The Road to Industrial Electrification

ELECTRIC POWER RESEARCH INSTITUTE

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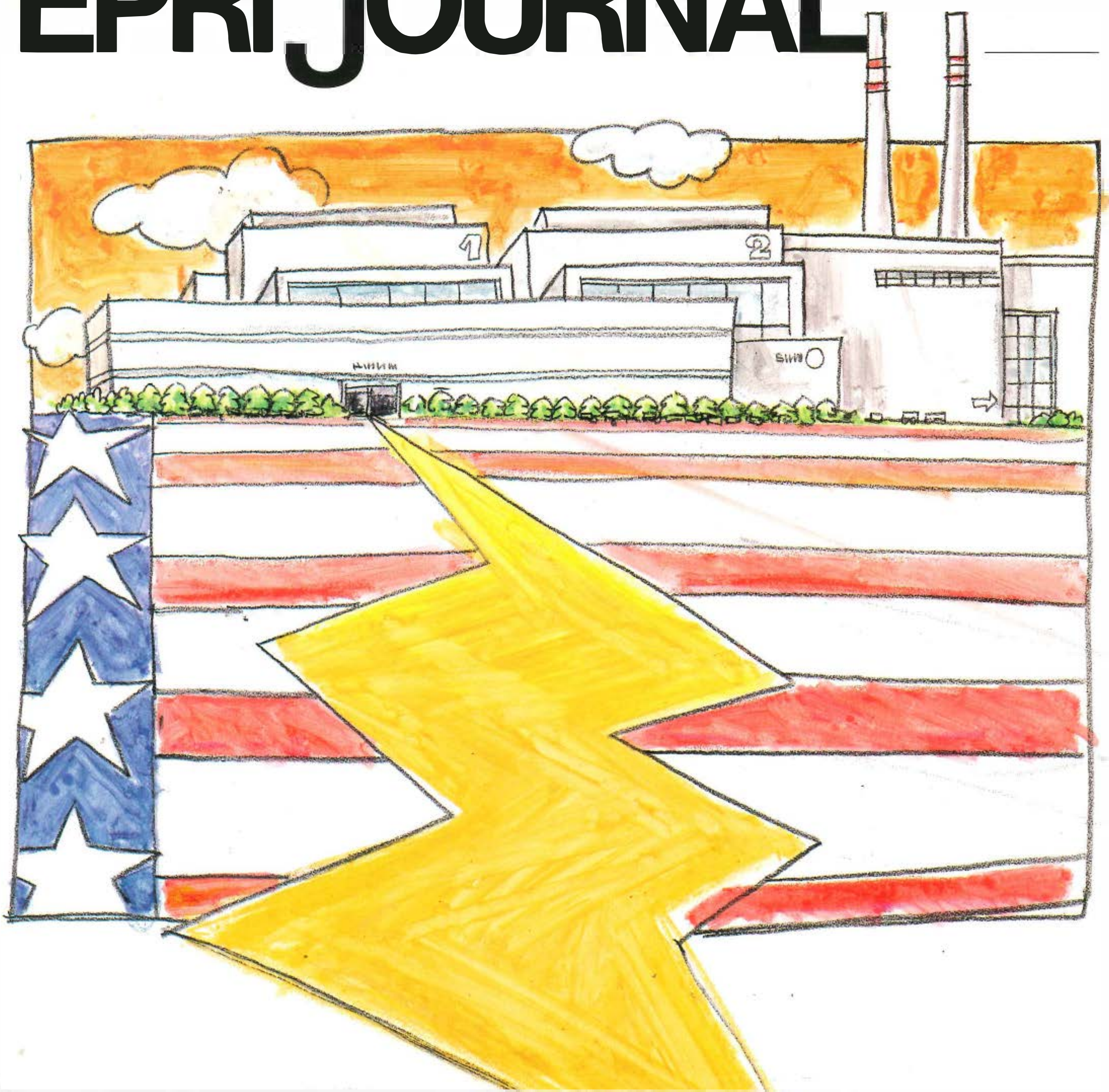

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Cover: Offering higher efficiency and flexibility, electrotechnologies provide an ideal path to greater competitiveness in the industrial sector.

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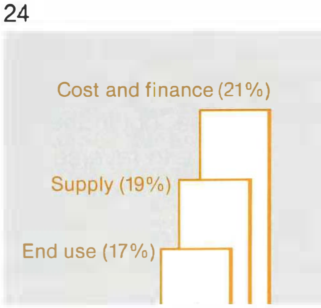

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Collaborating to Compete

Fickett

The industrial load tends to be a utility's best load. While the residential and commercial sectors' high daytime energy use requires the expensive cycling of peaking units by utilities, industries often operate nearly continuously, which allows their demand to be served on a more economical baseload level. Unfortunately, the industrial customer base of utilities has been slowly eroding. Until recently, this change was largely masked by such highly publicized issues as protracted schedules for nuclear construction, high inflationary costs, environmental protection, mandated conservation, and fuel price shocks.

Faced with increased energy and labor costs and the expense of complying with stricter environmental regulations, many U. S. industries have been unable to compete effectively with lower-cost foreign imports. Primary metals, textiles, appliances, and automobiles are but a few of the industries that have suffered in the marketplace. But the effects go further. As these industries lose market share and produce fewer goods, they also use less electricity. And as the industrial load erodes, the "peaky" residential/commercial demand becomes a greater proportion of a utility's total load, which increases the cost of producing electricity. Industrial customers are then faced with higher electricity costs and become even less competitive than before. The overall result is an insidious downward spiral—one that is just now being recognized by utilities and regulators.

Electrotechnologies offer a means of breaking this spiral. Electricity is unique in the flexibility and efficiency of its use, and when applied to industrial processes it can improve productivity, quality, and value in ways that are not possible with other energy forms. Laser welding and cutting, microwave drying, induction heating, and electric arc furnaces for steelmaking are examples of electrotechnologies that have created new industrial opportunities. The United States has the world's best electrotechnology resource base, but in the past we have been all too willing to watch this resource move offshore. If we are to reverse the downward spiral, we must find a way to deploy our electrotechnologies onshore and modernize industries through a collaborative effort of industry, utilities, regulators, and government. The payoff is obvious: industry becomes more competitive, jobs are created, the balance of trade is improved, utility generators are better utilized, and electricity costs are lowered.

"Marketing Electrotechnology to Industry," an international conference held in Atlanta last November, was an important step in this collaborative effort. Hopefully, the enthusiasm and momentum generated there will become contagious and accelerate as we move forward toward a new, mutually beneficial partnership.

Arnold Fickett

Arnold Fickett, Director
Energy Utilization Department
Energy Management and Utilization Division

Authors and Articles

Harry Roberts Bigger Feher Young Dalton Dene Syrett

Marketing Electrotechnology to Industry (page 4) restates the main lessons of a conference on new electricity applications and new utility business strategies that can boost the productivity and profitability of industrial electricity users. Written by Taylor Moore, the *Journal*'s senior feature writer, aided by staff members of EPRI's Energy Management and Utilization Division.

Arnold Fickett, director of the Energy Utilization Department since October 1985, previously headed EPRI's research on energy conversion and storage for nearly five years. He came to EPRI in 1974 as a project manager for fuel cell R&D, after 18 years with General Electric Co.

I. Leslie Harry, newly named manager of the Industrial Program, has managed research on electricity use in manufacturing processes since 1980. Two ongoing joint R&D programs in metals production and metals fabrication grew out of his projects. Harry was a consultant to Science Applications, Inc., before coming to EPRI, and from 1971 to 1978 he was with the Department of Energy. ■

Opening the Tap on Hydrothermal Energy (page 16) reports on the successful demonstration of a commercial-scale plant that is generating power from geothermal resources too cool to make steam. Written by John Douglas, science writer, with technical information from members of EPRI's Advanced Power Systems Division.

Vasel Roberts has managed geothermal R&D for EPRI since 1975, his program focusing on processes and equipment for energy recovery. He was formerly with the Jet Propulsion Laboratory (California Institute of Technology) for seven years, where he worked on systems for planetary landings and exploration. Still earlier, he was a systems engineer with Sperry Rand Corp.

John Bigger has been a project manager for geothermal energy system R&D since 1983, primarily coordinating the design, construction, and operation of the demonstration plant featured in this article. He earlier managed a demonstration project for solar-thermal power generation. Bigger came to the Renewable Resources Systems Department in 1976 from the Los Angeles Dept. of Water & Power, where he had worked for 10 years in transmission design and construction and in the planning and development of alternative energy resources. ■

Critical Issues: How Utilities See Their Future (page 24) highlights the answers that EPRI member utilities provided in response to an open-ended survey last year. Written by Michael Shepard, *Journal* feature writer, who drew on the analyses of two strategic planners in EPRI's Planning and Evaluation Division.

Sherman Feher, a planning analyst, investigates economic and regulatory factors that influence utilities and EPRI in their planning. He came to the Institute in 1978 after early career work in urban planning.

Frank Young, manager of strategic planning since 1981, has worked in that field since 1977. He joined the EPRI staff in 1975 as a program manager for overhead transmission R&D, after 20 years with Westinghouse Electric Corp., where he had become manager of UHV transmission research. ■

Scrubbers: Battling Corrosion on a Grand Scale (page 30) traces the evolution of utility problems with corrosive agents in coal combustion exhaust gas and reviews EPRI's work to identify and test corrosion-resistant construction materials for flue gas desulfurization systems. Written by Ralph Whitaker, *Journal* feature editor, with input from research managers of EPRI's Coal Combustion Systems Division and Materials Support Group.

Stuart Dalton, manager of the Desulfurization Processes Program since 1979, came to EPRI in 1976 after four years in engineering with Pacific Gas and Electric Co. and three years with Babcock & Wilcox Co.

Charles Dene, a project manager in desulfurization research, began his EPRI career in 1978 as a facilities manager for two pilot plant studies at a Tennessee Valley Authority power station. From 1973 to 1977 Dene was a research engineer for pollution control equipment at Detroit Edison Co.

Barry Syrett, a technical adviser specializing in aqueous corrosion, has been with EPRI since June 1979. He was previously with SRI International for seven years, where he organized a program of corrosion research. Before that, from 1970 to 1972, he was a research scientist with International Nickel Co. ■

MARKETING ELECTROTECHNOLOGY TO INDUSTRY

Strategic use of electricity-powered technologies and processes could help American industry regain a competitive edge. Utilities are joining equipment vendors in marketing a broad range of electrotechnologies to their industrial customers.

For years considered taboo, marketing is in a renaissance in the electric power business. Utilities are dusting off the marketing hats many packed away over a decade ago and are scrambling to compete in an ailing industrial sector against the less efficient but cheaper fossil fuels: oil and gas.

Meanwhile, a wide array of new or improved electricity-based industrial processes and technologies has been emerging against a backdrop of tightening international competition, lagging American industrial productivity, retrenchment from capital investment, and resistance to change on a broad front.

Promising substantially greater productivity, improved product quality, or reduced labor and materials input thanks to the high form value of the electricity they use, these technologies could prove to be the winning weapons in the international industrial arena. As diverse as the markets they serve, electrotechnologies have come to be seen by utilities as their best hope for maintaining or enlarging their industrial customer base—if utilities can encourage industry to adopt them.

Electrotechnologies are finding important niches across the full spectrum of industrial energy use. Arc furnaces have already made an impact in the wounded but convalescing metals production industry, now accounting for about a third of steel production. Electron beams, lasers, and electricity-powered plasmas could do as much and more for the melting, welding, and cutting jobs in other metals sectors. In manufacturing, robots are transforming, albeit slowly, Henry Ford's vision of the assembly line, while computer-aided design and manufacturing-control systems are reshaping the roles of draftsman and foreman.

In nonmetals fabrication, resistance heating, already in wide use in the glass and plastics industries, holds equal promise for other materials, particularly ceramics. Induction, infrared, ultraviolet, radio-frequency, and microwave heating, curing, and drying technologies have already demonstrated their value, as well as their potential for broader application.

In chemical and other process industries, whose electricity consumption nearly equals that of all other industrial manufacturing uses combined, electrotechnologies also have much to offer. Electric heat pumps can dramatically reduce energy requirements in many industrial processes by getting more work from heat that is normally wasted. And over the next decade, semiconductor-based adjustable-speed drives and other power electronic controls will forever change for the better every device that uses large amounts of electricity.

Understanding the markets for these technologies and ways of encouraging customers to apply them in the context of economic competitiveness and revitalization formed the themes of a three-day conference and workshop in Atlanta last November. Sponsored by EPRI, the Canadian Electrical Association, and Edison Electric Institute (EEI) and hosted by Georgia Power Co., more than 200 representatives of utilities and electrotechnology vendors gathered under the banner "Marketing Electrotechnologies to Industry" to trade insights and a few success stories.

Mutual dependence

Why should electric utilities entering a new era of interfuel and even interutility competition concern themselves with helping industrial customers be more competitive? "Because the financial health of individual utilities—and, to a significant extent, of the industry overall—is intimately coupled with the health of their largest customers, who have traditionally been among the best customers in terms of revenue and load profile," said Arnold Fickett, director of energy utilization at EPRI and a conference speaker.

Noting the trend among American manufacturers to either retreat from global competition or bid au revoir to domestic shores for more-favorable economic climes elsewhere, Fickett added, "We have no choice but to develop a strategy that will keep our industrial customers onshore—our own industry's health and future depend on them." Industry uses 36% of all the electricity consumed in the United States and a similar share of total primary energy.

EPRI is playing a key role in developing that strategy. Three new cooperative R&D applications centers in metals production, metals fabrication, and power electronics are focusing technical talent and pooling utility and industrial resources on the most promising electrotechnologies in major sectors.

The Center for Metals Production (CMP) and the Center for Metals Fabrication (CMF), located at the Mellon Institute in Pittsburgh, Pennsylvania, and at Battelle Memorial Institute in Columbus, Ohio, respectively, are gaining national reputations for excellence and expertise. Hopes are also high for the Power Electronics Applications R&D Center, recently established with the Tennessee Center for Research and Development in Knoxville for pursuit of a wide variety of applications. The centers complement an expanding EPRI program in industrial demand-side management that includes new data base and modeling tools for analyzing industrial energy use in specific customer categories and processes.

"With the applications centers, we've created some nuclei we would like to see industry build on," explained Richard Balzhiser, EPRI's senior vice president for research and development. "We're trying to make things happen and happen in real time," added Balzhiser, who spoke at the conference of renewing the partnership between utilities and their industrial customers.

Conferees heard a chorus of experts

update the status of three major industrial sectors—steel, transportation, and pulp and paper. The overviews backed up the observation by Paul Stewart, special assistant to the marketing and customer services vice president at Pennsylvania Power & Light Co. (PP&L), that "what many of us were predicting in the early 1980s has come true in terms of international competitiveness and the demise of our basic industrial manufacturing."

Stewart added that the secondary and tertiary effects of those developments are now being felt in the form of management and union workforce reductions, plant closings, continued high financial losses in some metals industries, divestiture, the breakup of integrated manufacturing operations, and drastic reductions in or elimination of R&D spending.

CORPORATE STRATEGIES of restructuring, cost containment, and restricting new ventures are "usually insufficient" to turn around a troubled business, according to Stewart. In the metals industries, the single feature distinguishing profitable and competitive enterprises is that they were "willing to take calculated risks to improve technology and manufacturing capability. Companies that refuse to take business ventures to improve their position will ultimately disappear from the manufacturing scene," warned Stewart.

Industrials should be seen as more than just marketing opportunities for utilities. "Each utility is only as strong economically as the service area and the industrial manufacturing it serves," Stewart commented. Expecting and planning for change will require great flexibility and adaptability on the part of utilities, including innovative rate options (an issue that surfaced frequently during the Atlanta meeting). In addition, utilities must promote least-cost production concepts, such as minimized overhead, modular facilities, and just-in-time delivery systems, and encourage the use of electrotechnologies through utility marketing organizations that fully understand customers and their needs. And, as other speakers echoed, utilities must often share the technical and financial risks with customers in demonstrating new technology.

But gaining the depth of familiarity with a particular customer necessary to influence a decision to adopt electrotechnologies can itself be a major challenge. Noting that two-thirds of the manufactured components in American-made automobiles come from independent suppliers each employing fewer than 250 people, Richard Macan of the Industrial Technology Institute said, "It's the Fortune 100 companies that spend the money for new technology, but the subtiered shops need the most help." Macan pointed out there is a delicate social balance in corporate management in implementing new technology—as much attention must be paid to training and other human aspects as to the technical apparatus.

The importance of a utility understanding and working closely with its customers was illustrated in one case by the example of Durivage Pattern Co., located near Toledo, Ohio. The maker of specialty molds and precision patterns developed a working-partner relationship with Toledo Edison Co. that led it to install three computer numerical control machines coupled with a full-scale computer-aided design and manufacturing (CAD/CAM) system. Through personal contact with the utility, the firm got help from CMF and now uses a telephone modem link for on-line assistance in generating molds directly from CAD tape, bypassing several pattern steps in the conventional process and increasing productivity. "CMF has been a big brother to lean on," reported Larry Durivage, company president. "Utilities have the power and the resources to help small shops like ours understand that they're there to help."

Several speakers cited high industrial demand charges—based on peak power demand and assessed over and beyond rates for kWh consumption—as a double barrier for electrotechnologies when considered in tandem with the already cheaper cost of oil or gas that many industrials use. "Utilities must eliminate or restructure demand charges if electrotechnologies are to be competitive," insisted George Krahn, vice president of BGK Finishing Systems, Inc., a Plymouth, Minnesota, producer of high-intensity infrared equipment for the rapid curing of industrial coatings.

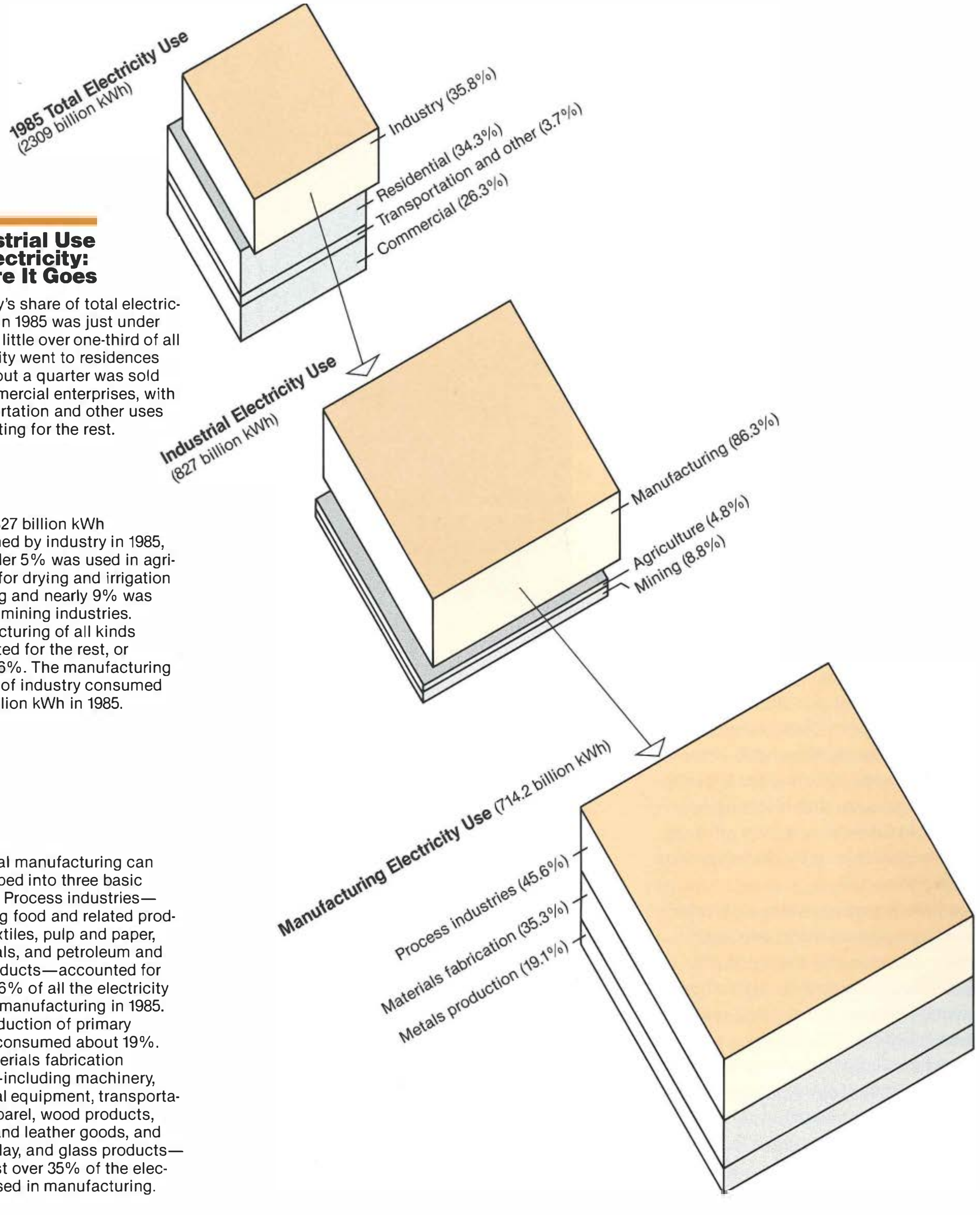
PP&L's Stewart noted a growing tendency among utilities to try to combine customer load shapes with capacity availability and offer the lowest rates possible. Many already offer liberal time-of-use and interruptible industrial rates. Charles McClelland, publisher of the *Industrial Heating Journal,* called the significantly lower cost of fossil fuels "a monumental stumbling block" to the adoption of electrotechnologies. "Meanwhile, fossil-fuel-based systems are not going out of date but are innovating and becoming more efficient."

The electric advantage

Electrotechnologies offer so much more in benefits, however—benefits that, when appropriately applied and documented, more than counterbalance the factor of 3–5 fuel price advantage enjoyed by oil and gas. In typical industrial use, fossil fuels may be less efficient than electricity-based processes by a factor of 3 or more. Because electro-

Industrial Use of Electricity: Where It Goes

Industry's share of total electricity use in 1985 was just under 36%. A little over one-third of all electricity went to residences and about a quarter was sold to commercial enterprises, with transportation and other uses accounting for the rest.



Of the 827 billion kWh consumed by industry in 1985, just under 5% was used in agriculture for drying and irrigation pumping and nearly 9% was used in mining industries. Manufacturing of all kinds accounted for the rest, or about 86%. The manufacturing sectors of industry consumed 714.2 billion kWh in 1985.

Industrial manufacturing can be grouped into three basic sectors. Process industries—including food and related products, textiles, pulp and paper, chemicals, and petroleum and coal products—accounted for nearly 46% of all the electricity used in manufacturing in 1985. The production of primary metals consumed about 19%. The materials fabrication sector—including machinery, electrical equipment, transportation, apparel, wood products, rubber and leather goods, and stone, clay, and glass products—drew just over 35% of the electricity used in manufacturing.

Note: The components may not total 100% because of independent rounding.

technologies allow precise control and focus of energy only when and where needed, they can be more efficient than fossil fuels, even on a primary-energy basis that accounts for the efficiency losses in power generation and transmission. Moreover, electrotechnologies can reduce a customer's costs for plant pollution control, free up space on the shop floor (because they are more compact than bulky fossil-fuel-fired ovens or furnaces), and dramatically cut processing and production time.

