine Generator Operation
Toronto, Canada
Contact: Denise Wesalainen, (415) 855-2259

29–August 1
Fossil Plant Maintenance Conference
Baltimore, Maryland
Contact: Lori Adams, (415) 855-8763

AUGUST

4–8
4th International Conference on Mercury as a Global Pollutant
Hamburg, Germany
Contact: Don Porcella, (415) 855-2723

5–7
Turbine Generator Operation
Redondo Beach, California
Contact: Denise Wesalainen, (415) 855-2259

6–9
Workshop on NO_x Controls for Utility Boilers
Cincinnati, Ohio
Contact: Susan Bisetti, (415) 855-7919

7–9
International Conference on Sustainable Thermal Energy Storage
Minneapolis, Minnesota
Contact: Beverly Speer, (608) 262-8220

11–16
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Amy Winn, (816) 235-5620

13–15
EMF Workstation 2.5: Training Seminar
Dallas, Texas
Contact: Robert Kavet, (415) 855-1061

18–23
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Amy Winn, (816) 235-5620

20–22
Nondestructive Evaluation Issues: Annual Meeting
Charlotte, North Carolina
Contact: Susan Otto, (704) 547-6072

26–30
Condenser Technology Seminar and Conference
Boston, Massachusetts
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

3–4
Nuclear Plant Performance Improvement
Asheville, North Carolina
Contact: Susan Otto, (704) 547-6072

10–13
1996 EPRIweb Conference
Atlanta, Georgia
Contact: Michele Samoulides, (415) 855-2127

11–13
Underground Transmission Lines: Technical Review
Baltimore, Maryland
Contact: Kathleen Lyons, (415) 855-2656

15–22
Transmission and Distribution Conference and Expo
Los Angeles, California
Contact: Andrea Duerr, (415) 855-2640

17–18
Advanced Market-Based Products for Electricity Pricing
Denver, Colorado
Contact: Connie Smyser, (415) 855-2396

19–20
Remediation of Contaminated Sites
Chicago, Illinois
Contact: Ishwar Murarka, (415) 855-2150

22–25
7th International Symposium on Interaction Between Sediments and Water
Baveno, Italy
Contact: Bob Brocksen, (415) 855-7961

24–25
Motor Rewind Seminar
Atlanta, Georgia
Contact: Denise Wesalainen, (415) 855-2259

24–25
Operational Reactor Safety Engineering and Review Group
San Antonio, Texas
Contact: Susan Bisetti, (415) 855-7919

25–27
International Workshop on Main Coolant Pumps
Pittsburgh, Pennsylvania
Contact: Susan Otto, (704) 547-6072

30–October 1
Power Quality Marketing Workshop
Knoxville, Tennessee
Contact: Karen Forsten, (423) 974-8288

OCTOBER

1–3
Risk Management for Competitive Markets
Baltimore, Maryland
Contact: Susan Marsland, (415) 855-2946

1–4
1996 Gasification Technologies Conference
San Francisco, California
Contact: Michele Samoulides, (415) 855-2127

2–4
Magnetic Field Management Seminar
Lenox, Massachusetts
Contact: Leeka Kheifets, (415) 855-8976

3–4
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Robert Goldstein, (415) 855-2593

7–10
Hydrogenerator Maintenance
Seattle, Washington
Contact: Denise Wesalainen, (415) 855-2259

9–10
Advanced Market-Based Products for Electricity Pricing
Atlanta, Georgia
Contact: Connie Smyser, (415) 855-2396

14–16
Managing Fossil Generating Assets in the Marketplace
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

15–16
Using EPRI Land and Water Models
Dallas, Texas
Contact: Ishwar Murarka, (415) 855-2150

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