New applications are emerging with increasing frequency. One—using freeze concentration processes—is already being applied commercially in some petrochemical and food industry applications and holds significant potential in those areas as well as in the pulp and paper industry, according to Philip Schmidt, professor of mechanical engineering at the University of Texas at Austin.

"For many mixtures and solutions, it can often be more energy-efficient to separate components by freezing than it is to separate them by distillation and evaporation," explained Schmidt, a leading authority in this country on electrotechnologies. "Since refrigeration is almost exclusively done with electricity-based systems, this implies a transition from a process that is largely heat-driven by fossil fuels to a very efficient process largely driven by electric motors and compressors."

In a wide-ranging session on electrotechnology applications in process industries, Schmidt also surveyed new membrane and electrolytic separation techniques and microwave and radio-frequency systems for heating and drying dielectric (nonconducting) materials. He said that the process heating area was the only class of industrial applications of electricity growing faster than the rate of GNP growth, indicating they are becoming more electricity-intensive. "Process heating represents a large target of opportunity because there are ways of reducing the amount of re-

Metals Production

Photo courtesy of the American Iron and Steel Institute

Electrotechnologies

Direct arc melting This is the most common electric melting method used today, accounting for a third of U.S. steel production. Once used mainly for high-alloy specialty steels, electric furnaces now produce a broad range of carbon and low-alloy steels.

Electrogalvanization Electrolytic processes bond zinc or alloys to steel strip or plate for corrosion resistance. There is an expanding market for this technology in automobile bodies.

Induction melting Magnetic field–induced currents melt metal (or keep it molten) in foundry operations or for vacuum refining of high-alloy and specialty metals. The process is also used in holding furnaces for nonferrous metals.

Plasma processing Temperatures of 10,000°F or more can be maintained in plasmas generated by high-intensity electric arcs. Rapid heat transfer and excellent controllability suggest that plasmas can be an efficient and economical medium for industrial materials processing, including direct reduction of iron ore, scrap remelting, surface hardening, and recovery of metals from arc furnace dusts.

quired process heat by using electricity."

Krahn of BGK Finishing Systems explained how semiconductor controls and new ceramic reflectors boost the efficiency of infrared lamps that can go from cold start to 4000°F (2200°C) in as little as three seconds. Such lamps are being used to cure water-borne, high-solids, and powder coatings on a wide variety of products, from Christmas tree ornaments to complete axles for three-quarter-ton trucks and even assembled car bodies, in time spans once thought impossible. "This heating technique and the ultrafast cure times associated with it not only allow the change from old, solvent-based coatings to the new coatings without major line changes but also conserve energy, time, and valuable plant floor space," asserted Krahn.

Joseph Goodwill, director of EPRI's CMP, outlined the status of induction melting, arc furnaces, plasma processing, and electrolytic reduction in the steel, iron, and aluminum industries. (EPRI recently completed a highly successful demonstration of a plasma torch retrofit to an iron-melting foundry cupola; as a result, at least one major commercial installation is expected this year.)

AT PRESENT, CMP's major thrusts are in documenting case studies of induction-melting applications, working with equipment suppliers in evaluating new uses for plasma torches (including recovery of useful metals from steel dusts and scrap metal), and developing better metal-casting technology. The center recently completed a major techno-economic assessment of electric steel-making through the year 2000.

Downstream from metals production in manufacturing, induction heating has great potential in heat treatment and high-speed seamless welding, according to Larry Kirkbride, assistant director of CMF. That center's efforts are aimed at the 150,000 small metals-related shops and manufacturers in the automotive, aerospace, and other industries.

Backed by some 150 Battelle scientists, CMF offers technical assistance to utilities and industry through a utility subscription service that includes the toll-free Metaline. It is distributing easy-to-read technical brochures for utilities to pass along to industrial customers considering new equipment; a number of specific reference guides are already available for induction heating, infrared curing, resistance heating, and other electrotechnologies. "CMF's goal is to support utilities in keeping their industrial customers viable, help them identify where electrotechnologies can be implemented, and provide the necessary technical backup," commented Kirkbride.

James Thompson, Toledo Edison Co.'s industrial marketing director, also stressed the value to utilities of matching expertise available through CMP and CMF with electrotechnology vendors in direct customer contacts. "It takes a long time to build credibility. We're just now getting to the point where our customers think to call us first when they consider upgrading equipment. Just mailing out brochures won't do it—you've got to get eyeball-to-eyeball with the customers."

Strategies for end use

Much of the give-and-take discussion during the conference touched on how to formulate the most effective strategy for approaching industrial customers with electrotechnology possibilities. Some utilities seem uneasy with the basic concept of industrial marketing because they do not want to appear to be selling equipment they either do not make and cannot guarantee or are unfamiliar with. Moreover, marketing can mean many things, and there are no firm guidelines or established procedures, although EPRI is contributing to improvements in this area. What works for one utility with one customer may not do the trick for other customers or other utilities.

The importance of working closely with electrotechnology vendors was equally stressed by utilities and equipment suppliers in several roundtable discussions. But before those relationships can evolve and bear fruit, there must be a strong corporate commitment to marketing and a solid plan for achieving results, said Richard Popeck, supervisor of energy utilization research at Detroit Edison Co., in an interview. "Foremost, a utility must establish a priority for marketing with support from the highest corporate levels, because it's going to require commitment and resources."

Detroit Edison, now two years into industrial marketing beyond its largest and most-familiar customers—automakers—has established a corporate staff to provide technical support to the industrial marketing engineers in its operating divisions. "We're making a team effort of going out to our customers and showing an interest in what they're doing. We're not only saying we'd like to help—we're saying we think there might be some electrotechnologies that could help them become more productive and stay in business. And we're getting a good reception," said Popeck.

By all accounts, the most closely followed session of the Atlanta conference featured speakers from utilities that already have impressive marketing success stories to tell. Although not on the agenda, clearly one of the more successful utility marketing operations in the country was that of the conference

EPRI at the Conference

Although some utilities have extensive industrial marketing and demand-side management programs, others are struggling to regain a footing in this unfamiliar territory. And they are looking to EPRI for tools and help in developing strategies. "It comes down finally to a threefold perspective," I. Leslie Harry, EPRI's industrial program manager, told the Atlanta marketing conference; "that is, know the customer, know the technologies, and understand the application, whether it's motor drives, electrolytic processes, heating, or lighting."

In several conference sessions, Harry and other research managers outlined elements of EPRI's program that are designed to assist utilities in all three areas, including technology assessments and information transfer through the applications centers. Where possible, EPRI tries to leverage limited R&D funds by sponsoring electrotechnology development with significant potential for payoff in the industrial sector.

In technology transfer, one example cited was that of the Utility Subscription Service offered by CMF in addition to the volumes of technical reports and brochures produced by the metals centers. The customized service provides market analysis, utility staff training, telephone assistance, and management briefings tailored to fit the needs of specific utilities. So far, 25 utilities have signed on.

Clark Gellings, senior program manager for demand-side planning, described one new EPRI-developed tool that will soon be available for forecasting industrial electricity use at the service-area level. This modeling software, called INDEPTH, complements forecasting models already developed for residential, commercial, and agricultural end-use categories.

"With INDEPTH, a utility can develop energy forecasts for its entire industrial sector, examine in detail those industries and processes most important, and investigate those uses of electricity, such as motors or lighting, of most interest," said Gellings. The system combines econometric models for forecasting, process models for end-use assessment, and equipment models (covering motors, lighting, chillers, dryers, space heating systems, and furnaces) for a highly detailed, integrated analysis.

That sort of analysis, plus parallel work to better understand customer preferences and behavior, could prove to be most useful in the process industries: chemicals, paper, food, petroleum, and textiles. Alan Karp, an EPRI project manager for electrotechnologies, noted that approximately 70% of the energy used in the process industries is for so-called prime movers (pumps, fans, and compressors)—equipment utilities use themselves.

"The value of steam and power inside an industrial process plant can vary greatly depending on where you look in the process. This complicates the evaluation and marketing of electrotechnology benefits in these industries," Karp explained. He cautioned that "much of the growth in electricity use among process industries in the 1990s may not accrue as load to utilities—it could be in the form of on-site cogeneration," unless the utilities take a more aggressive marketing stance.

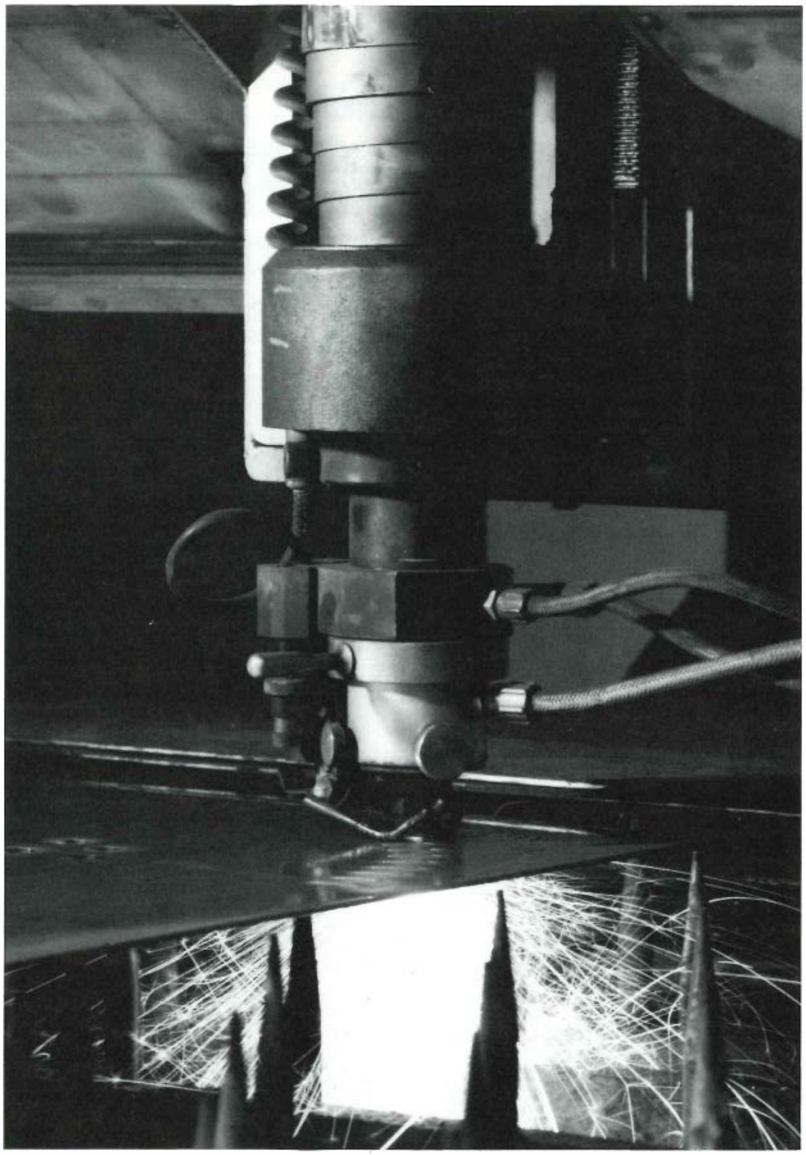
In support of that imperative, EPRI's industrial program has several projects in motion, including studies of ways utilities can influence process industries in applying electrotechnologies and optimizing the use of motor drives. Also under development is software for analyzing industrial heat pumps and marginal energy costs.

Ralph Ferraro, EPRI program manager for power electronics, surveyed that fast-moving world, where critical challenges include the retention of American semiconductor device manufacturing and expertise as well as encouraging the use of power electronics by utilities and customers.

Refuting the notion that microprocessor-based adjustable-speed drives (ASDs) only save energy, Ferraro commented, "It's true that electronic ASDs eliminate losses dissipated by mechanical process control valves, and in many applications the energy savings are substantial. But perhaps more significant to ASD users are the potential benefits derived from more precise electronic tracking of process variables that affect the quality of the product being produced. Moreover, because ASDs can be programmed for soft-starting, other credits include reduced wear and tear on mechanical switchgear, motors, and pumps."

A highly promising, largely untried use for ASDs is on large steam-driven pumps of municipal water and waste treatment systems, Ferraro added. "In these applications, ASDs are going to replace the variable-speed steam-driven pumps, thereby substituting electricity as the fuel of choice over fossil fuels. The projected benefits are increased system reliability, improved productivity and product quality, and significantly lower fuel costs." EPRI estimates that by 2000, three-quarters of all motor drives in the country will have electronic controls. □

Materials Fabrication



Electrotechnologies

Radio-frequency heating and drying Like microwaves but at lower frequencies, electromagnetic radiation vibrates molecules of dielectric (nonconducting) materials to produce heat. Applications include drying of paper, preheating of plastics, and drying of glue in furniture and particle board.

Flexible manufacturing systems Integrated machine tool assemblies make maximum use of computerization and automation to process a variety of finished parts without direct operator involvement; they afford increased productivity, improved quality control, and lower inventory requirements.

Infrared drying and curing The selective surface absorption of infrared energy by many industrial materials makes infrared technology ideal for drying and curing metals, wood products, textiles, and some electronic components.

Laser processing Pulsed or continuous-power industrial lasers offer wide-ranging applications, including cutting, drilling, welding, surface treatment, and scribing of metallic, ceramic, and semiconductor materials.

host, Georgia Power, a subsidiary of The Southern Company. Conferees were bused a few miles to tour the utility's Energy Planning Center at Norcross, a state-of-the-art multimedia showcase for prospective local industry and electrotechnology suppliers that has become a focal point for Georgia Power's industrial marketing.

In addition to the planning center, Georgia Power this year established the Technology Application Center on the Georgia Institute of Technology campus for production-oriented demonstrations of electrotechnologies, including plasma, infrared, and radio-frequency systems. Innovative rates and an aggressive, 34-member industrial marketing department in the general office helped the utility increase revenues by $45 million over forecasted gains under its Marketing Challenge '86 program. "We're trying to help our customers modernize to maximize their production and meet their quality and profit goals, as well as strengthen our industrial base," reported James Doggett, manager of market applications, in a later interview.

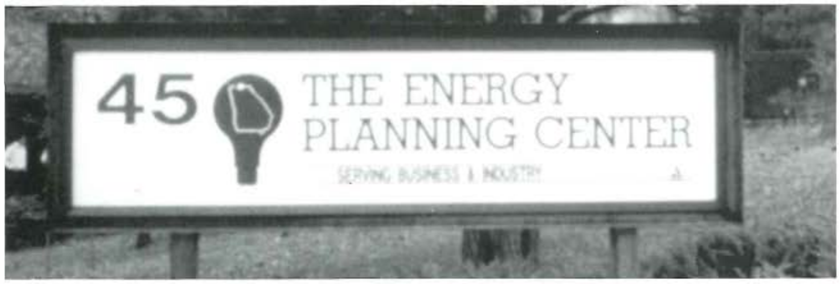
CORPORATE CULTURE and organizational philosophy were stressed at the conference by Preston Roberts, manager of research and technical services at PP&L, who suggested that utilities really sell more than electricity. "Even though that is our product, it is only the end result of the selling of ideas and solutions to problems that customers have.

"We don't sell hardware; we don't go out and market induction furnaces because we don't supply them—a vendor supplies them. But we plant the seed and show the customer how he can make his process more productive and profitable. By selling that idea and obviously selling more electricity as the energy source, we achieve our and the customer's objectives," Roberts added. PP&L's test is that neither the customer nor the utility loses in a new application of electrotechnology. PP&L committed nearly $20 million for marketing and economic development last year and, through a combination of tailored customer analyses and rate enticements, increased industrial sales by 85 million kWh in the first nine months of 1986.

Toledo Edison's Thompson echoed the importance of flexibility on rates. "There is no time for negative thinking with regard to rates. We must make time for innovative thinking."

Often, a utility must help industrial customers understand how to take advantage of existing time-of-use rates, as Pacific Gas and Electric Co. found in the pilot phase of its process management program.

Thomas Morron, vice president for customer services and marketing at EEI, outlined the investor-owned utility trade association's new national accounts program. Launched last year and based on a concept already tried in the Midwest, the program is intended to make available to utility marketing professionals information on large national customers' energy use and specific needs—information gained from marketing contacts by other utilities in a region and EEI. Calling it "an organized way to store the essence of a utility's experience with a customer and pass it on to the next guy who needs it," Morron said the program will be expanded to offer attractive financing from both within and beyond the electric utility industry for commercial and industrial customers purchasing new electrotechnologies. Similar financing arrangements for new gas-fired equipment, meanwhile, are being developed



Innovative Marketing at Georgia Power

Georgia Power Co. has established the Energy Planning Center outside Atlanta as a focal point for showcasing innovative equipment and services to existing and prospective customers. Integrated videodisc and computer graphics allow audiovisual presentations to be customized for special audiences and seminars. A full-scale kitchen features the latest in commercial cooking equipment. Ample exhibit areas highlight key industrial systems available from various vendors—including heat pumps and infrared, induction, and plasma heating technologies. Georgia Power also has a center on the Georgia Institute of Technology campus for actual process demonstrations of electrotechnologies specifically tailored to customer requirements.

by a subsidiary of the American Gas Association.

Foreign successes

The industrial marketing experiences of four foreign utility organizations brought an envious gleam to the eyes of their domestic counterparts, who are somewhat newer to the game. Anne McMillan, superintendent of industrial product development at Ontario Hydro, described her utility's approach, including close cooperation between her staff and that of the utility research department in evaluating and demonstrating electrotechnology applications.

"Ontario Hydro's approach to industrial marketing has been quite low-key," commented McMillan. "Such devices as monetary incentives, rate revisions, and the like have been used only to a very limited extent. Instead, the emphasis has been on establishing an effective link between our staff and industry, with the idea of becoming its energy management partner over the long term."

Ontario Hydro's research department sponsors customer demonstrations of microwave heating systems and industrial heat pumps and has maintained a laboratory for studying plasma torches since 1981; installation of an industrial CO_2 laser for demonstrations is planned for this year. Technology transfer activities like publications and workshops are important. "However," McMillan added, "the technical input is not the first step; it is very important, but the commercial and human aspects are the first steps in successful marketing."

Corporate recognition of that fundamental insight may mean changing the traditional, narrow technoeconomic focus of utilities, according to Maurice Orfeuil of Electricité de France (EdF). "There is a cultural shock implied in marketing. At EdF it has been more than a cultural shock, it has been a cultural revolution since the 1970s. It has meant the progressive development of a corporate culture that is customer-driven from the top to the bottom," said Orfeuil, one of the world's top authorities on electrotechnologies.

In that time the national utility has transformed France from a country dependent on imported fossil fuels into a more-electrified, self-sustaining energy producer with some 40,000 MW of commissioned nuclear capacity. But an integral part of France's electrification strategy has been aggressive and comprehensive marketing and R&D aimed at creating some 50 billion (10^9) kWh in annual sales over projected trends by 1990, 30 billion of them in industry.

Orfeuil noted that results so far have met or exceeded expectations, with over 6 billion kWh in new industrial and more than 1 billion kWh in new commercial sales in 1985. Most of those gains have come in the transportation, chemicals, food, metals, and paper and textiles industries, with variable-speed motors, resistance furnaces and ovens, heat pumps, and dual-fuel energy systems the most broadly applied technologies.

Orfeuil, author of the widely acclaimed reference *Electrothermie Industrielle* (recently published in English by Battelle Press under the title *Electric Process Heating*) and until recently chief of EdF's electricity applications department, said that for the French, "marketing and research always go together. Can you sell to big companies? Yes, as long as you are involved with them and understand their needs. But you cannot electrify process industries without studying the entire process."

He added that one key to EdF's marketing success has been a flexible approach to rates and financing, offering "a broad range of optional tariffs plus financial incentives and assistance with bank credit arrangements. Imagination in this field has no limit. When you want results you have to invest." On the research and development side, EdF's industrial electrification R&D budget of the equivalent of $38 million (10% of the total R&D budget, or 2% of its total annual revenue) has allowed it to support the improvement and transfer of existing technology, as well as the development of brand new technologies across the full range of industrial electrical equipment.

BRITAIN'S PROGRAM was summarized by Brian Booth, who heads industrial marketing for the United Kingdom's Electricity Council. The program was revived in 1982 after being maintained in a quiescent state through the 1970s. Now, on behalf of the Central Electricity Generating Board and regional distribution organizations, the council pursues increased electricity sales to the nation's 200,000 industrial customers under its Marketing for Recovery program. The program includes direct customer contact by sales engineers, as well as some 60 product package applications that target technical information and, in some cases, design guides at specific markets.

A key element of the pitch is energy substitution. "In the manufacturing industry this is primarily the substitution of fossil fuel process routes by more-efficient electrical methods, but it also extends to the substitution of existing electricity applications by more-efficient electrical methods," Booth explained. "Virtually all the electrical applications we market to industry can be shown to save energy compared with traditional fossil fuel processes, and nearly always the energy saving is back to the primary level."

With industrial and agricultural sales

accounting for 96 billion kWh, or 38% of the UK's total sales last year (250 billion kWh), the council wants to push the annual increase in those sectors from 500 million kWh in 1982 to over 2 billion kWh in 1990. "We are now about halfway through the program, and actual sales for the past four and a half years are well up to target," Booth said. For the 1985–1986 sales year, the council counts 860 successful projects in metal heat treatment, process liquid heating, metal melting, and process drying, representing 137 MW of new load and 316 million kWh in additional yearly sales.

Equally encouraging results have been achieved by Hydro Québec under its program offering technical and financial assistance for electrotechnology applications, in place since mid-1985. Micheline Bouchard, a Hydro Québec commercial delegate, said that the utility plans to invest $90 million over three years with the goal of creating 300 MW of new load. As of last September, 59 successful installations had added 173 MW of load, with nearly half of the increase in annual sales going for resistance heating systems.

"So far, our customers have invested $66 million in capital, 30% of that provided by Hydro Québec, representing an average investment cost of $110/kW of new load. The additional revenues from new load represent some $60 million a year and an aggregate payback period of 1.2 years," said Bouchard; these results satisfy the utility's rule of thumb to recover its financial assistance for projects within about 18 months through increased revenue.

"Electrotechnologies are slow to penetrate the industrial market because of competition and traditional conservatism, plus the misappreciation of electrotechnologies arising from the belief that they pose risks when integrated into industrial processes. Under the circumstances, Hydro Québec must use every means at its disposal to open a

Process Industries

Electrotechnologies

Adjustable-speed drives Semiconductor control circuits allow large electric motors to soft-start and vary speed to match loads, thereby conserving energy and reducing wear. Applications include conveyor systems and pumping and air-handling systems in the chemical, refining, pulp and paper, and food industries. Utilities are installing ASDs on power plant cooling fans.

Freeze concentration A refrigeration cycle is used to crystallize solvent, leaving a concentrated product. More efficient than evaporation and distillation methods, this technique is now used in food processing and could be applied in desalinization and to a wide variety of aqueous solutions.

Heat pumps Heat pumps absorb and compress heat for reuse. They are currently applied in food processing and electrolytic separation as well as in hot-water-driven absorption chillers. Heat pumps also have great potential for drying applications in the chemical, pulp and paper, and ceramic products industries and could be used for fractional distillation in the petroleum and chemical industries.

Electrolytic separation This technology involves electrochemical processes in which reactants are maintained in an electrolyte and immersed electrodes apply voltage for separation. It is commonly used to produce chlorine and caustic soda.

Centers for Electrotechnology R&D

EPRI is extending the model for collaborative R&D on which it is based to three new cooperative centers for developing and encouraging the application of industrial electrotechnologies. Established by EPRI but supported as well by the industries they serve, the centers complement expanding utility and EPRI initiatives in industrial demand-side management and marketing.

The Center for Metals Production, administered by the Mellon Institute at Carnegie-Mellon University in Pittsburgh, Pennsylvania, focuses on improving the productivity and competitiveness of American steelmakers and other primary metals producers. **The Center for Metals Fabrication** at Battelle Memorial Institute in Columbus, Ohio, addresses the technologies and processes used by some 150,000 metalworking and manufacturing shops serving the automotive, aerospace, medical supply, and other industries. **The Power Electronics Applications Center,** operated by the Tennessee Center for Research and Development in Knoxville, is pursuing a broad range of applications of semiconductor devices to industrial motors, process control systems, and power supplies.

commercial dialogue," noted Bouchard, "including sharing the risks of innovation with our customers."

EPRI's Fickett reiterated that theme in the conference's final moments. "We all must think 'we' instead of 'they,' and implement and act instead of react. It is, in fact, far safer to take risks than to let events overtake you."

Marketing: a key to survival

Earlier, Bouchard seemed to speak for many utilities when she said, in closing, "We have an excellent product to sell and everyone knows about it. However, it is only in the past few years that we have learned to divine all its possible commercial advantages. It behooves us as an industry to set some basic objectives in light of the present situation of availability, competition, and regulation in which all of us must operate. We must equip ourselves with structures and instruments that will offer us optimal flexibility to adapt to ever-changing conditions. While respecting our commitment to customers and the community we serve, we must gear ourselves to selective selling—that is, to meeting the specific needs of better-targeted marketing sectors.

"We should not hesitate to invest in marketing, research, and technical and personal development—in anything that can make us full partners of our customers. This is how in three years we succeeded in changing our direction, from a growth rate of −3% in 1982 to one of +15% in 1985.

"Without marketing, developments in the electricity market will be left to the vagaries of the prevailing energy situation and competition. The very survival of electricity producers and distributors will depend on their directly influencing their markets to control both growth rates and consumption patterns. We can say an unqualified no when asked if we have any regrets about our investment in marketing." ■

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This article was written by Taylor Moore. Technical background information was provided by Ralph Ferraro, Arnold Fickett, Clark Gellings, I. Leslie Harry, and Alan Karp, Energy Management and Utilization Division.

Opening the Tap on Hydrothermal Energy

Half our identified hydrothermal resources are simply not hot enough to make electricity by conventional geothermal technology. The Heber plant in southern California is demonstrating a binary-cycle approach that is custom-made for generating power from these medium-temperature brines.

One of the most important untapped sources of renewable energy for commercial power generation is the moderate-temperature hot water found in underground reservoirs in more than a dozen western states. Since this water is not hot enough for direct use in driving a turbine generator, EPRI has sponsored the adaptation of a binary-cycle geothermal technology to make these resources economically viable for producing electric power. The first large-scale demonstration power plant based on a binary cycle has now successfully completed its initial year of operation at Heber, California, and has begun to confirm some important advantages of the technology.

"The Heber project is on target in helping clarify the cost, performance, and environmental characteristics of binary-cycle power plants for utility application," says Vasel Roberts, manager of EPRI's Geothermal Power Systems Program. "Construction took only two years, and we now expect total project costs to be less than originally estimated."

With a net capacity of 46.6 MW(e), Heber is by far the largest binary-cycle plant ever built. The current test and demonstration period, to be completed in 1988, is expected to provide data and information that will establish the commercial feasibility of this technology—thereby providing utilities and developers with an important new option for power generation. In recognition of its importance, the Heber project won *Power* magazine's 1986 Electric Utility Energy Conservation Award.

Doubling recoverable energy

Most of the geothermal energy used for power generation now comes from reservoirs that produce dry steam. These resources are easy to tap but occur in only a few places. Electricity-grade hydrothermal resources contain about 10 times more energy than dry steam resources, but only about half of this water is hot enough to be used directly in generating power. For high-temperature hydrothermal fluids, simply reducing the wellhead pressure causes part of the water to flash into steam, which can be used to drive a turbine. Such direct-flash hydrothermal technology is already being used for commercial power generation, both in the United States and in several other countries.

For most hydrothermal resources with moderate temperatures (150–210°C; 300–410°F), direct-flash technology may not be efficient enough to ensure economically competitive electric power generation. The efficiency of energy conversion can be increased, however, if a second fluid with a lower boiling point is used to drive the turbine. In such a binary cycle heat from the geothermal hot water is transferred to a hydrocarbon fluid, which vaporizes and passes through the turbine. An additional advantage of this configuration is that it uses about one-third less hot water to produce the same amount of electricity as a direct-flash unit.

Relatively small binary-cycle systems have been used for several years in industrial applications and in a few small hydrothermal facilities. A commercial-scale demonstration plant was needed to advance binary-cycle technology to maturity, to determine the economics of the technology, and to establish its environmental acceptability. The greatest challenge in scaling up this technology for utility use was the need for a hydrocarbon turbine approximately four times larger than any previously built.

With results from Heber's experience, utilities and project developers will soon be able to exploit moderate-temperature hydrothermal resources economically on a larger scale. Early studies for the Heber project, dating back to 1976, helped stimulate interest in binary-cycle technology, which led to plans for other plants. The Imperial Valley, where Heber is located, is particularly rich in hydrothermal resources and promises to become one of the next major geothermal development areas in the United States. One new binary plant came on-line in the valley during 1986, and more have been announced for other sites.

"Commercial-scale use of moderate-temperature brines will almost double the amount of energy potentially recoverable from hydrothermal resources in the United States," says John Bigger, EPRI project manager for Heber. "At the present time, identified high-temperature resources could support about 12 GW of generating capacity through direct-flash plants with a lifetime of at least 30 years. Binary-cycle technology could add about 10 GW from moderate-temperature resources. By comparison, about 2 GW of dry steam resources have so far been developed."

Plant as good neighbor

The need for a large, commercial-scale binary-cycle demonstration plant was first identified at an EPRI workshop in 1974. After a long series of feasibility studies, conceptual design studies, and field experiments, construction began at the Heber site in June 1983. Two years later, almost to the very day, the first electricity from Heber was delivered to the distribution system of the Imperial Irrigation District (IID), in whose service territory the plant is located. The total cost of design, construction, and startup for the new plant was $128 million.

Because the plant is located amid some of the world's most productive agricultural land, in the Imperial Valley of southern California, it was important for the Heber facility to be a "good neighbor," says Vasel Roberts. This consideration has taken several forms. All brine removed from the underground hydrothermal reservoir, for instance, is pumped back into the reservoir to prevent subsidence of the land surface.

In addition, land use for the Heber plant was minimized by grouping all brine production wells together on a small site adjacent to the power plant and drilling them obliquely in different directions. This production island is operated by Chevron Geothermal Co., which, together with Union Oil Co., owns the Heber geothermal resource. Eventually the Heber facility is expected to utilize 7.5 million lb of brine an hour (945 kg/s) from 13 production wells. The wells will be drilled to various depths—from 4000 to 10,000 ft (1220 to 3050 m)—to tap different portions of the underground reservoir. Full flow from all wells is now scheduled for mid-1987.

Brine is returned to the geologic formation at the periphery of the reservoir from an injection island situated 2.5 mi (4 km) northwest of the plant. This site has seven injection wells. By keeping the brine in a closed loop, the Heber power plant reduces the scaling and the atmospheric emissions that can result when brine is vaporized. Vaporization of brine inside the loop is prevented by keeping it under a pressure of 200 psig (1.38 MPa), which is maintained by pumps set down into the production wells at a depth of about 1000 ft (305 m). Each pump is driven by a long shaft attached to a 650-hp electric motor at the surface.

Finding a way to obtain cooling water is a major concern for most plants located in arid regions of the West. At the Heber facility water is needed to remove waste heat from the condensers that return the hydrocarbon working fluid to its liquid state after it passes through a turbine. Currently this cooling water is taken from a nearby irrigation canal, which is supplied from the Colorado River.

San Diego Gas & Electric Co. (SDG&E) is the host utility and project manager for Heber, operating the plant and sharing the generated power with IID. Other sponsors of the Heber binary project—which have provided substantial technical and financial support—are EPRI, Southern California Edison Co., the California Department of Water Resources, the state of California, and the U.S. Department of Energy. Additional contributors include Pacific Gas and Electric Co. and Magma Energy, Inc.

Innovations for performance

Several important technological innovations have been incorporated into the Heber plant and are demonstrating their readiness for utility application in the near future. Perhaps the most daring of these innovations is the world's largest hydrocarbon turbine. Rated at 95,000 hp, it was scaled up by a factor of four from previous models, with the initial design studies funded by EPRI.

At peak power more than 8.4 million lb of hydrocarbon fluid an hour (1060 kg/s) will flow through the turbine, which is connected to a generator with a rated capacity of 70 MW(e). About 23.4 MW(e) of power is required to run auxiliary equipment, including the brine production and injection pumps, so that the plant has a net output of 46.6 MW(e). At a commercial plant a utility would probably just purchase the brine, with no need for outside power to pump and reinject it.

Another significant innovation at Heber is a "floating" cooling system. Conventional, "fixed" cooling systems maintain a constant condensing temperature; this approach provides a constant power output from a plant but not always the greatest efficiency. Heber's floating cooling system operates continuously at full capacity, resulting in power output that varies with changes in ambient temperature—sometimes higher and sometimes lower than with a fixed system. This approach maximizes power production for any given atmospheric condition, thereby improving the plant's annual energy production and reducing brine requirements. The system's water is cooled by evaporation in a forced-draft tower, and makeup water from an adjacent irrigation canal is kept in two settling ponds on the plant premises.

A third unique feature of the Heber plant is the use of a hydrocarbon working fluid mixture that was specially selected to match the thermodynamic characteristics of the hydrothermal resource and the site's ambient temperatures. After evaluating a number of fluids (including water) and conducting optimization studies, the project team chose a working fluid that contains 90% isobutane and 10% isopentane. This composition can be changed to compensate for a decline in brine temperature as time goes by or to match conditions at other geothermal fields. Four sets of pumps are used to circulate the working fluid, which can be removed from the power loop entirely and placed inside a 7100-barrel storage sphere.

A critical part of the Heber demonstration program is to show that flammable hydrocarbon fluids can be used safely in a power plant environment. Although utility personnel are accustomed to handling fuels, conventional plants normally use air or water as the working fluid. At Heber SDG&E is demonstrating that personnel can also be trained to work safely with flammable working fluids.

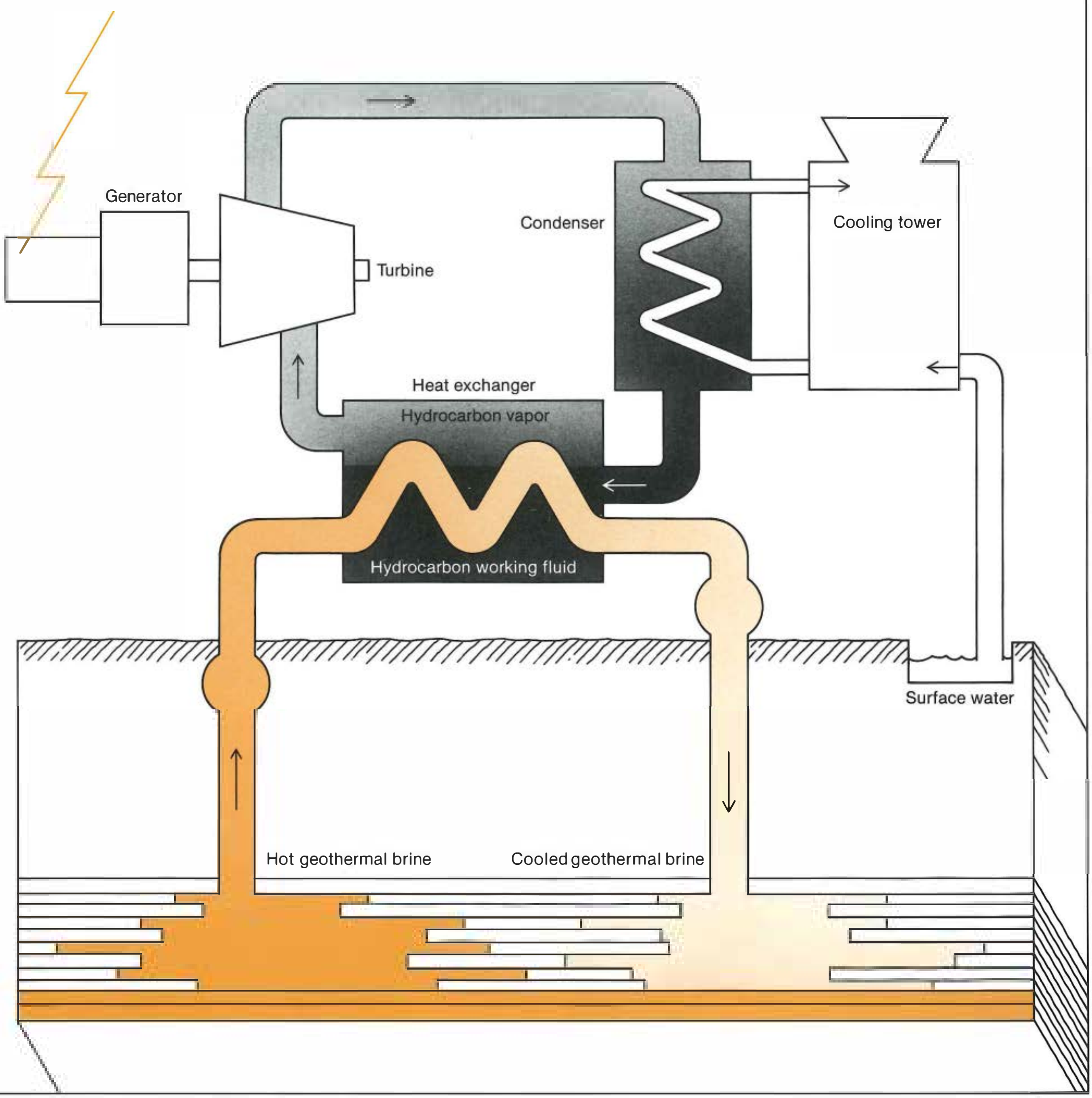
Finally, the Heber plant features an advanced distributed digital control system. Operators seated before three large color viewing screens can monitor and control any part of the plant through a system of computer graphics displays and keyboards. Because of the need for extensive data during Heber's test and demonstration program, the data acquisition system and the central computer are also connected to more than 800 sensors that continuously record conditions throughout the plant. These data will be critical in the design of future commercial binary-cycle plants.

Shakedown and testing

The testing emphasis during Heber's first year of operation was about equally divided between reservoir and plant. The purpose of the reservoir tests was to es-

Binary Basics

The binary-cycle process uses a secondary fluid loop to generate power from geothermal brines. Hot brine from a natural underground reservoir is pumped under pressure through a heat exchanger containing a hydrocarbon working fluid, which boils at a relatively low temperature. The fluid is vaporized by the brine's heat and the vapor fed through a turbine generator to produce electricity. The hydrocarbon fluid is then condensed for another cycle through the loop, and the cooled brine is pumped back into the geothermal reservoir.



Touring the Plant

Located in the Imperial Valley of southern California, the Heber project is by far the largest binary-cycle geothermal plant ever built.

1 The **production island** is the site of the hydrothermal wells, which pump hot water from as deep as 10,000 ft below the ground.

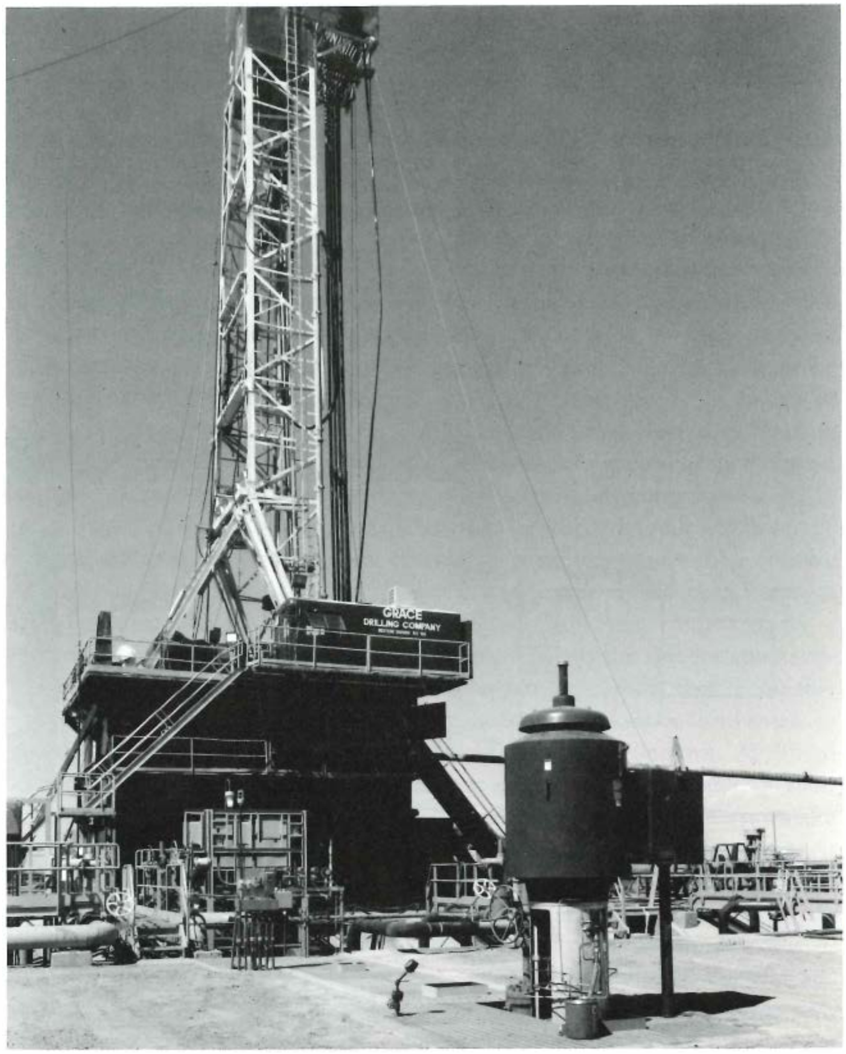
2 A bank of eight cylindrical **heat exchangers**, each weighing more than 200 tons, can handle a brine flow of over 2000 lb/s.

3 At 70-MW gross output, Heber's **hydrocarbon turbine** is over four times as large as any previously built.

4 Inside the **condensers**, returning the working fluid to liquid state requires the circulation of over 140,000 gal/min of cooling water.

5 A single spherical **storage tank** holds the entire 330,000-gal inventory of hydrocarbon fluid when the plant is shut down.

6 Heber's highly automated **control room** features color control and display screens that show plant status by means of computer graphics.



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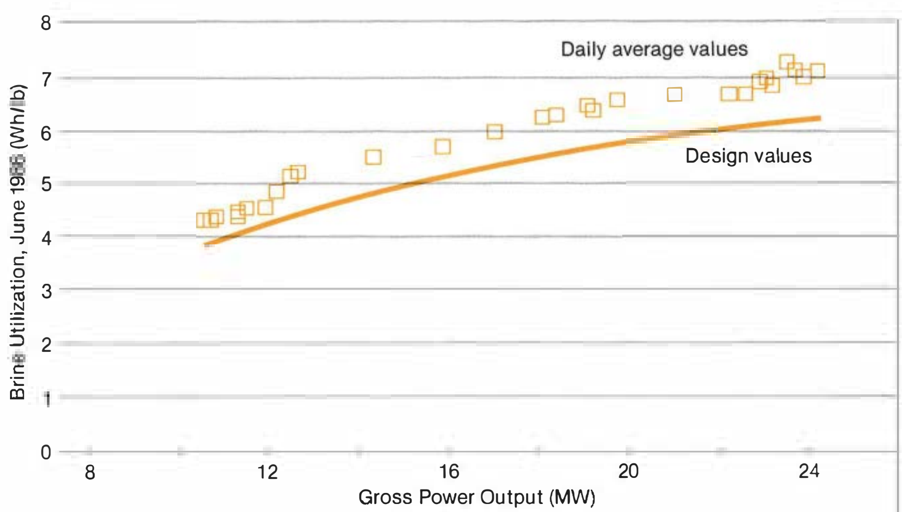
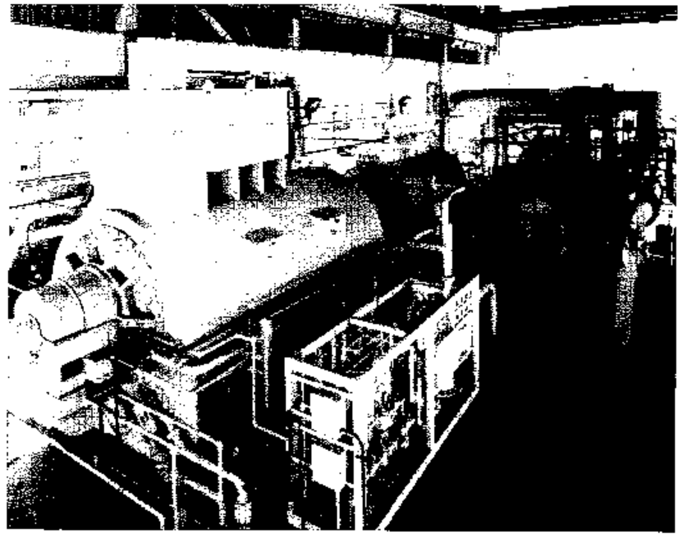
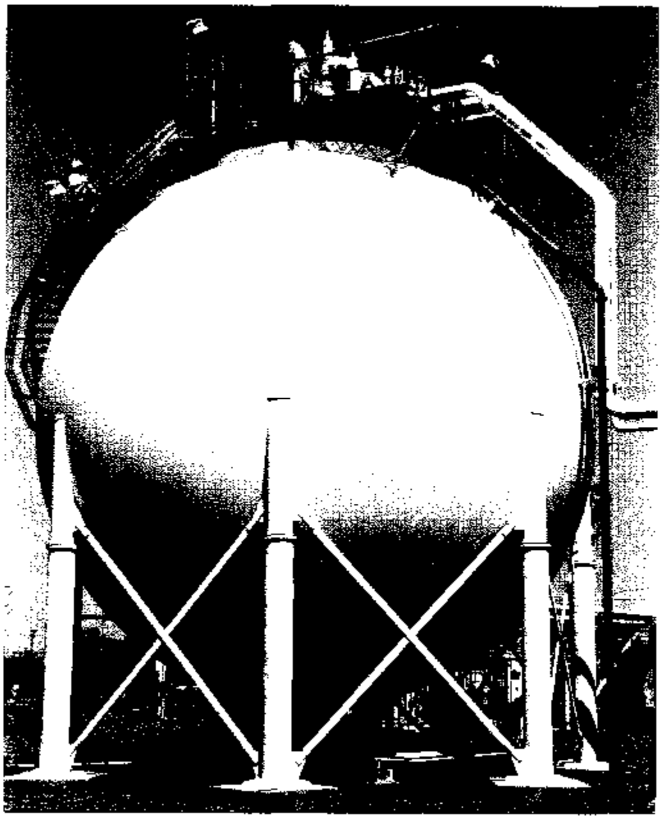
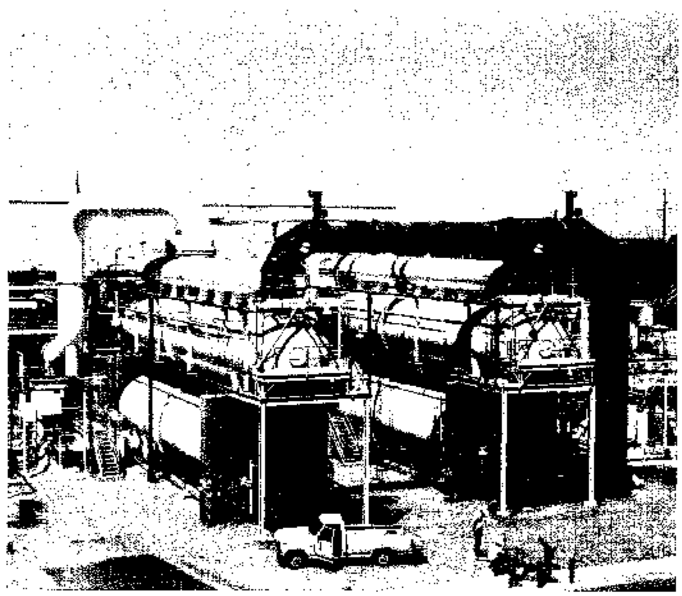
Demonstration Continues

The reams of performance data from Heber's more than 800 sensors will help in the design of future-generation geothermal plants. As shown below, plant operators found they were converting more energy from each pound of brine than predicted in the plant design. The plant's innovative cooling system also allows the generation of more electricity each year than with a conventional system.




tablish production characteristics in order to plan the balance of the drilling program, estimate the reservoir's production capability, and determine the maximum acceptable reinjection pressures consistent with maintaining reservoir integrity. These tests also provided Chevron with data for validating its reservoir computer programs.

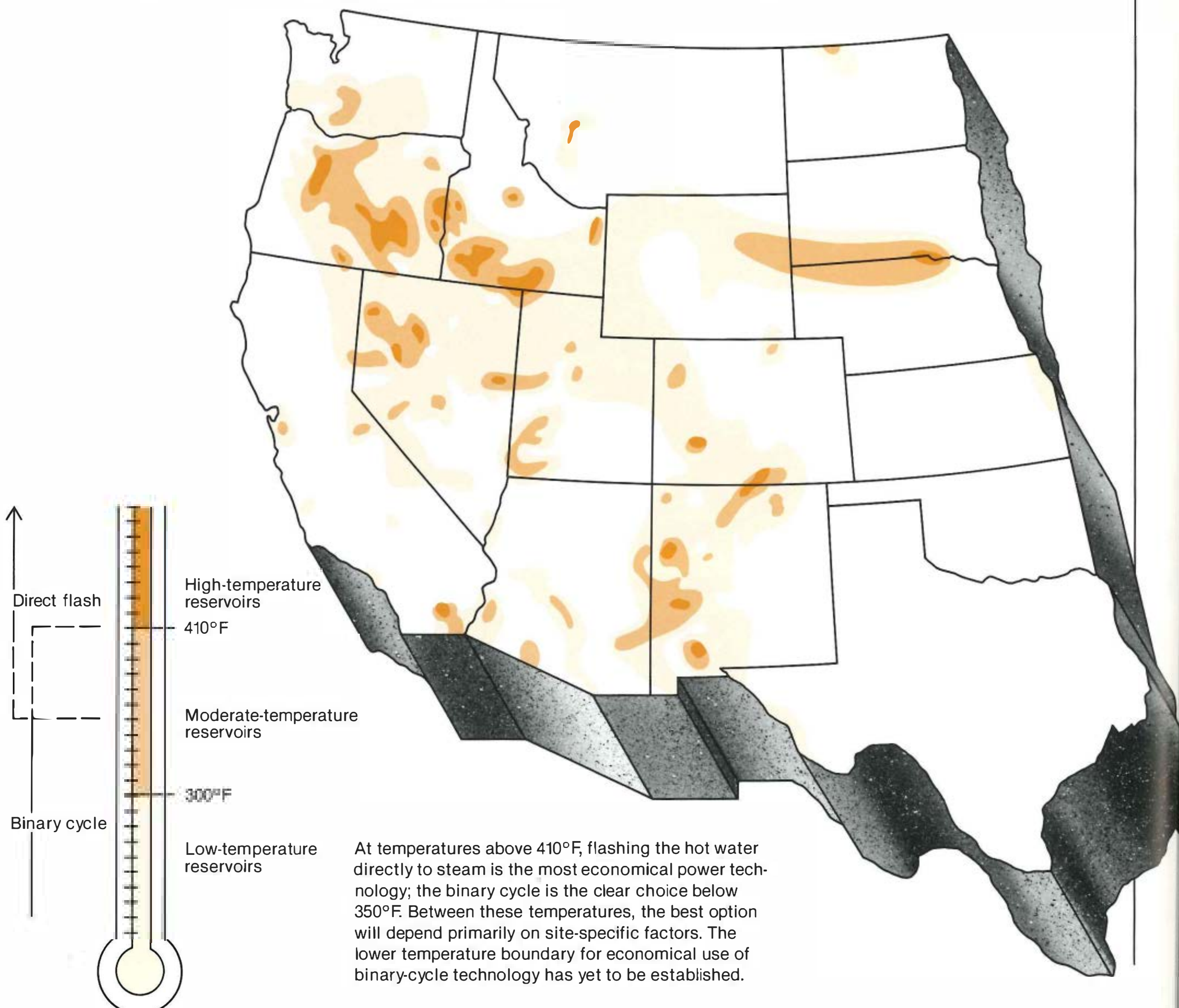
Inside the plant itself, the testing emphasis has been on establishing the baseline performance of each major piece of equipment. Most of these equipment tests produced satisfactory results, and no significant degradation of performance has been noted in key plant components. Because of limited brine flow, maximum plant operation has not yet been demonstrated, but the excess capacity has enabled the plant to operate above its design capability. Two EPRI test engineers are at Heber participating in the test program, which is expected to last two to three years.

After an initial six-month shakedown period, from June to December 1985, the plant compiled an excellent operating record—remaining on-line 93.3% of the time from January to June 1986. During this low-load test period, net energy of 14,831 MWh was produced.

During the first annual inspection, beginning in late June 1986, engineers

Tapping the Resource

Geothermal resources suitable for utility power generation are concentrated almost exclusively in the western states, with moderate-temperature brines about four times more common than high-temperature brines. Approximately 4700 MW of geothermal generating capacity is expected to be in place in the United States by 1995.



At temperatures above 410°F, flashing the hot water directly to steam is the most economical power technology; the binary cycle is the clear choice below 350°F. Between these temperatures, the best option will depend primarily on site-specific factors. The lower temperature boundary for economical use of binary-cycle technology has yet to be established.

opened and inspected many of the major pieces of equipment. They were particularly pleased that no significant scaling or corrosion had occurred in the plant's eight large tube-and-shell heat exchangers, which transfer heat from the brine to the hydrocarbon fluid. "After conducting field tests and considering a number of candidate materials, project engineers selected a special high-chromium steel (Al29-4C) for the tubing," says John Bigger, "and got even better results than we had hoped for." Estimates based on earlier field tests suggested that the heat exchangers might have to be cleaned as often as every six to eight months; after more than a year of operation, however, the tubing interiors were still so clean that maintenance crews simply closed the heat exchangers back up after inspection.

Some system failures are, of course, expected when a new plant begins operation, especially when innovative technologies are being tested for the first time. At Heber the most serious equipment breakdowns involved the booster pumps that pressurize and move the working fluid from condenser to heat exchanger. The units in question developed high levels of vibration when used with the hydrocarbon fluid, which is more compressible than conventional working fluids. Apparently because of this vibration and some problems with materials, the booster pumps experienced seal and bearing failures.

Several modifications were made to the pumps, including the substitution of different shaft material, seal coolants, and bearings. After these changes were completed, they were evaluated in a second shakedown period of about three months. Engineers at the plant and the vendor are continuing to study this issue. Since late November 1986, the Heber plant has remained on-line essentially full-time.

Future prospects

"Our job in EPRI's geothermal program is to make sure new technologies are available when utilities need them," says Vasel Roberts. "Right now, most of the western utilities with geothermal potential are not capacity-constrained, but we expect to see them ordering new plants, possibly in the 1990–1995 time frame. Quite likely, utilities will want to add new capacity in relatively small increments that can be brought on-line quickly. Heber is demonstrating that larger binary-cycle geothermal plants would be ideally suited to help meet these utility needs where moderate-temperature hydrothermal resources are available."

Generating capacity based on geothermal resources of all types is expected to expand rapidly over the next few years. According to projections of the North American Electric Reliability Council, this capacity will grow at an annual rate of nearly 8.6% in the next decade. EPRI surveys of utilities show a probable total geothermal generating capacity of 4700 MW by 1995, up from 2115 MW in 1986.

With the development of the binary cycle and other technologies, utilities will have considerable leeway in matching plant technology to resource characteristics for optimum performance. A binary-cycle plant will be the clear choice for resource temperatures up to about 176°C (350°F). In the temperature range of 176–210°C (350–410°F), either binary or flashed-steam technology could be considered. The choice would be determined by a number of factors, including reservoir productivity, mineral and gas content of the geothermal fluid, environmental considerations, and economics. Above 210°C (410°F) binary cycles can still be considered but will probably give way to direct flash.

Three direct-flash options are now available: single-stage and two-stage systems and a system that features rotary separator–turbine (RST) augmentation. Already a two-stage direct-flash unit is generating power commercially with 182°C (360°F) water from the same reservoir that supplies the Heber binary project. The development of RST technology, now being pursued by EPRI, could further enhance the performance of direct-flash units over the temperature range for which they are suitable.

The demonstration of the binary cycle in utility application should open up the commercial potential of lower-temperature brines for the first time. The first commercial binary units are expected to range in size from 5 to 50 MW(e). Utilities are expected to favor the larger units, which will require hot water from several wells; but the smaller, "wellhead" units, which use the flow of only one or a few adjacent wells, will still be needed.

Capital costs for the first commercial binary plants similar to Heber are expected to run around $1650/kW(e), not including reservoir development, according to John Bigger. "Their competitiveness with plants based on other new technologies will depend largely on the cost of delivered brine, which usually comes from non-utility-owned wells. At full capacity the project expects to pay $1.15 per million Btu for hydrothermal energy, or about the equivalent of oil at $20 a barrel. At that rate, one might expect the busbar electricity cost from a commercial binary plant to be 83 mills per kWh."

That figure could change significantly, Bigger says, depending on the specific contract between a utility and the owner of a hydrothermal resource. In any case, he concludes, "The Heber demonstration program is showing that larger binary-cycle plants will be technically ready for commercial orders once the appropriate market conditions exist." ■

This article was written by John Douglas, science writer. Technical background information was provided by Vasel Roberts and John Bigger, Advanced Power Systems Division.

What lies ahead for the nation's electric utilities? What do they perceive as their greatest challenges and opportunities? Which issues are growing in importance and which are fading from the scene? And how can EPRI's research and development help its members reach the future they are striving for?

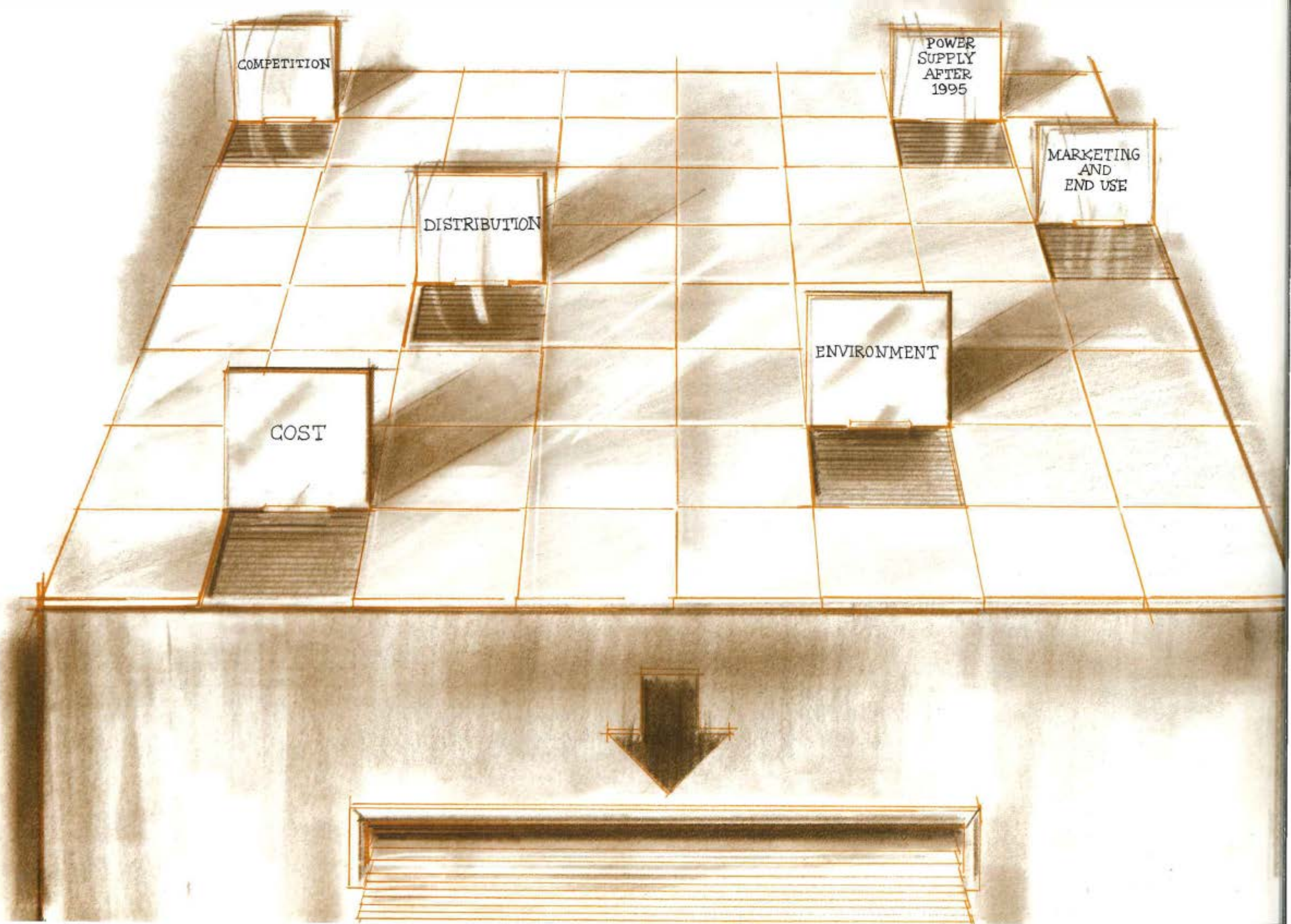
Sorting out such matters for an industry this diverse is not easy. Utilities vary widely in size and style. Some produce power, others simply distribute it. They range in their mix of generating technologies and in the needs of their customers. Despite such differences, however, there are patterns of common concern and interest within the industry.

To keep its R&D attuned to the shifting needs of its members, EPRI solicits advice through a network of committees composed of utility experts and from scientists, policymakers, and other officials from outside the industry. In addition to these vital people-to-people channels, the Institute takes the pulse of the industry by conducting a strategic survey of its

Cost control and environmental concerns are well entrenched as top concerns of the utility industry. But EPRI's ninth member utility survey shows a number of other issues popping up in the foreground as utilities look to the coming decades.

CRITICAL ISSUES

How Utilities See Their Future



members every other year. The ninth and most recent survey was administered in the spring and summer of 1986. The responses from a broad cross section of EPRI member utilities confirmed a number of familiar themes and raised several new issues that historically have not been high among members' concerns.

A focus on issues

Sherman Feher, the project manager in charge of developing the survey and analyzing the results explains, "The survey contained eight questions. The first few were open-ended, issue-oriented questions in which we asked the utilities, basically, to tell us what is on their minds.

"For starters, we asked them to list the three most significant issues they face today and will face after 1995." There was a wide range of responses. One utility listed public relations as one of their greatest challenges. Another cited education. Most focused on a handful of familiar issues, including cost control, the environment, and competition.

"Following up on the critical issues question, we asked them to indicate how amenable these concerns are to resolution through R&D, and where their greatest needs for R&D lie," says Feher. "Next we asked how they expect to meet demand over the next two decades, where they plan to invest their capital in the next 5 years, and what environmental issues they will face in the next 10 years and after 1995. Finally, we asked them to rank the criteria EPRI uses for evaluating prospective R&D efforts and the relative importance of EPRI's strategic program areas."

Feher analyzed and ranked the utility responses by raw frequency and, for some of the questions, used a weighting system based on the kilowatthour sales of the respondents. "It's analogous to Congress," he explains. "The first technique is like the Senate, where each state gets the same number of votes. The second approach is like the House of Representatives, where votes are allocated by population, or in our case, by electricity sales. The combination gives us a fair and balanced assessment of the industry's views."

Richard Zeren, who directs EPRI's Planning and Evaluation Division, explains that the absolute ranking in either system is less important than the broad mosaic of trends and priorities that the results provide. "We cluster the results into rough groups," he comments, "and we don't pay as much attention to where within each group a given issue lies. But when an issue that was historically in the lowest cluster jumps to the top, or vice versa, that's significant."

Familiar themes and a few surprises

No single issue dominated the utilities' responses. As in the past, the most pressing challenge utilities said they face in the next decade is to control costs and maintain the financial health of their companies, especially in the face of competition and deregulation, which rose into the top tier of concerns for the first time. End use and marketing continued to grow in importance. Environmental concerns and power supply maintained a strong position, as they have in recent surveys.

Another newcomer to the list of first-order issues is distribution. Frank Young, EPRI's manager of strategic planning, explains that as utilities finish building power plants, their next biggest investment is in the distribution system. So they will look there next for cost-saving innovations and opportunities to increase reliability and service quality.

In looking beyond 1995 the respondents overwhelmingly listed power supply as their top concern. Such a response came as no surprise, as future power supply concerns have become a common theme recently in industry circles.

In the past, utilities simply built more plants to meet a predictably rising demand. Today, nuclear construction programs are winding down and past cost overruns are causing utilities to be very cautious about committing to large new central station plants. Purchases of hydroelectric power from Canada have increased dramatically in recent years in the Northeast. Electric load is being managed as never before by end use, conservation, and marketing programs. Cogeneration and self-generation are cutting into industrial and commercial markets, independent power producers are clamoring to sell power to meet utility demand growth, and the entire industry is grappling with the prospects and problems of deregulation. It is no wonder that in such a volatile climate, with so many actors involved and so much uncertainty, utilities are uneasy about where new power supplies will come from.

Cost control, power supply, environmental concerns, and end use were all viewed as having high potential for resolution through R&D. The respondents said that R&D would contribute relatively little to institutional and political issues, like rates, regulation, plant licensing policies, finance, and deregulation.

Reflecting society's ongoing concern for environmental quality, the utilities listed clean coal technologies, advanced power sources, environmental control and research on acid rain, electromagnetic field effects, and hazardous wastes as having high priority for R&D.

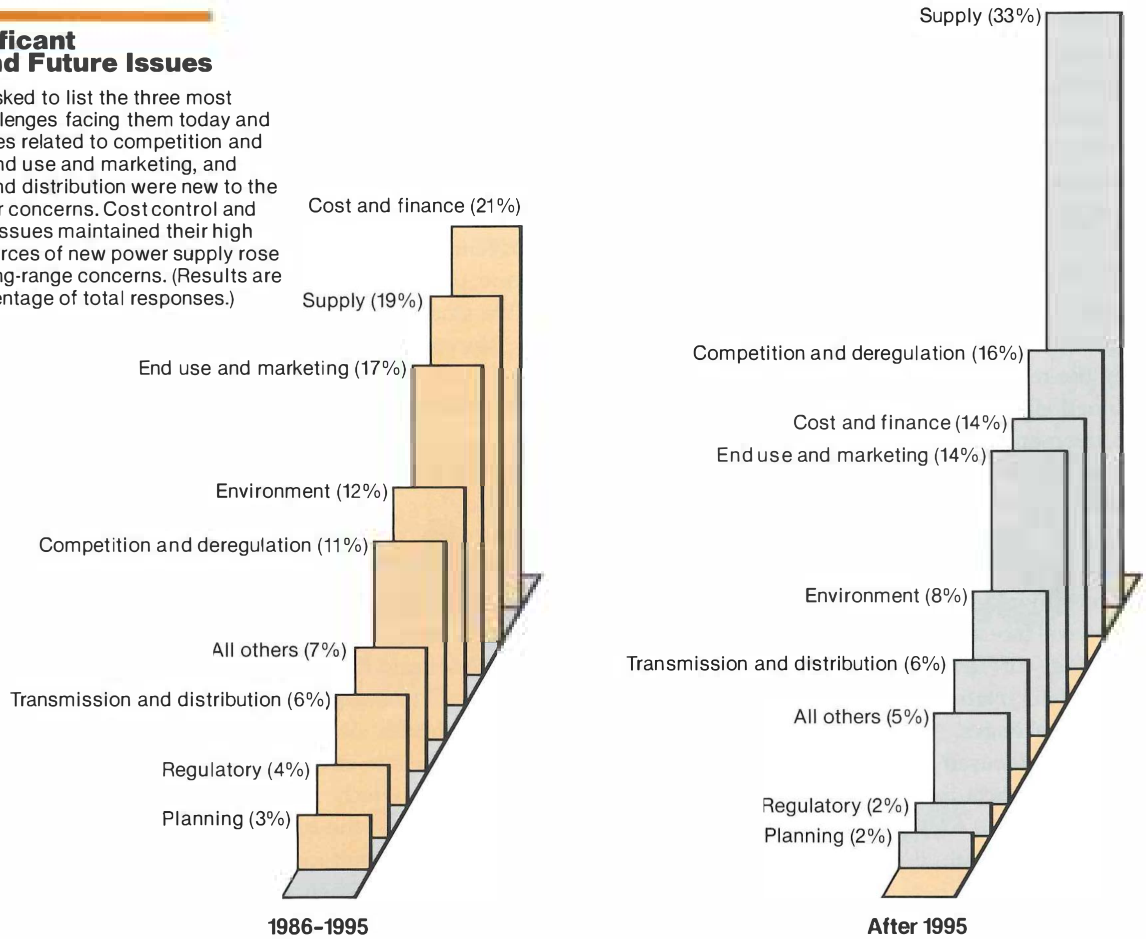
Research on planning in general—with particular emphasis on demand-side planning, forecasting methods, and energy management—ranked high, as utilities seek to reach beyond the meter and provide customers with energy services rather than raw kilowatthours.

Utilities are clearly moving cautiously when it comes to new plant construction. When asked how they plan to meet demand through the year 2005, they responded that three-quarters of their power will come from existing facilities, including those whose service is prolonged through life extension, and from power purchases from other utilities.

Recognizing that dollars sometimes

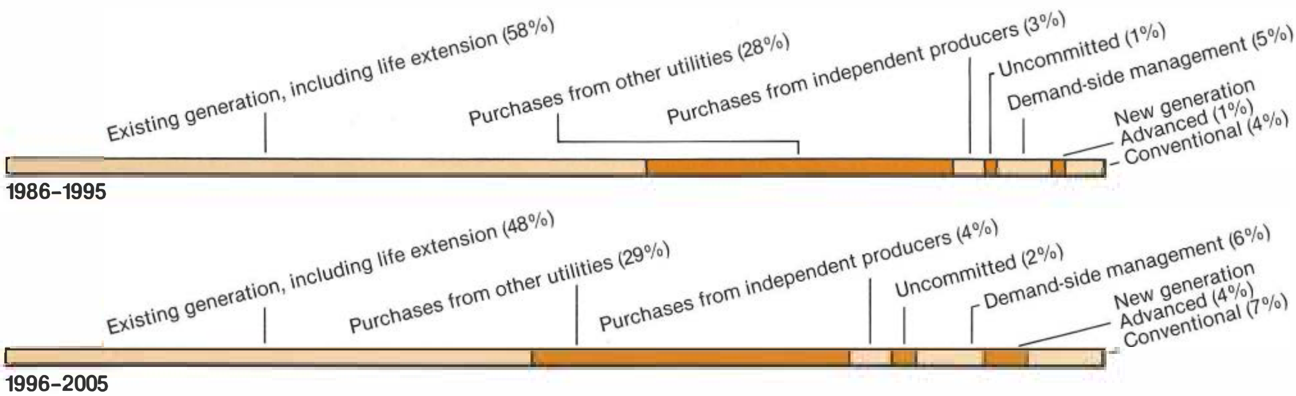
Most Significant Current and Future Issues

Utilities were asked to list the three most significant challenges facing them today and after 1995. Issues related to competition and deregulation, end use and marketing, and transmission and distribution were new to the list of first-order concerns. Cost control and environmental issues maintained their high profile, and sources of new power supply rose to the top of long-range concerns. (Results are shown as percentage of total responses.)



How Utilities Will Meet Demand

When asked how they will meet customer demand in the next 10 years and from 1996 to 2005, the respondents indicated that existing power plants—including those whose life is extended—and power purchases from other utilities will provide the bulk of their supply. Interest in advanced generating technologies rises after 1996.



speak louder than words, EPRI included for the first time a question asking utilities where they expect to invest their capital in the next five years. Although utilities are often reluctant to discuss their planned expenditures far in advance, Zeren maintains that getting a rough picture of where the industry plans to allocate its resources can help EPRI attune its R&D portfolio to the members' most pressing needs.

Those responding indicated that they would spend the most money in the next five years on completing power plants now under construction, stringing distribution lines to new customers, extending the life of existing plants, upgrading transmission facilities, and improving service fleets, internal information systems, and office facilities. A few utilities expect to spend considerable sums on committing to new plants, but most appear to have no near-term plans to build new capacity.

Ranking environmental concerns

For some time environmental issues have been among the highest priorities for electric utilities. Deciding which ones to focus on with limited R&D resources is a perennial challenge, however, so the survey asked utilities to rank the likelihood of encountering and the potential costs of dealing with 31 specific environmental areas for two time periods, 1986–1995 and beyond 1995.

The highest-ranking issues for the next decade were ones that have often filled the headlines in recent years. PCBs, acid rain, hazardous waste disposal, leaking underground storage tanks, transmission siting and right-of-way management, and local air quality were all deemed important in the near term.

Utilities obviously envision progress in some of these areas because when they look beyond 1995 the priorities shift. As PCB-contaminated equipment is identified and removed from service, the problem posed by that class of compounds fades into the middle third of long-term concerns. Similarly, cleanup of underground tanks is expected to reduce the severity of that problem after 1995. Local air quality concerns are also expected to diminish, presumably as new plants with high-performance emission controls installed over the last two decades come to dominate the generating mix. As emission controls get stronger, the acid rain issue would be expected to fall slightly, and that is reflected in the survey results, although utilities expect it to stay relatively high on the agenda.

Because pressure is mounting to deliver more electricity over greater distances, especially in order to share lower-cost power, the problem of siting new transmission lines is becoming more urgent. Although they consider it an important issue today, utilities ranked transmission siting and management among their highest environmental concerns after 1995. Nuclear plant decommissioning is also expected to be a major issue in the late 1990s, as first-generation nuclear facilities reach the end of their service lives. The problem of high-level radioactive waste disposal will also be a major issue within 10 years, as decommissioning gets under way and as the temporary storage facilities now in use for spent fuel reach their capacity. Hazardous wastes, groundwater protection, and ash disposal and reuse are expected to remain strong concerns, and the greenhouse effect rises from the bottom third of the current list into the middle range of concerns at the end of the century.

Grading EPRI program priorities

Cost control and protection of health and the environment are the primary criteria that EPRI should use in evaluating its R&D, according to the respondents. Reflecting this view, the members ranked environmental assessment and controls among the most important of EPRI's strategic programs. Recognizing that the present hiatus in nuclear plant construction is likely to continue and that coal will remain the dominant fuel in U.S. electricity production for some time, the members placed high importance on the Institute's work on fossil fuel power plants.

Demand-side planning and distribution programs recorded the largest increases in priority from the previous survey. This shift reflects the fact that new plant construction has slowed and that utilities are getting more involved in marketing and service issues.

"One of the most remarkable facts revealed by the survey," observes Young, "is that utilities are facing so many pressing issues. There are at least three dozen front-line concerns. The sheer number of issues presents a particularly challenging agenda for utilities and for those of us trying to design a responsive R&D program."

Most of the highest priorities raised in the survey correspond to areas of strong emphasis at the Institute. "Environmental programs continue to get strong support, end use is our most rapidly growing program area, and we're working hard on life extension and new supply options for the 1990s," observes Zeren. "Competition and deregulation have a new urgency that we haven't seen in past surveys. We think a lot of what we are doing can contribute there. Transmission and distribution, which appear to be rapidly attracting interest, will receive increased attention."

Getting all the members involved

When asked why EPRI conducts the utility survey, Zeren responds, "We are a customer-driven organization. The survey is an essential ingredient in our understanding of our members' concerns and priorities. It helps us see how they view the future, and from that vision we try to craft a research program that fits their needs." Young adds, "The survey opens up the planning process and enables EPRI member utilities to participate in shaping the Institute's R&D agenda."

Earlier surveys were sent to only those member utilities represented on the various EPRI advisory committees. Because most of the members who participate in EPRI activities are fairly large utilities, Zeren's staff felt that the survey was not reaching the smaller members. Consequently, the ninth survey was sent to all 548 member utilities, from the Tennessee Valley Authority, with annual sales of over 100 billion kWh, to utilities like the Albion (Idaho) Light & Water Plant with 175 customers and an annual demand of about 3 million kWh.

The response rate in past surveys had been about 80%, an extremely high return but not surprising, since the respondents were utilities already active in the EPRI advisory structure. With the larger sample in the ninth survey, only 20% of EPRI's total membership responded—a more typical return rate for surveys of this type. "The survey was something new for a number of utilities," says Feher. "Many of our members were seeing the survey for the first time and chose not to respond. We're optimistic that we can raise our return rate and broaden the base of response in the next survey."

To bring the response rate up, Young and Feher asked their secretary, Susan Lubonovich, to call the utilities that had not been heard from. Her conversations with the membership yielded some rich anecdotes and several important insights that should help improve future surveys.

When asked how the smaller utilities reacted to the survey, Lubonovich responds, "They were interested in what we were trying to do, but for some of them, it just wasn't relevant. It doesn't

Environmental Issues After 1995

The survey asked utilities to rate the likelihood—on a scale from 1 (not likely) to 5 (very likely)—of confronting 31 environmental issues during the next 10 years and after 1995. Some issues, such as acidic deposition and hazardous waste disposal, rank high in both time frames. Transmission line siting, nuclear plant decommissioning, and high-level radioactive waste disposal are expected to become more pressing after 1995. Utilities expect PCBs, leaking underground tanks, and local air quality to fall from their current position in the top tier of concerns to the middle range of issues in the future.

Rating	Issue (after 1995)
3.4	Transmission right-of-way siting
3.4	Hazardous waste disposal
3.1	Acidic deposition
3.1	Transmission right-of-way management
2.9	Nuclear plant decommissioning
2.9	Groundwater contamination and protection
2.8	Ash disposal and reuse
2.6	High-level radioactive waste disposal
2.6	Habitat and wetlands preservation
2.6	Regional air quality
2.6	Routine chemical handling and disposal
2.6	PCBs
2.5	Scrubber sludge disposal
2.5	Hazardous air pollutants
2.5	Local air quality
2.5	Leaking underground storage tanks
2.4	Low-level radioactive waste disposal
2.3	Hazardous waste disposal siting
2.3	Victim compensation (toxic torts)
2.3	Wood pole disposal
2.2	Carbon dioxide (greenhouse effect)
2.2	AC field effects
2.1	Cooling system and biota interactions
2.1	Visibility
2.0	Hazardous aqueous discharges
2.0	Indoor air quality
1.9	Ionizing radiation
1.9	Hydroelectric effects
1.9	Mercury vapor lamp disposal
1.7	Town gas–coal tar site cleanup
1.7	DC field effects (ion effects)

5 = Very likely   3 = Moderately likely   1 = Not likely
4 = Likely   2 = Less likely

Ranking EPRI's Strategic Program Areas

EPRI's 17 strategic program areas were ranked in importance by respondents according to their utilities' specific needs. The unweighted rankings reflect one vote for each utility responding, while the weighted responses reflect kilowatthour sales. Consistent with their response that cost control and protection of health and the environment are the primary criteria that should guide EPRI's R&D priorities, utilities ranked environmental assessment, environmental control, and fossil fuel plants as their top three priorities. Reflecting their greater interest in power generation, larger utilities placed relatively more importance on the areas of advanced fossil fuel systems, fossil fuels, and nuclear power plants. Smaller utilities were predictably more interested in distribution.

Strategic Program	Unweighted Ranking	Weighted Ranking
Environmental assessment	1	3
Environmental control technology	2	1
Fossil fuel power plants	3	2
Demand-side planning	4	6
Distribution	5	10
Energy management, conservation, and productivity	6	5
Advanced fossil fuel systems	7	4
Utility planning and analysis	8	11
Transmission	9	9
Fossil fuels	10	7
Power system interconnections and operations	11	12
Plant electrical systems and equipment	12	13
Nuclear power plants	13	8
Renewable resource generation	14	15
Supply management	15	16
Nuclear fuels	16	14
Advanced nuclear systems	17	17

make sense to ask a utility with 300 customers about its nuclear power options. On the other hand, there were areas like our work in distribution that they found very interesting.'' She suggests that many of the small utilities be surveyed in the future as a group, through organizations like the American Public Power Association, the National Rural Electric Cooperative Association, and the government power wholesalers, such as the Tennessee Valley Authority and the Bonneville Power Administration.

Lubonovich's efforts paid off. With her encouragement an additional 60 utilities responded to the survey.

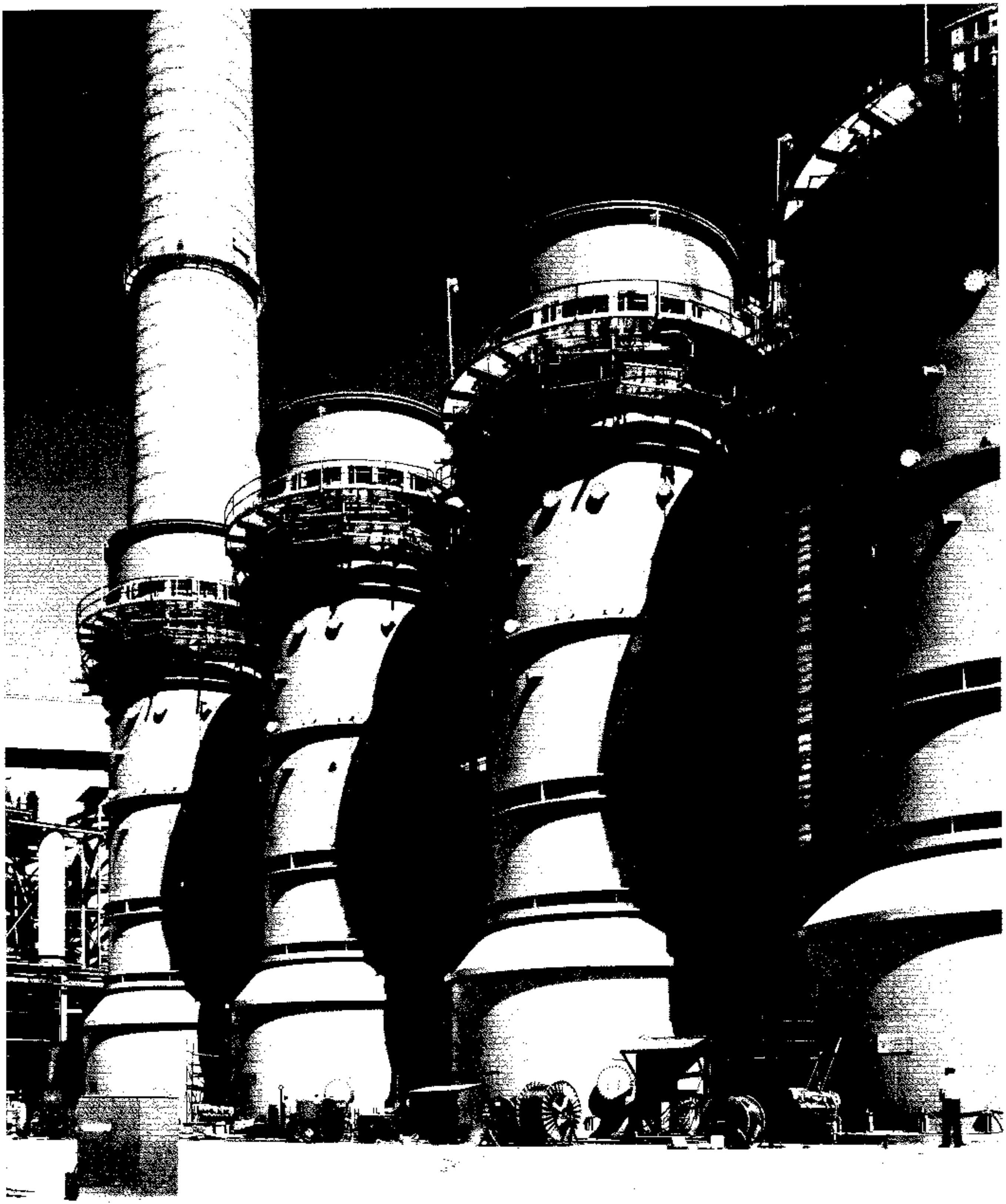
"Those phone calls gave us a much better understanding of how our smaller members view R&D,'' reports Feher. "The larger utilities identify problems and initiate R&D to tackle those problems. The smaller utilities don't have the staff to do this. Many of them think of R&D as something that will come to them in the form of a salesman knocking on the door with a new product or process that will save them money. We'd like to change that a little bit by giving even the smallest of our members a voice in shaping the R&D we conduct on their behalf. The utility survey is an ideal tool for allowing them to be heard. And if we hear from them, we can do a better job of developing new products that will meet their needs.''

Feher stresses that the survey is by no means the final word on the industry's views and that it is only one way in which utilities communicate their R&D needs to EPRI. It is nevertheless an essential element in an ongoing effort to keep EPRI as focused as it can be on the ever-evolving priorities of its member utilities. ■

Further reading

Ninth EPRI Member Utility Survey Results. Prepared by Planning and Evaluation Division. EPRI P-5160-SR. Forthcoming.

This article was written by Michael Shepard. Technical background information was provided by Sherman Feher, Susan Lubonovich, Frank Young, and Richard Zeren, Planning and Evaluation Division.



Acid condensation creates a corrosion battleground in the huge vessels and ductwork of flue gas scrubbers. Utilities are hardening their defenses against this expensive problem with a variety of corrosion-resistant alloys and lining materials.

Scrubbers: Battling Corrosion on a Grand Scale

Acid constituents in coal combustion exhaust gases are no surprise. Always known to be potentially corrosive, they used to be avoided in power plant designs by keeping temperatures above the acid dew point—above 300°F (150°C)—so that there would be no condensation of acidic solutions anywhere. Boiler outlet temperatures were kept high, and ductwork was insulated to keep exhaust gases hot; these practices also made for a buoyant plume that would quickly rise into the air above the plant stack.

The advent of flue gas desulfurization in the 1970s changed all that. The most thorough (and most prevalent) FGD system is the wet scrubber, in which the hot gas stream is showered by a water-and-limestone (or lime) slurry that absorbs most of the sulfur dioxide (SO_2) formed in coal combustion. Scrubbing cools the gas sharply, well below the acid dew point, to about 125°F (52°C). Moreover, the gas is totally water-saturated after passing through the scrubber.

"It's a very aggressive environment," acknowledges Stuart Dalton, manager of the Desulfurization Processes Program in EPRI's Coal Combustion Systems Division. "We condense all kinds of acids—hydrochloric, sulfuric, hydrofluoric. Utilities and FGD suppliers knew it from the start," he adds, "so they called for organic coatings on the carbon steel of scrubber vessels and downstream ductwork. In some instances they turned to stainless steel."

But the severity of corrosive attack was a complete surprise. Utilities were accustomed to 30-year plant lifetimes or better. When some early scrubbers "virtually dissolved," as Dalton puts it, in less than seven years, their owners and operators were taken aback. Clearly, there was more to the corrosion phenomenon than had been anticipated.

Two R&D missions

In simplest terms scrubbers, their auxiliaries, and the downstream ductwork corrode because acidic solutions condense out on progressively cooler surfaces—and because mechanically entrained droplets (so-called scrubber carryover) contain a little bit of everything that dissolves in or reacts with the slurry spray, not to mention some very fine particles of limestone, calcium sulfate, and even residual fly ash.

It is these complex environmental conditions inside FGD system components that lead to severe corrosion. Unknown constituents, unforeseen chemical reactions, unsuspected corrosion mechanisms—all these were possibilities. At the same time, FGD process chemistry proved to be highly variable and complex, and rapid investigation was required to deal with the chemical scaling that plugged and disabled systems, sometimes on a daily basis.

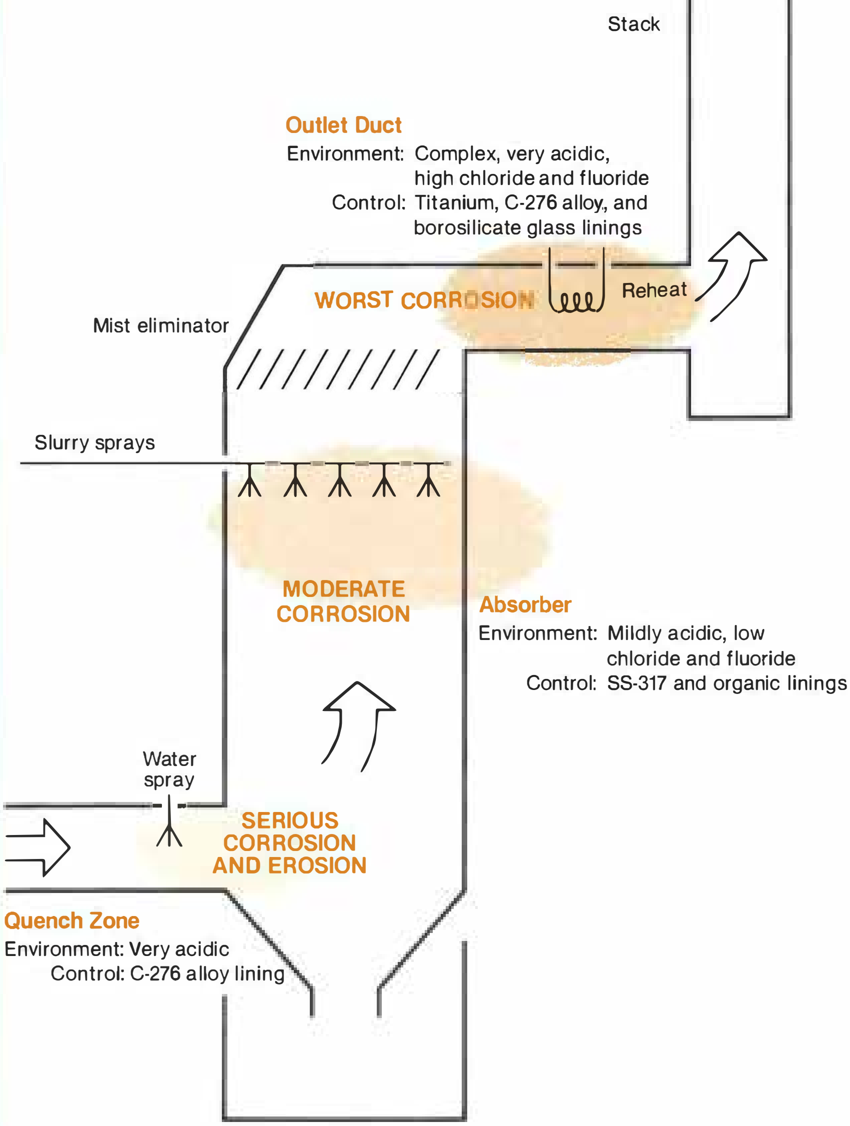
Both problems have been R&D targets of Dalton's program. Better on-line availability is the objective, and new knowledge of scrubber chemistry is paying off. "We sometimes see 100% operability of a scrubber today," says Dalton, "but better understanding and closer control of operating conditions is only part of it. Materials selection is also key," he continues, pointing out that "corrosion can force an entire power unit off-line for weeks, or even months, while the scrubber components and outlet ductwork are relined or rebuilt."

One measure of the corrosion research task alone is the $6 million of field and laboratory work that EPRI has sponsored since 1979. Another measure is the size of the scrubber universe. "There are about 90 lime and limestone scrubbers today," Dalton says, "and they dominate an industry population of some 140 scrubbers of all types, installed on about 60 GW of generating capacity. That figure just about doubles, to 120 GW, when you add in the power plants where scrubbers are under construction, committed, or planned."

For Dalton and his colleagues, the importance of their R&D becomes even more evident when the possibility of a retrofit scrubber market is considered. The threat of acid rain may lead to tighter restrictions on SO_2 emissions. If so, at least some of the power plants that were approved for construction before the lat-

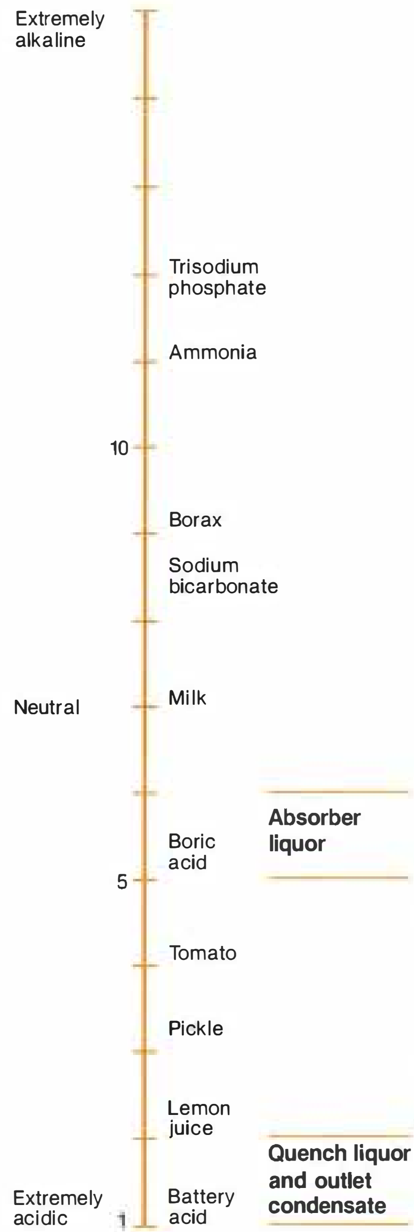
Where Corrosion Occurs...

Wet scrubbers, the choice for removing the most sulfur from fossil fuel combustion exhaust, create their own corrosive environments, as flue gases become saturated and are sharply cooled below the acid dew point. Three zones draw the most attention from researchers, engineers, and material specialists who are identifying and developing corrosion-resistant linings and construction materials.



...And How Acidic It Is

Quench liquor and the condensate from a scrubber outlet duct have a lower pH value than any common liquid except battery acid. Each successively smaller unit on the pH scale represents a tenfold increase in acidity.



est amendments to the Clean Air Act could be required to add gaseous emission controls as a condition of continued operation. Altogether, these plants represent about 150 GW of capacity.

Morrow plant experience

South Mississippi Electric Power Association provides an example of what many utilities experienced in their early use of scrubbers. Acknowledging the corrosion potential of the cooled and saturated exhaust gas that would leave the new scrubber of its R. D. Morrow plant, the utility lined the outlet duct with an organic material.

That lining failed within only months, separating somehow from the carbon steel behind it and permitting corrosion there. Or could it first have been penetrated by species that were able to establish cells or pockets of corrosion and thereby cause the debonding? The utility turned determinedly to Alloy G, a high-nickel, high-molybdenum alloy known for its corrosion resistance but costing perhaps six times as much as carbon steel. Amazingly, this new lining was extensively pitted, a virtual failure within a year.

As a result of this experience, the Morrow plant became an early host to EPRI's field research. Ironically, the failed duct linings were traced in part to good operating practice and successful water conservation. The utility had achieved virtually closed-loop scrubber operation at Morrow by closely controlling the chemical reactions that yield sulfate waste (sludge) and by recycling the reactive scrubber slurry with minimal addition of makeup water. An unintended result was high levels of dissolved solids in the scrubber liquor and about 20,000 ppm of corrosive chloride in the carryover moisture.

Chloride is a special problem because it is highly soluble. It originates in the coal, passes into the combustion gas as hydrochloric acid, and becomes absorbed in the scrubber liquor, where it dissociates as free chloride. Furthermore, its concentration builds up each time the slurry is recirculated to capture more sulfur. Controlled amounts of makeup water and limestone maintain slurry reactivity and consistency, but chloride builds up faster than the added water can dilute it.

EPRI's Charles Dene, who has managed desulfurization research projects for eight years, puts the chloride buildup into context. "It used to be that 500 ppm of chloride was considered a very high concentration in a power plant process," he remarks. "Chloride in a scrubber can surpass that point within only hours. Concentrations in modern, well-controlled units may be held at around 20,000 ppm, but they can run as high as 50,000 ppm." Dene adds emphasis by noting that "it would make better sense if we expressed concentrations as percentages."

Another contributor to corrosion is an extremely fine mist of sulfuric acid, which is formed by shock condensation when highly reactive sulfur trioxide first contacts the scrubber's water-saturated atmosphere. This acid mist represents only a minor fraction of the SO_2 present, but because it is so fine (its droplets less than 1 μm in diameter), as much as half of it may leave the absorber and enter the outlet duct.

Conducive duct environment

The exhaust duct beyond a scrubber may be only 15 feet long, or it may be several hundred feet, with elbows and flanges where acid mist droplets can eventually impinge. Moreover, although the duct is insulated, the saturated gas flowing through it cools still further, especially at the duct wall, thus falling below the acid dew point and yielding a film of corrosive condensate.

Flue gas is usually reheated in the duct leading to the stack, for greater buoyancy of the exhaust plume as it rises into the atmosphere. That heating is seldom sufficient to preclude the condensation of sulfuric and other acids, however, much less to evaporate the entrained droplets of acid mist. Furthermore, so long as the temperature remains below the dew point, the corrosion rate increases with temperature.

One reheating technique creates special problems. Bypass reheat, as it is called, diverts a relatively small volume of unscrubbed hot gas around the scrubber and returns it downstream to heat the gas there. The resulting temperature of perhaps 200°F (93°C) is much higher than that of the scrubbed, saturated gas alone, but it is below the acid dew point. Therefore, the incoming unscrubbed gas condenses and contributes still more acid to an environment of accelerated corrosion. This was the situation at Morrow and many other scrubber installations.

If an organic coating did not adhere and a high-cost alloy did not resist attack, what then? The Morrow plant experience symbolized an industrywide problem, and Morrow became one of three utility sites where duct lining samples were tested against the corrosive action of flue gas from low-, medium-, and high-sulfur coals. This 18-month field program engaged EPRI materials scientists beyond Dalton's group.

Barry Syrett, a technical adviser specializing in aqueous corrosion, joined in managing wide-ranging research on scrubber materials. The work began with steel and other alloys but went on to include organic and nonmetallic inorganic materials, largely plastics and ceramics.

Corrosion-resistant metals

The metal samples installed in the scrubber ducts of the host plants included a number of austenitic and ferritic stainless steels—having different amounts of chromium, molybdenum, and nickel—as well as nickel-, zirconium-, and titanium-base alloys. Of these, the clear winners were titanium (both the commercially pure Grade 2 and the more expensive Grade 7, which is alloyed with a fractional percentage of palladium to improve crevice corrosion resistance) and a nickel alloy known as C-276.

Laboratory results were more mixed, in part because very different environments (pH level, chloride concentration, and temperature) could be created. Syrett and his research contractors soon came to realize, however, that while the real world was unknown, the laboratory world was unreal; that is, the composition of flue gas from an operating unit was often incompletely and imprecisely known, but the contrived environment of the laboratory chamber was simplified to the point of being unrepresentative.

Until just a few years ago, according to Syrett, only temperature, pH, and chloride level were seen as major parameters of duct environments. The controlled introduction of fluoride, sodium, calcium, and magnesium ions was the first step toward more realistic laboratory simulations, but still there were problems.

Chloride concentration, for example, was varied in a strongly acidic (pH of 1) laboratory setting thought to be representative of condensate in a duct. The corrosion rate increased with the chloride level, up to a point, then decreased sharply. Titanium samples were destroyed in a week when the chloride level was 30 kg/m^3 (30,000 ppm) but survived well at 100 kg/m^3 (100,000 ppm). This was clearly at odds with field experience, where titanium is known for its corrosion resistance.

Continued investigation gradually revealed the significant roles of other trace species in either advancing corrosion or inhibiting it. Depending on the mix and the concentrations (up to 2000 ppm), corrosion rates were found to vary by a factor of 1000. Aluminum, for example, was found to improve the corrosion resistance of titanium when the environment is acidic and also contains fluoride; aluminum and fluoride somehow combine in a soluble complex that does not harm titanium.

Analyses of condensate from the duct walls yielded data on the trace elements there. Concentrations in the flue gas and the wall condensate are now seen to be quite different. At the Morrow plant sulfate, aluminum, magnesium, sodium, chlorine, iron, and fluorine were hands-down leaders in concentration (2600–59,000 ppm) among 34 species measured in condensate on the duct walls. The elements may originate in the fuel, the limestone, or even the makeup water.

The eventual solution at Morrow was to add another lining, of Alloy C-276, over the areas of Alloy G that were pitted. The C-276, with less iron and chromium but substantially more molybdenum, is holding up well.

Resolving Lab and Field Findings

The sharp sensitivity of scrubber materials to their chemical environment is illustrated by these two specimens of highly corrosion-resistant titanium. When subjected to laboratory chloride-fluoride solutions that differed only in pH, one specimen survived and the other was destroyed in a week. Analyses of more realistic solutions containing other species eventually revealed that aluminum, a trace element in flue gas condensate, combines with fluoride in a way that consistently preserves titanium in real-world applications.

The varied influences of chemical species suggest their use as additives to inhibit scrubber corrosion. Little is yet known of the chemical mechanisms involved in this. "Still," admits Syrett, "if the presence of a species in the outlet duct will cut the corrosion rate, there is a temptation to spray a solution of that species into the duct." Laboratory work is continuing in order to evaluate possible corrosion inhibitors and methods of introducing them—into the duct or, perhaps, into the scrubber slurry.

Inorganic and organic materials

Several nonmetallic inorganic materials were also field- and laboratory-tested for corrosion resistance in scrubber ducts. The principal candidates were a sprayed-on silicate cement and a borosilicate foamed glass. The foamed glass exhibited the best performance throughout the 18-month program, with no failures of any kind. For use as a duct lining, it is fabricated in blocks and laid up with a urethane-based cement. In fact, the urethane cement itself is the corrosion barrier. Since the cement would melt away at duct temperatures, however, the foamed glass is used to insulate it, acting like the heat shields on the nose cones of spacecraft.

The organic materials subjected to scrubber duct environments at EPRI's three host utility plants (and investigated in the laboratory) included a fluoroelastomer, a fiberglass-reinforced polyester, vinyl esters, and several reinforced epoxies. The vinyl ester and epoxy coatings suffered only localized failure.

An important point, however, is that all the organic coating materials are to some degree permeable. The trick is how to delay the migration of moisture or corrosive species so as to achieve a cost-effective service lifetime. EPRI's Dalton cites fiber reinforcement as one possible technique; another is the use of graphite powder or other materials as fillers in the organic matrix.

As a class, organic coatings also respond distinctively to other environmental variables, notably to temperature cycling, which hastens their deterioration and separation from the steel duct wall. Depending on what penetrates a coating, separation may result from corrosion directly or from other chemical action (as gases or deposits build up and wedge the coating away from the wall).

Surface preparation is important to the adhesion of organic coatings and their performance. The precise degree of surface roughness is thought to be a major variable in mechanical bonding, but its effect on coating lifetime was an unknown quantity in the 18-month field tests, for which various proprietary practices were used. Thus, EPRI sponsored a subsequent study that used just two coatings (a fluoroelastomer and an epoxy) in conjunction with five carefully documented preparations involving combinations of steel and alumina grit blasts, acid pastes, and alkaline washes.

One observation alone indicates how difficult it has been to limit variables in scrubber research. When alumina grit was used to achieve a desired surface profile, traces of it remained and were covered by the organic coating. In the opinion of the investigator, the alumina itself acted as a corrosion inhibitor.

Better use of what we know

As Dalton reflects on the scrubber corrosion R&D conducted under his direction and on the specialized studies of materials coordinated by Syrett, he concludes that although no panacea has turned up, the progress is noteworthy. "The fixes have been expensive," he admits, "not just in the titanium and high-nickel alloys to resist corrosion but in redundant components to avoid outage, too." The result, he says, is that emission controls (fly ash removal, FGD, water cooling and treatment, and waste disposal) may be 25–40% of a power plant's capital cost.

Syrett phrases the price of progress a little differently. "It makes sense to pay a high price for materials alone if you can thereby avoid scrubber outages that take an entire power unit off-line. Selecting a lining that works is the trick," he says, "not agonizing about how one alloy costs twice as much—even 10 times as much—as another." Syrett's point is that even an expensive material costs less than lost availability.

Both men applaud the growing understanding of FGD systems by utilities and the growing interest in scrubber materials. These are revealed, in part, by a perceptible move toward design specifications as opposed to purely performance specifications. "You need some guarantees on hardware and materials," Dalton agrees, "but performance guarantees for today's coal, plant use, and emission standards won't mean much when conditions change."

Dalton sees potential for such new coal technologies as fluidized-bed combustion and integrated gasification–combined-cycle generation, which yield low sulfur and nitrogen oxide emissions without scrubbers. He also knows that tomorrow's generation of pulverized-coal-fired power plants will need advanced materials for their integrated emission control systems. But he is most mindful of today's scrubber-equipped plants—in operation, under construction, or still in planning—that need upgraded materials, as well as yesterday's plants that may at some time have to be retrofitted with scrubbers. The R&D now falling into place will serve them for years to come. ■

Further reading

The Effects of SO_2 Scrubber Chemistry on Corrosion. Final report for RP1871-7, prepared by Rockwell International Science Center, October 1986. EPRI CS-4847.

The Effects of SO_2 Scrubber Environments on Alloy Corrosion. Final Report for RP1871-6, prepared by Battelle, Columbus Laboratories, July 1986. EPRI CS-4697.

G. H. Koch and B. C. Syrett. "Progress in EPRI Research on Materials for Flue Gas Desulfurization Systems." In *Dewpoint Corrosion*, ed. D. R. Holmes. Chichester, England: Ellis Harwood Ltd., 1985.

This article was written by Ralph Whitaker, feature editor. Background information was provided by Stuart Dalton and Charles Dene, Coal Combustion Systems Division, and Barry Syrett, Materials Support Group.

TECH TRANSFER NEWS

EPRI Codes Easy to Use at Niagara Mohawk

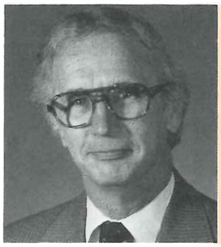
To be widely usable across the utility industry, EPRI software for mainframe computers is designed for generic application; however, the variety of different operating systems in use on utility corporate computers requires the construction of in-house links to allow easy user access to EPRI codes. Niagara Mohawk Power Corp. in Syracuse, New York, is going one step further in access assistance by publishing easy-to-follow guides to accessing EPRI software and by setting up in-house user groups.

Charles J. Blattner, a senior engineering specialist in the engineering standards group at Niagara Mohawk, has pioneered this effort, recognizing that engineers at his utility are more likely to use EPRI-developed software if it is easily accessible. Blattner follows a four-step program to achieve this goal: he familiarizes himself with a particular piece of EPRI software, works with Niagara Mohawk's computer applications group to provide the proper interface, writes an in-house user's guide to this interface, and organizes and coordinates the user group.

To become thoroughly familiar with the software, Blattner, with assistance from the computer applications group, screens EPRI report summaries and then reviews EPRI final reports on projects of special interest to Niagara Mohawk. Focusing on selected software, he attends EPRI-sponsored workshops and seminars, studies the documentation, and learns how his utility can apply these computer tools.

Preparing an interface is the crucial next step. One member of the computer applications group is responsible for adapting EPRI software for in-house use and updating an on-line list of EPRI codes available at the utility. The group also prepares program-specific aids that are available to a perplexed user at the touch of a HELP key.

When the interface is ready, Blattner takes about one month to prepare the in-house user's guide. It contains easy-to-follow instructions on how to access the code, describes the material that will appear on the screen, provides keywords, and gives directions on how to select and work on portions of the code. To make certain that the guide really is easy to follow, Blattner gives it to another staff member—not a computer specialist—for trial use.



Blattner

Once the guide passes this test and is published, Blattner begins organizing the user group. He schedules an introductory meeting and contacts engineering supervisors who may have staff members interested in applying the software. At this first meeting Blattner provides background on the code—the why and how of its development. The computer applications staff member who designed the interface describes how to use the program and shows some on-line examples. Blattner continues as coordinator of the user group and sends minutes of its meetings to interested supervisors.

Blattner points to three factors that have contributed to the success of this approach at Niagara Mohawk: his role as an EPRI adviser (on committees for the overhead lines and transmission substations programs), the close working relationship of the engineering research and computer applications groups, and management support.

Niagara Mohawk recognizes the value of Charles Blattner's work. In late 1986 he received one of the utility's coveted exceptional service awards because the implementation of EPRI's SGA (substation grounding analysis) software saved Niagara Mohawk a significant amount of money. Not content to rest on his laurels, Blattner has also organized a user group for EPRI's GATL (grounding analysis of transmission lines) software and is currently working on the in-house guide for CORRIDOR (right-of-way sharing with railroad and pipelines), which is part of the TLWorkstation package.

Contact: Charles J. Blattner, Niagara Mohawk Power Corp. ■ *EPRI Contact: Richard Kennon (415) 855-2311*

Check Valve Checkup

Credit one of a utility's experienced technical advisers to EPRI with a way for his company to examine a nuclear plant check valve without downtime.

The success story began late last year when inspections at Pacific Gas and Electric Co.'s Diablo Canyon plant revealed that a nut, which should have held the disk to the swing arm, was missing from a main steam check valve in one of the four main steam loops of Unit 1. A similar nut was found to be partially unscrewed when a valve in another loop was inspected.

The 28-in-diam valve is a vital part of the plant safety system and would be relied on in case of a downstream steam line failure. The integrity of similar valves in Unit 2 was therefore immediately in question, but that unit was in full power operation and the usual inspection procedure would have required a five-day shutdown for valve inspection.

An attempt to radiograph the valve by using cobalt-60 was unsuccessful because the method was not powerful enough to penetrate 11 inches of steel.

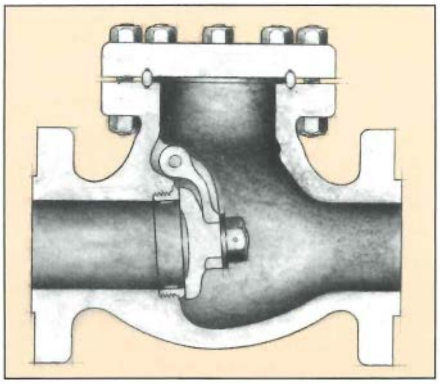
Spencer Friedrich, a senior metallurgical engineer in PG&E's Engineering Research Dept., suggested using the new, 6-MeV version of Minac (a portable linear accelerator system originally developed by EPRI) to radiograph the valves while Unit 2 remained on-line. The Minac services were contracted from Schonberg Radiation, and the job was completed over a weekend.

The Minac inspection served two technical purposes. Most important, it verified the integrity of check valves in Diablo Unit 2. It also gave PG&E a set of baseline images for future use and a way to monitor valve condition. If a valve deteriorates, the Minac images will show its progress and help reveal the cause. The Unit 2 valves were reinspected a month later to verify that there had been no changes in the condition of the valves.

Equally important, use of the Minac system forestalled shutting down the Diablo Canyon unit and buying replacement power.

Tracking new R&D technology is part of Friedrich's responsibility as a PG&E staff member. When problems arise, his department reviews advances in relevant technologies and suggests new products that may offer solutions.

Thorough knowledge of EPRI's nondestructive evaluation (NDE) research lay behind the Minac suggestion. Friedrich has been a member of EPRI's Nuclear Power Division Materials and Systems Development Task Force for five years, and development of the Minac accelerator was closely monitored by a subcommittee of that advisory group.



Contacts: Thomas Jenckes and Spencer Friedrich, Pacific Gas and Electric Co. ■ *EPRI Contact: M. E. Lapides (415) 855-2063*

Central Source for Cool Storage Information

Utility personnel, engineers, building owners, and others seeking information on cool storage technology can benefit from the publications and services of the International Thermal Storage Advisory Council (ITSAC). Founded in 1986 by an international team of experts with financial support from EPRI and the Edison Electric Institute, ITSAC is a nonprofit corporation that publishes a newsletter and technical bulletins covering all aspects of cool storage system design and operation.

The monthly ITSAC newsletter describes new products, installations, and utility incentive programs; announces upcoming seminars; and reviews available reports and publications. The technical bulletins, issued at least once each month, cover such topics as the fundamentals of ice and chilled-water systems, customer and utility benefits, system case studies, load curve effects, residential and commercial applications, and operation and control strategies.

ITSAC also acts as a clearinghouse for current information on cool storage issues, offering its members telephone updates. In addition, new ITSAC members receive a set of publications designed to provide a basic understanding of cool storage technology.

By shifting 80–85% of a building's air conditioning load to off-peak hours, cool storage systems offer substantial benefits to both electric utilities and their customers. The utilities gain a valuable technology for load management, while commercial users enjoy substantial energy cost savings. An increasing number of utilities are adopting rate schedules and other programs to encourage the installation of cool storage systems and to help commercial and industrial customers with system operation and maintenance.

"With applications of thermal storage technology increasing rapidly in the United States and around the world, there is a corresponding increase in the need for information on the systems among utilities, builders, vendors, and users," explains Loren McCannon, the chairman of ITSAC.

Linda Willoughby, a marketing engineer at Arizona Public Service Co., agrees: "The information exchange and technical assistance provided by ITSAC have been valuable to us in this growth phase for cool storage technology around the country. Our program to promote thermal storage is moving ahead rapidly, with eight systems operating and eight more committed. We are also exploring a program in which we would lease equipment to customers."

For information on ITSAC publications and membership, contact Loren McCannon, 5252 Balboa Avenue, Suite 401, San Diego, CA 922117, (619) 560-4878. ■ *EPRI Contact: Ronald Wendland (415) 855-8958*

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

MEETING UTILITIES' DYNAMIC OPERATING REQUIREMENTS

In the next decade, declining load factors, excess baseload capacity, growing nonutility generation, and aging power plants will pose significant operating problems for utilities. Compounding these problems, traditional methods of optimizing the generation mix have not adequately taken into account the dynamics of matching generation to load. The resulting problem: increasing difficulty and costs to achieve desired system reliability. EPRI is helping utilities respond by developing planning tools that recognize both energy costs and operating flexibility. One early result of this work is an increased appreciation for the benefits that result from storage, hydro, and fuel cell systems.

Today the utility industry is operating under conditions very different from those that prevailed when most of the power plants were designed and when the current generating mix was defined. In the 1970s, when utilities were deciding on power plants to add to their systems for the 1980s, the dramatically higher price of oil and large projected increases in baseload demand convinced them to build large coal and nuclear power plants, instead of more-flexible oil-fired or energy storage plants.

In the past 15 years, however, utilities have seen baseload electrical demand grow slowly and in some cases actually decrease. This change is a result of a number of factors, the most important of which is the changing nature of the utility customer—heavy industry with its 24-hour electricity consumption is giving way to service industries with primarily daytime operation. Exacerbating this situation is the increasing role of nonutility generation, which is expensive, undispatchable energy that utilities must purchase whether it is supplied during a demand peak or valley. Further, over 85% of the power plants under construction were designed for baseload operation; as these plants come on-line, more baseload plants will be forced into cycling operation, and utility operating problems can be expected to worsen.

These changing conditions have resulted in a number of operating problems for the utilities: inefficient part-load operation, minimum loading, cycling, and load following of thermal power plants. There are substantial economic penalties to utilities if these operating problems are not dealt with effectively, including highly visible expenses (such as increased fuel costs), as well as penalties equally important but not as easily measured. In this second group are reduced power plant life, increased O&M costs, and potential degradation of power system reliability. EPRI recognizes these problems and is developing cost-effective solutions.

Energy storage plants

Historically, energy storage technology has been developed and applied by utilities primarily to alleviate utility peaks and to use low-cost off-peak energy to displace expensive on-peak generation. In addition, however, energy storage plants exhibit a number of desirable dynamic operating characteristics, many of which are also exhibited by fuel cells and pumped hydro, such as low startup costs, short startup time, fast changeover from energy storage to power generation, efficient operation at a wide range of loads, fast load-changing capability, and high unit availability. These characteristics can alleviate dynamic operating costs in a number of ways.

- Reduce cycling in existing units
- Provide load during off-peak periods
- Provide spinning reserve during peak periods to minimize inefficient operation of thermal plants
- Reduce minimum loading requirements in nonstorage plants
- Reduce the need to precommit units to meet morning pickup requirements
- Reduce the need to postpone decommitment of units in the evenings
- Provide minute-to-minute load regulation and second-to-second frequency control

The dynamic operating benefits that can result from operating energy storage plants are getting increasingly greater attention from EPRI and utilities. In May 1984 the international symposium and workshop on the dynamic benefits of energy storage plant operation, jointly sponsored by EPRI and DOE, was attended by representatives of 15 countries and 40 organizations. That symposium pointed up the fact that utility operators all over the world have routinely used pumped-hydro plants to meet dynamic operating requirements. The dynamic operating benefits currently being realized by utilities with energy storage plants are as important as the cost saving that results from leveling load, despite the fact that most of these plants were planned and built to address only peak demands.

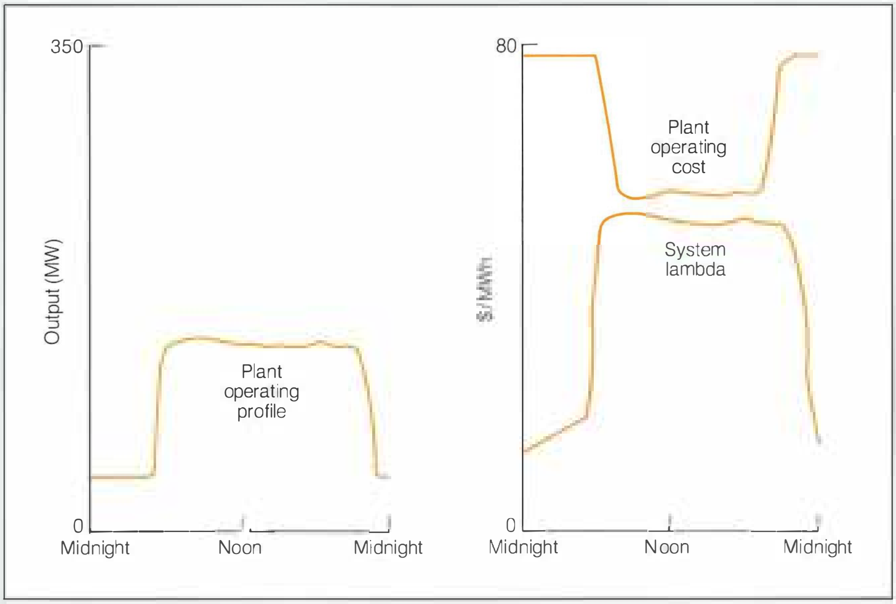
To quantify the dynamic operating benefits of energy storage and to identify (from a utility operator's perspective) how the inclusion of dynamic operating considerations might influence the utility planning process, EPRI sponsored a study of the dynamic operating costs and benefits of pumped-hydro energy storage for three utilities. The study evaluated the total value that pumped-hydro offers the utility.

This total value has two parts: the energy value based on the instantaneous marginal cost of electricity (i.e., system lambda, or the instantaneous value of generated power) and the value of dynamic benefits based on the saving associated with minimizing the part-load and minimal-load operation of thermal plants that otherwise would have provided the dynamic benefits.

In Figure 1, these thermal plant costs are defined and calculated. This figure shows operating costs and the value of power generated by an actual plant that is minimally loaded at night and is operated below optimum during the day to provide dynamic operating capability. This nonoptimal operation results in poor heat rates and associated high costs. In this rather typical case, the cost of operating the plant exceeded the value of the energy delivered by about one-third.

The three utilities involved in the study had

Figure 1 Dynamic operating costs of a cycling 350-MW gas-fired thermal plant. The plant is minimally loaded during the night and is operated below optimal output during the day to provide load following and system regulation. The cost of the power generated (about $129,000/d) exceeds its value (about $97,000/d) by approximately $32,000/d.



very different generating mixes, but all found surprisingly high values for assumed or actual pumped-storage operation. For one utility, which operated coal-fired plants only, the study determined that a pumped-hydro plant could be operated economically because of its dynamic operating benefits, even though the utility has a flat daily lambda profile. This was quite unexpected and was counter to conventional wisdom. But the results have been verified and confirmed by the chief dispatcher of that utility.

In the other two cases, results showed that TVA and Northeast Utilities, both of which operate large pumped-hydro plants, were realizing dynamic operating benefits of between 20% and 60% of the plants' total operating costs, much greater benefits than conventional planning studies would have projected. The results for the Northfield Mountain Pumped Storage Plant of Northeast Utilities are shown in Table 1. The plant provides system regulation, spinning reserve, and load-following capability with its 200-MW/min ramp rate. The value of this plant to provide these dynamic services is about equal to its value to level load.

New planning tools

Despite the significance of dynamic operating costs, these costs are not typically included in most system planning studies. One result is that the competitive advantages of technologies offering dynamic operating benefits, such as energy storage and fuel cells, are often not considered. Recognizing these deficiencies, industry advisers recommended that EPRI assume the leadership to develop new planning tools to meet this need.

Although power sources with high operating flexibility are generally recognized to be valuable to the industry, quantifying the value of operating flexibility has proved difficult and cumbersome. The ideal planning approach would be credible, afford realistic operations, isolate dynamic benefits, be broadly applicable, and be efficient. *Credibility* refers to results that are sufficiently accurate to be used in the utility's decision-making process; *realistic operations* means power source dispatching that reflects dynamic considerations; *isolation of dynamic benefits* quantifies the portion of a power source's benefits that results from its dynamic operating capabilities; *broad applicability* refers to quantifying a range of applications, including capacity and operation planning, power transactions, life extension, and refurbishment; and *efficiency* has to do with accomplishing dynamic operation evaluations with as little expense as possible and as an adjunct to existing evaluation methods (to make the approach more acceptable).

Significant progress toward all these objectives has been made. One effort resulted in a research code called DYNAMICS, which was developed by using the same mathematical optimization techniques that utility operators with pumped storage are beginning to use for unit commitment decisions. This technique, called Lagrangian relaxation, separates the attributes of a dispatch decision into such components as the value of energy and the value of flexible operating capacity.

In the process of finding the optimal unit commitment, the technique also determines the system marginal value of operating flexibility. DYNAMICS uses a decomposition approach that focuses on the interaction of specific components of a power system (e.g., power generation units) with the rest of the system. It can, therefore, quickly assess the economic effects of changing dynamic operating characteristics of any component.

The DYNAMICS code is useful in making technology choices, plant design, operations planning, and power transactions.

□ Technology choice. Quantifying system marginal costs of energy and operating flexibility provides a means of comparing operating expenses and potential benefits of alternative technologies for a range of potential utility operating environments.

□ Power plant design. For a given technology, computing dynamic operating benefits for different plant designs (e.g., various capacities and capabilities, such as additional cycling capacity and lower minimal load) enables utility planners to evaluate the cost trade-offs associated with various design options. This capability is important in life extension and plant refurbishment studies.

Table 1
DYNAMIC OPERATING BENEFITS: NORTHFIELD MOUNTAIN PUMPED-STORAGE PLANT

Week	Total Operating Benefits ($1000/wk)	Lambda Replacement Value ($1000/wk)	Dynamic Operating Benefits	
			$1000/wk	% of Total Operating Benefits
9/26/83 to 10/3/83	395	196	199	50
1/9/84 to 1/16/84	292	192	100	34
1/30/84 to 2/6/84	282	89	193	68
4/2/84 to 4/9/84	579	373	206	36

▫ Operations planning. Flexible resources provide utility systems with an additional reliable and low-cost service. By valuing system attributes, operators can efficiently examine the cost trade-offs for a much larger set of operation alternatives. For example, DYNAMICS could help identify advantageous opportunities for routine maintenance and inspections.

▫ Power transactions. By valuing system flexibility attributes, utilities can determine important pricing information. Greater competition both between utilities and with nonutility power producers increases the need for utilities to understand the cost and value of their services on a component basis (e.g., the quality, reliability, and amount of energy and power).

Pacific Gas and Electric Co. is now trying DYNAMICS for technology choice evaluation. EPRI is soliciting the participation of other utilities in testing the application of DYNAMICS in life extension and plant refurbishment studies.

Another planning tool now under development is DYNASTORE, which evaluates the costs associated with load following and the operational approach and benefits of energy storage to meet morning pickup requirements and evening load reductions. Storage is used, for example, in the morning to delay and optimize the use of thermal plants. The overall saving for load following with storage can reach a value (when calculated as a capital cost credit) of $190/kW if the alternative is gas- or oil-fired steam plants. This is a value that is above that associated with load leveling; however, equipment specifications and storage needs will have to accommodate both applications. In the case of storage, hydro, and fuel cells, such an accommodation can normally be achieved at little cost. The Salt River Project is now trying DYNASTORE to determine the value of rapid-response technologies to meet its load-following requirements.

The success to date promises significant benefits to the industry. Commercial transfer requires several more steps, including carefully verifying the current technical results, determining the best approaches to integrating the new planning approaches with current planning practices, producing and validating commercial-grade software and documentation, and providing initial user training and support.

Future decisions

The studies and results described above have led to the following conclusions.

▫ The dynamic operating costs of utilities are substantially higher than expected.

▫ Current planning tools and approaches do not properly consider these high dynamic operating costs and, therefore, may inappropriately guide utilities to technologies that lack dynamic operating capabilities.

▫ Pumped storage is being used today at great economic advantage to meet utility dynamic operating needs; compressed-air storage, battery energy storage, and fuel cells also have desirable dynamic operating characteristics.

▫ The improved evaluation methods now under development can provide useful information to assist utilities in evaluating technologies, plant design options, operation alternatives, and costs of power transactions.

Further, although the evaluation of dynamic operations is very important, it is but one of a series of factors that if addressed properly can improve system planning. Others include (1) improved system reliability and savings in transmission facilities and reduced energy losses from dispersed urban siting of generation and storage systems; (2) shorter lead time and improved matching of supply and demand from modularity of generation; and (3) reduced uncertainty in lead time from standardized modular power plants with desirable environmental characteristics.

System planning without proper consideration of these factors could lead to decisions that could unnecessarily increase annual costs by tens or even hundreds of millions of dollars. As a result, EPRI will continue to work with the utilities to develop and modify planning tools to improve the utility decision-making process. *Project Managers: Tim Yau and James Birk*

CHARACTERIZATION OF KILnGAS WASTEWATER

Coal gasification processes produce wastewaters containing varying amounts of dissolved organics, ammonia, salts, and other contaminants that must be treated before they are discharged into the environment. The concentration of these contaminants is substantially higher in wastewaters from moving- and fluidized-bed coal gasification processes than it is in wastewaters from entrained-flow processes. The KILnGAS coal gasifier is a horizontal-retort, dry ash, moving-bed gasifier. For the past three years, a 600-t/d (rated capacity) KILnGAS demonstration plant has been intermittently operated in East Alton, Illinois, by its developer, Allis-Chalmers Corp. EPRI has funded a program to (1) collect and characterize the wastewater produced by the KILnGAS process, (2) compare the KILnGAS wastewater with wastewaters from other coal gasification processes, and (3) project a conceptual scheme for treating KILnGAS wastewater (RP2526-2).

The KILnGAS coal gasifier is a rotating, air-blown, ported kiln (i.e., a horizontal, dry ash, moving-bed gasifier), operating at about 60 psig (517 kPa). Over 30,000 t of Illinois No. 6 coal have been gasified in the Allis-Chalmers 600-t/d (rated capacity) demonstration plant since operations began about three years ago.

Coal enters the kiln at the feed (cold) end and is gasified in the presence of steam and air injected through ports along the length of the kiln. The resultant low-Btu gas exits from both ends of the reactor. The low-temperature (about 1000°F; 540°C) feed-end gas, which contains significant amounts of methane and condensable hydrocarbons, is cooled (scrubbed) before being routed to the sulfur removal system (Stretford plant). The high-temperature (about 1900°F; 1040°C) discharge-end gas contains only negligible amounts of condensable hydrocarbons; it is sent to a heat recovery system before being scrubbed and routed to the Stretford plant.

The wastewater and condensable hydrocarbons (tar and oils) from the feed-end gas are sent to a tar-water separator. Raw wastewater from the separator is combined with raw wastewater from the discharge-end gas scrubber and sent to a condensate treatment train (oil wash and ammonia stripper) before being routed to the Alton municipal treatment plant. Wastewater production from the demonstration plant is about 80 gal/min (4.9 mm^3/s) at the rated coal throughput of 600 t/d.

Wastewater analyses

Nine samples of raw wastewater were collected by personnel from the Oak Ridge National Laboratory during a six-day KILnGAS operating period in late November and early December of 1984. The samples were preserved on site and transported to ORNL, where they were subjected to detailed chemical analyses.

The KILnGAS operating data obtained during the sampling period indicated a large variation in the wastewater flow rate, whereas other process parameters remained relatively stable. It should be mentioned, however, that the wastewater flow rates were recorded during the time the samples were taken and are discrete rather than averaged values.

The characterization results for the collected KILnGAS wastewater samples are presented in the first column of Table 2. As can be seen, the wastewater contains a significant amount of organic material, of which phenolic compounds are a large portion. The water also contains ammonia, cyanide, thiocyanate, sulfate, chloride, suspended solids, and oil and grease, which generally are found in all coal conversion wastewaters. It should be noted that the large variations in the concentrations of the major dissolved species for the nine samples could have been caused by near-term fluctuations in wastewater flow rate, by

Table 2
COAL GASIFICATION WASTEWATER CHARACTERISTICS
(mg/L, except for pH)

Component	KILnGAS (Illinois No. 6) Moving Bed	Lurgi Dry Ash (Montana Rosebud) Moving Bed	Lurgi Dry Ash (High-Sulfur Eastern Coal at Sasol) Moving Bed	Lurgi Dry Ash (Lignite at Kosovo) Moving Bed	British Gas–Lurgi Slagger (Pittsburgh No. 8) Moving Bed	Grand Forks Slagger (Lignite) Moving Bed	HYGAS (Illinois No. 6) Fluidized Bed	Texaco (Illinois No. 6) Entrained Flow
Chemical oxygen demand (COD)	4100–6100	21,000–23,000	12,000	20,000	20,000	25,400	4050	1100
Total organic carbon (TOC)	810–1610		3500	6000				
Total phenols	260–660	4200–4400	3800	3000	3000	5100	710	<1
Cyanides and thiocyanates	130–300	8–19	<3	80	1150	150	30	50
Total nitrogen	1200–2300			4300		5200	3700	
Ammonia	840–1700	4000–14,000	7000	3700	3000			2100
Total sulfur	430–1030		950		700			
Chloride	450–710	40–45	670		1500			3500
Total suspended solids (TSS)	150–700							
Total dissolved solids (TDS)	1070–2100	1700–4000		2000	7000			2220
Oil and grease	25–340		50	900		300		6
pH	8.3–8.8	8–10	9	9	9			

unsteady operation of the plant, or by errors introduced by the sampling procedures.

The KILnGAS wastewater was also analyzed for volatile organic compounds and trace elements. As expected, the major volatile organics were benzene and toluene, and the trace element compounds were typical of those in other coal conversion wastewaters.

Comparison with other wastewaters

Measured characteristics of wastewaters from five additional coal gasification processes are also presented in Table 2. As expected, the moving- and fluidized-bed gasifiers produce wastewaters containing significantly more organic material, particularly phenolics, than the entrained-flow gasifiers. It should be noted, however, that direct comparisons of the wastewater characteristics of these gasification processes is difficult because of variations in the coals used and in the operating conditions.

The primary reason for the differences in concentrations of dissolved organic material between the three gasifier types is associated with differences in the raw gas outlet temperature. The gas outlet temperature for the countercurrent, vertical retort, moving-bed gasifiers (Lurgi dry ash, British Gas–Lurgi) is typically between 900 and 1200°F (480 and 650°C). As a result, some coal devolatilization products (tars and oils) are present in the outlet gas, and the wastewaters produced are generally high in dissolved organics. In fluidized-bed systems (e.g., HYGAS, KRW), the gasifier is usually maintained at temperatures between 1600 and 1800°F (870 and 980°C), which is below the coal ash fusion temperature but is still high enough to ensure destruction of most of the coal devolatilization products. In entrained systems (e.g., Texaco, Shell), the gasifiers operate above the ash fusion temperature, typically at 2400–2800°F (1320–1540°C), which virtually eliminates tar production and results in wastewaters with only traces of dissolved organics.

As can be seen in Table 2, KILnGAS wastewater is significantly less concentrated in phenol and total organic carbon than are wastewaters from the vertical-retort, moving-bed gasifiers. Most other compounds analyzed for, including cyanide, thiocyanate, total sulfur, and oil and grease, fall in approximately the same concentration range as those for the other moving-bed gasifiers.

Wastewater treatment

The data generated during this project, as well as those from other work performed with coal gasification wastewaters, indicate that conventional treatment should be suitable for use on the KILnGAS wastewater. A conceptual sequence of the processing steps to treat KILnGAS wastewater before it is discharged to the environment follows.

- Oil-water separation, followed by air flotation
- Solvent extraction to remove phenolic material
- Steam stripping to remove ammonia
- Biologic treatment to remove organics and residual ammonia
- Clarification and filtration to remove sludge solids
- Activated carbon adsorption to remove residual organics
- Ozonation to destroy trace cyanides and any remaining organics

Results from an ongoing EPRI project show that nitrification (ammonia removal) of KILnGAS wastewater did not occur in the biotreatment reactor (RP2526-1). Therefore, an additional process step (e.g., adsorption on activated clay) may be required to complete the KILnGAS wastewater treatment.

It should be noted that there is limited commercial experience and therefore only limited data on which to draw in designing coal gasification wastewater treatment processes. Any proposed design may therefore require treatability testing at bench or pilot scale on actual wastewater to produce a flow sheet that can be applied with confidence at commercial plant scale. *Project Manager: Michael Epstein*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

FLY ASH UTILIZATION IN HIGH-VOLUME APPLICATIONS

Since 1984 EPRI has sponsored an ash utilization research, development, and demonstration program aimed at supporting the increased use of fly ash in high-volume applications, particularly in roadway construction (RP2422). High-volume applications are those that consume large quantities of fly ash or whose products contain a high percentage (over 50%) of fly ash. They do not require a certain type or quality of ash; the key factors in these applications are consistent particle size distribution and product quality. High-volume uses of fly ash include fills, embankments, backfills, landfill cover, soil amendment, subgrade stabilization, pavement base courses, grouting, slurry walls, and hydraulic fills.

In 1985 the electric utility industry produced nearly 50 million tons of fly ash, of which 11.4 million tons were used in some form. High-volume applications accounted for only 20% of the ash used. RP2422 seeks to significantly narrow the gap between ash production and utilization. The project involves a variety of efforts: the documentation of existing high-volume ash utilization projects, the preparation of design and construction manuals, the preparation of a guide for developing an effective ash marketing program, the construction and monitoring of several demonstration projects, and an extensive technology transfer program.

Utilization survey

Many contractors, professional engineers, and state highway and regulatory agencies consider fly ash a new or unconventional construction material. They are generally unaware of past projects in which it has been successfully used in high-volume applications. Thus EPRI has published a report that documents over 270 high-volume fly ash utilization projects in the United States and Canada (CS-4446).

The projects were identified through a literature review and mail and telephone surveys of electric utilities, state highway agencies, ash marketers, engineering firms, and private industrial firms known to have used ash in the past. The report categorizes the projects by the class of fly ash used, the type of application, and region. Twenty-one of the most thoroughly documented projects are highlighted in loose-leaf brochures included in the report. Each brochure presents a general project description, characterizes the fly ash used, and summarizes design procedures, construction and monitoring methods, materials performance, project costs, and any required permits or approvals.

Guides for utilities: design, construction, marketing

To help electric utilities implement and promote high-volume fly ash utilization, EPRI has sponsored the preparation of project design and construction manuals and ash marketing guidelines.

The design manual (CS-4419) reviews key design considerations in various road and construction site applications in which fly ash has been substituted for conventional construction materials. These include structural and nonstructural fills for site development, embankments for highways and railroads, backfills, highway subgrade improvement and base courses, and grouting of subsurface voids. The manual has two volumes. Volume 1 describes the use of fly ash conditioned with small amounts of water to produce a solid, soil-like material; Volume 2 describes the use of fly ash mixed with sufficient water to create a fluid or semifluid material (slurry).

The manual summarizes information from previous design manuals by EPRI, the Federal Highway Administration, the American Coal Ash Association, and others and updates it in light of current practices. The manual details the physical, engineering, and chemical properties of bituminous, subbituminous, and lignite fly ashes. It also covers field and laboratory testing methods, design data and procedures, specifications, quality control procedures, and methods for monitoring before, during, and after construction. Finally, it provides detailed descriptions of the actual procedures and methods used in some completed ash demonstration projects for each application. Bibliographies are included where possible, and a glossary of key terms is presented.

The manual was published as an interim report and distributed to the various utilities and consultants participating in the demonstration projects being conducted as part of EPRI's ash utilization program. The design teams for these projects, which are described below, are making thorough use of the manual and reviewing its content, applicability, and organization. Their comments and suggestions will be incorporated into an updated, final version.

A construction manual describing equipment, procedures, specifications, and monitoring methods applicable to projects using fly ash will be developed during 1987. It will serve as a companion volume to the design manual and will include comments from utilities and their engineering consultants and construction contractors. Emphasis will be placed on documenting the experience gained in completed projects and the practical construction methods developed by utilities and contractors.

To help utilities promote high-volume fly ash utilization, guidelines for developing an effective ash marketing program have been prepared (CS-4763). These management guidelines can be used to evaluate various courses of action that may lead to greater fly ash utilization and lower-cost electricity generation. Background information for the report was solicited from utility marketing representatives, ash marketers, and contractors experienced with fly ash utilization. The management activities addressed include market research, marketing constraint analysis, and policy planning and implementation. Many of the issues and guidelines presented in the report are also relevant for the development of marketing programs for other coal combustion by-products.

Demonstration projects

EPRI has selected four high-volume ash utilization demonstration projects for funding through 1988. Their purpose is to demonstrate the environmental and technological acceptability of ash utilization in roadway construction and thus to promote this kind of application among interested utilities and state highway and regulatory agencies. These field demonstration projects are also serving as test cases for the design manual described earlier.

The first of the four EPRI projects has involved the construction of a cement–fly ash pavement base course and the use of a lime–fly ash mixture for subgrade stabilization along a relocated state highway near Crawfordville, Georgia. The project is cosponsored by Southern Company Services, Inc., and Georgia Power Co. Construction was completed in the summer of 1985, and monitoring of the test sections is proceeding. A report will be prepared at the completion of the demonstration.

In the second demonstration project, cosponsored by Consumers Power Co. and Detroit Edison Co., highway shoulders stabilized with fly ash and cement are being constructed for a state route extension near Flint, Michigan. The project was scheduled for completion in late 1986, but construction was delayed until this spring by poor weather and the unexpectedly poor native soils encountered during the initial grading activities. The laboratory testing program, mix design, and construction specifications for the stabilized shoulders were completed in 1985 under the direction of the University of Michigan.

EPRI awarded a contract for the third demonstration project to Delmarva Power & Light Co. and VFL Technology Corp. The project, still in the preconstruction phase, calls for the use of approximately 50,000 yd^3 (38,200 m^3) of fly ash as fill material in the construction of access ramps at an interchange just north of Wilmington, Delaware.

The contract for the fourth demonstration project has been awarded to the Kansas Electric Utilities Research Program. This project will demonstrate pavement recycling, a process in which existing pavement is pulverized and then stabilized with Class C fly ash. Approximately 1000 tons of fly ash will be used per mile of two-lane roadway. Demonstration sites have been proposed in Sedgwick County, Shawnee County, and the city of Lenexa, Kansas, for construction this summer.

EPRI is also supporting ongoing monitoring activities at three independently sponsored ash utilization projects to establish data on the long-term strength of cement-stabilized fly ash road bases and the long-term performance of soils amended with fly ash. Two cement-stabilized base course projects were selected for monitoring: a parking lot at the Harrison power station in Haywood, West Virginia (constructed in 1975) and a road in Harborcreek, Pennsylvania (constructed in 1977). A series of cores will be obtained from each site for tests of compressive strength; the initial cores were sampled in 1985, and additional sampling is planned for 1988. The third project involved the use of fly ash in the reclamation of abandoned mine lands in Harwood, Pennsylvania. In 1984 (on completion of the reclamation) and again in 1986, the utility sponsoring the project surveyed the site to observe overall vegetative cover and sampled the soil to analyze trace elements and nutrients. It plans to survey the project area again in 1989. EPRI conducted a similar monitoring program in 1985 and will do so again in 1987 and 1988 in order to ensure six continuous years of postconstruction monitoring.

A very important part of the ash utilization program involves communicating the information gained from these demonstrations and the other program activities to utilities, engineers, state agencies, contractors, and other interested parties. Field experience, technical data, and marketing information will be presented at several regional technical conferences throughout the United States; the first will be held this fall. Conference sites will be selected on the basis of utility interest and the opportunities afforded for high-volume ash utilization. *Project Manager: Dean Golden*

CLEANING LOW-RANK COALS TO IMPROVE COMBUSTION PERFORMANCE

Coal is formed as decaying plant matter progressively changes in physical and chemical composition over time. This process usually involves a continuous progression through a series of ranks: lignite, subbituminous coal, bituminous coal, and anthracite. The low-rank coals, lignite and subbituminous, typically have a high volatile matter content, a high moisture content, and a low heating value. They represent approximately 46% of total demonstrated U.S. coal reserves and 86% of demonstrated reserves west of the Mississippi River. Until recently, it was generally believed that physical coal cleaning had little or no potential for improving the combustion performance of low-rank coals. Test programs at EPRI's Coal Cleaning Test Facility (CCTF), however, show that such potential does exist (RP1400).

Low-rank coal deposits often occur in shallowly buried, thick seams that allow relatively inexpensive mining. This and the abundance of low-rank coal reserves (in some cases near areas of high projected electricity demand growth) have given impetus to the use of this fuel source. In fact, in 1985 low-rank coals accounted for 40% of the total coal received at power stations 50 MW or larger, up from 27% in 1979.

The efficient use of this vast energy resource poses special problems. Low-rank coals are low in heating value. Thus, to produce the same energy as a given amount of higher-rank coal, more low-rank coal must be mined, transported, and handled—at greater expense. And at the power station, the low heating value means increased capital expenditures on such equipment as boilers and pulverizers. Fouling, slagging, and erosion problems are also commonly associated with low-rank coals. The only commercially available technology with the potential of addressing all these utilization problems is physical coal cleaning.

Coal cleaning

Physical coal cleaning is a sorting process whereby coal particles are separated into clean coal and refuse on the basis of one or more physical properties, such as particle size, density, or surface characteristics. A particle's chemical characteristics (e.g., ash and sulfur content) are not changed by the sorting process.

In actual practice, coal cleaning is complicated by various factors. Its ability to improve a coal's combustion performance depends on the existence of a relationship between some physical coal characteristic and a chemical one. For example, particles high in carbon tend to be less dense than particles high in ash-forming mineral matter. Sorting to remove high-density particles, then, reduces a coal's ash content to an extent that depends on the strength of the ash-density relationship as well as on the details of the cleaning process. Such physical-chemical relationships vary greatly from coal seam to coal seam, even in the same geographic area. Another complicating factor is that coal can be cleaned to various quality levels; hence a given raw coal can yield a wide range of clean coals differing in terms of cost and combustion characteristics.

EPRI's Coal Cleaning Test Facility near Homer City, Pennsylvania, characterizes the effects of coal cleaning on major U.S. steam coals. The overall objective of this effort is to reduce the cost of electricity generation. Characterization results enable utilities to improve the economic trade-offs between as-fired coal quality, on the one hand, and coal transportation costs and power station performance and availability, on the other. The results are also used to develop improved methods of predicting cleaning-related coal quality changes on the basis of inexpensive, laboratory-scale tests. In addition, characterization results are applied in the design of more cost-effective coal-cleaning plants. Toward that end, the CCTF develops and demonstrates new coal-cleaning equipment, processes, and technology.

Since beginning operation in late 1981, the CCTF has characterized 1 anthracite, 19 bituminous coals, 1 subbituminous coal, and 4 lignites; another lignite is now being characterized. These characterizations involve a series of tests that define a coal's susceptibility to physical cleaning and indicate possible changes in combustion characteristics from cleaning. The results are published in CCTF Campaign Reports, Updates, and technical papers. The CCTF has also developed, and will periodically update, the *Coal Quality Information Book;* this summarizes the qualities of a variety of U.S. utility coals (at present, 20 raw coals and 50 clean coals derived from them), including all those characterized so far at the CCTF. A coal quality information system that includes these data will be available from the Electric Power Software Center in early 1988.

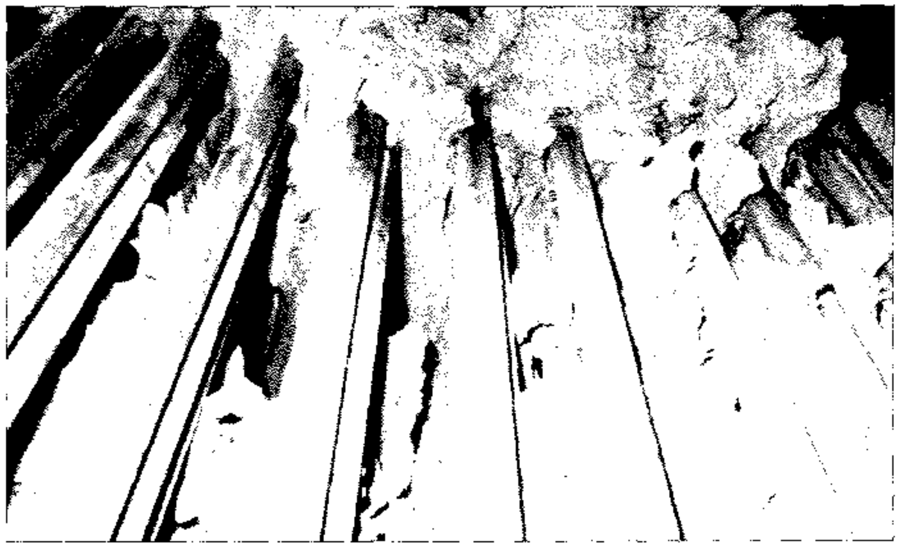
Low-rank coals are of special interest because work at the CCTF—specifically, the characterization of a subbituminous coal from Montana and a lignite from Texas—has demonstrated that contrary to common assumptions, cleaning can improve their combustion performance.

Subbituminous coal cleanability characterization

The CCTF has characterized a subbituminous coal from the Robinson seam in the Powder River Basin in Montana. At the time of the characterization, Central Illinois Light Co. (Cilco) was burning this coal at its E. D. Edwards generating station in Peoria. This station was designed to fire bituminous coal; however, when the state of Illinois reduced the sulfur dioxide (SO_2) emission limit for the station, Cilco switched to the low-sulfur Robinson seam coal.

The use of the Robinson seam raw coal led to various problems at the station. Because of the low heating value of the as-received coal (approximately 8500 Btu/lb), the pulverizers were unable to handle enough coal to achieve the station's 900-MW rated capacity; thus the steam generators were derated to 65–75% of capacity. Moreover, during operation at approximately 75% of rated capacity, there was a buildup of slag on the boiler walls that sootblowers could not control. As the slag built up, the boiler exit gas temperature increased and the slag crept into a superheater screen and finally onto the superheater tubes (Figure 1). The accumulation of slag on these tubes constricted the gas passage, resulting in increased gas velocities in the unobstructed areas and severe tube erosion. To control the slagging and tube erosion, Cilco further derated the units to 50% of capacity before eventually switching back to a bituminous coal.

Figure 1 Slag buildup in this boiler convective pass led to tube erosion. Subsequent CCTF testing of the subbituminous coal fired in the boiler indicates that cleaning can reduce its slagging potential.



Despite such combustion-related problems, a number of utilities remain interested in Powder River Basin coals as a potential lower-cost, low-sulfur fuel source. The results of the CCTF characterization of the Robinson seam coal are encouraging, since they suggest that cleaning can mitigate the three major problems encountered with this fuel.

▫ Slagging: The slagging index and the silica percentage for the clean coal both indicate a reduction in slagging potential. Further, gravity fractionation analyses on pulverized coal indicate that compared with the raw coal, the clean coal has 80% less iron associated with particles heavier than 2.5 specific gravity; these results also imply a decrease in slagging potential.

▫ Erosion: In this case alleviating slagging problems tends to alleviate boiler tube erosion problems as well. Cleaning also reduced ash loading (from 9.4 to 5.3 lb/million Btu), which will reduce erosion.

▫ Pulverizer capacity: Cleaning can increase the coal's heating value by 700–1000 Btu/lb (as-received basis), thereby decreasing the amount of coal that must be pulverized to generate a given quantity of electricity.

Another benefit of cleaning was a reduction in the SO_2 emission potential, from 1.64 to as low as 0.67 lb/million Btu. In contrast, cleaning increased the fouling potential (as predicted by the fouling index). The degree to which this might affect specific plant operations is unknown, but fouling is a potential problem that any utility interested in this fuel must consider. Because predictive indexes are not always reliable, fouling concerns are best addressed by combustion testing, which would also substantiate the predicted reduction in slagging. The Robinson seam coal characterization is documented in EPRI CS-4081 and *CCTF Update*, No. 3.

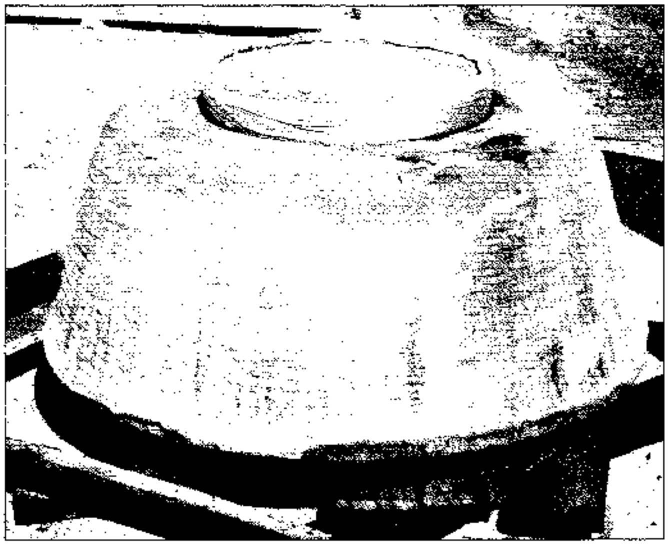
Lignite cleanability characterization

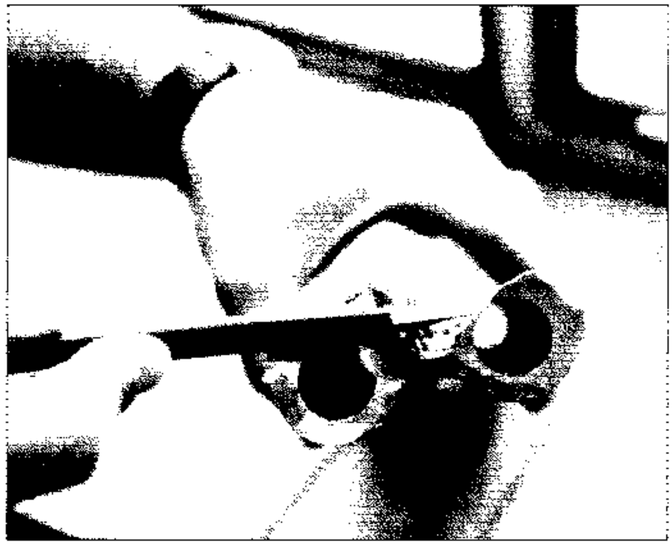
A lignite sample from the Big Brown mine in Freestone County, Texas, has been characterized at the CCTF. This lignite, part of the Wilcox Group, is fired by Texas Utilities Electric Co. at its Big Brown generating station near Fairfield. Although mining and transportation costs for the lignite are low, the station has had problems with boiler performance and availability.

Two special problems with Texas lignite are mill wear and boiler tube erosion (Figure 2) due to the lignite's high quartz content. Some of the quartz occurs as visible, sand-size grains; however, petrographic examination of the Big Brown lignite has revealed that microscopic grains are also present. Physical cleaning is less successful in removing any mineral impurity as grain size decreases.

Conventional equipment for physical coal cleaning was evaluated during the lignite characterization program. The concentrating table shown in Figure 3 proved to be very effec-

Figure 2 Excessive pulverizer wear (left) and boiler tube erosion (right) have resulted from firing Texas lignite with a high quartz content. Cleanability and combustion tests indicate that coal cleaning can lessen these problems and extend equipment life.





tive. Flowing water carries the lighter, high-carbon-content particles over the ridges on the surface of the table, while the denser, high-mineral-content particles are channeled by the ridges to the end of the table. This technique reduced the lignite's ash content from 21 to 10% (dry basis) and reduced its SO_2 emission potential from 2.07 to 1.66 lb/million Btu. Its heating value was increased by almost 1500 Btu/lb (dry basis). Commercial-scale water-only cyclones were also tested, with similar results.

Twenty-ton samples of raw and clean lignite were tested in a pilot-scale furnace under EPRI's Availability and Life Extension Program (RP2425). Results from these tests, performed by Combustion Engineering, Inc., show the following benefits from cleaning.

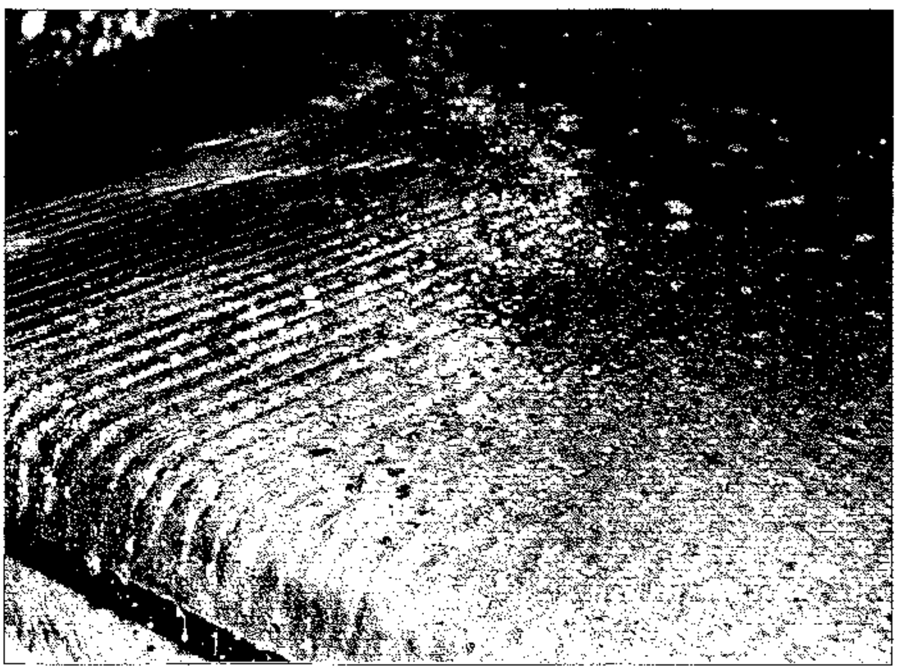


Figure 3 In CCTF tests a concentrating table was successfully used to clean Texas lignite. The lighter, high-carbon-content particles are carried across the ridges by flowing water. The heavier particles, high in minerals, are trapped between the ridges and discharged at the end of the table (lower left).

- Pulverization characteristics improved, leading to a 16% reduction in the energy required for pulverizing and to significantly reduced mill wear.
- The lignite's heating value increased sufficiently to suggest that one coal mill per unit at the Big Brown station could be taken out of service for maintenance without a loss of generating capacity.
- Ash slagging characteristics improved slightly, resulting in a reduction in deposit accumulation.
- Ash fouling characteristics improved, resulting in increased sootblower effectiveness and lower deposit buildup rates.
- Fly ash erosivity was reduced by 45%, indicating that convective tube life could be doubled.

In general, this lignite responded well to physical cleaning, which could lead to major improvements in boiler performance and availability. As higher-quality lignite reserves are depleted, the potential benefits of cleaning lignites may become even greater.

In 1987 the CCTF plans to characterize two more low-rank coals, tentatively to be supplied by Arizona Public Service Co. and Central & South West Services, Inc. Other work on low-rank coal, including the development of improved laboratory test procedures, is planned. A report summarizing the general cleaning characteristics of Texas lignites will be published after the current lignite characterization is completed. *Project Managers: Clark Harrison and James Hervol*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

Narain G. Hingorani, Vice President

POWER SYSTEM PLANNING AND OPERATIONS

Control center CRT display design

Computers have had a significant impact on the operation of electric utility dispatch control centers. Their introduction and cathode ray tube (CRT) displays have dramatically changed the way system operators perform their job. However, as with any new technology, there are opportunities to improve system performance. One key area for such improvement is the display interface between the computer and the operator.

Although numerous handbooks have been written about displays in general or about special applications, none has been developed specifically for an electric utility dispatch control center. EPRI recently funded a two-year study with Westinghouse Electric Corp. to fill that need (RP2475-1).

The project team built on information available from the extensive work done on displays by the military and on other EPRI display-related projects. In addition, the team surveyed three dispatch control centers to obtain insight into the electrical industry's special needs. After the draft handbook was completed, it was field-tested at four utilities and reviewed by an energy management system vendor. The selected utilities had just completed a design or were redesigning their dispatch control center displays. Comments from the test utilities and the vendor were incorporated into the handbook.

The EPRI handbook, EL-4960, is designed to provide the reader with two different yet supporting approaches to display design. First, the handbook provides a detailed procedure for designing dispatch control center displays. The procedure is a step-by-step process on the predesign analysis, the final design process, and the evaluation of the display's effectiveness. Second, the handbook provides a set of prototype displays, along with the data needs each is intended to address and the rationale that was used in the design of each prototype. These prototype displays show effective use of information presentation methods not currently used in control centers. The handbook can easily be used to design a set of displays, as well as to evaluate existing displays for redesign to meet system operators' needs.

Two dispatch control center display design seminars, using the handbook as the source material, were held in July and September 1986. Attendees at both seminars were able to get hands-on experience in display design. A videotape describing the use of the handbook is available on request. *Project Manager: Charles J. Frank*

Uncertainty and risk in electricity resource planning

In the past, resource options for system expansion were limited, and it was possible to forecast load growth and operating costs on the basis of historical records. Today, however, the unknowns to be considered in electricity resource planning are affected by a number of resource options, with their attendant uncertainties. Few methods have been developed in the industry to make sound decisions under these conditions. EPRI initiated a project in July 1985 with Power Technologies, Inc., to identify the sources of technologic and economic uncertainties, to develop a suitable method for evaluating the technical and economic effects of various options, and to integrate the sources of uncertainty into a decision analysis method (RP2537).

The contractor has reviewed the sources of risk, developed and tested a linear interpolation technique for analyzing them, and developed a computer program entitled TRADE-OFF to evaluate the impact on electric utility planning. Central Maine Power Co. has used the computer program for evaluating resource alternatives, using a wide range of fuel prices, load growth rates, and assumed inflation rates. It has used this program as one of many tools for making decisions on major resource commitments.

A test and validation of the computer program is expected this spring. *Project Manager: Neal Balu*

Harmonic power flow

Electric power systems with nonlinear loads, such as high-voltage direct-current (HVDC) converters, fluorescent lighting, and industrial rectifiers, are likely to produce high levels of harmonic signals. Such signals can interfere with communications, protective relays, and computers. They may also cause resonant conditions at shunt capacitors and increased dielectric stress. In 1984 EPRI developed the HARMFLO computer code to analyze the generation and propagation of harmonics in power systems as a result of nonlinear loads (EL-3300). Since then, EPRI has twice updated the code to include extra features suggested by users (EL-4366). Today, more than 30 utility companies use this program.

HARMFLO has the unique ability to calculate harmonics flowing in a given circuit by using only information on the type of harmonic source and information required for a power flow study. Other commercially available harmonic analysis programs require a priori knowledge of the magnitude and frequency of harmonics injected at a network node. Unlike these other programs, HARMFLO can model only balanced networks because of its power flow formulation.

As concern about the problems of harmonics increased, users wanted additional HARMFLO features. To identify the most desirable code changes and enhancements, researchers consulted users of version 3.1 of the code at a special seminar. They then developed the necessary models and incorporated them, along with other features, into a new version of the code (version 4.0). After completing the program for mainframe computers, project personnel produced and tested a version for IBM PCs (RP2444-1).

Important new capabilities and features of version 4.0 include the following.

- Models of induction motors and of rectifiers with more than 12 pulses
- Calculation of the telephone influence factor, which describes the effect of power line harmonics on telephone circuits

▫ A quick-look option that provides a fast but approximate analysis

▫ Significant reduction in computation time and storage requirements

▫ Documentation for typical applications, such as the analysis of harmonics produced by large industrial rectifiers, the evaluation of the effectiveness of harmonic filters at HVDC inverters, and the prediction of harmonic propagation in transmission networks

The code still has several limitations. For example, it can analyze only balanced three-phase systems. Also, it cannot accurately simulate harmonics above the nineteenth frequency (1140 Hz) because the models of transformers and loads become inaccurate at higher frequencies.

This latest revision of the HARMFLO code is easier to use and operates more efficiently on less computer memory than version 3.1. The code is now a mature product, incorporating many changes prompted by utility experience with earlier versions. EPRI therefore has no plans to modify the code further and is now seeking to commercialize it. *Project Manager: James V. Mitsche*

OVERHEAD TRANSMISSION

Transmission lines and gas pipelines

Both gas and electric utilities have traditionally been reluctant to share their rights-of-way with other users. Although some utility departments may look on a proposed sharing agreement as a good source of revenue, engineers and operators see only potential problems. Obviously, adding another user to a right-of-way is inconvenient, and if the new utility system is not properly designed, it could create a potential hazard. EPRI's research on joint-use compatibility has not advocated right-of-way sharing or new standards; rather, EPRI projects have sought to develop engineering tools that would help define the electrical effects of transmission lines on parallel facilities. Using these tools, engineers from a power company and a pipeline or railroad company can analyze a problem, then mutually decide on an acceptable engineering solution.

An earlier status report reviewed the work on compatible designs of power lines and railroads (*EPRI Journal,* December 1985, p. 60). This status report reviews research activities cofunded by EPRI and the American Gas Association (AGA) to develop tools for the mutual design of transmission lines and gas pipelines (RP742).

In 1984 EPRI and AGA completed the work on steady-state analysis, and the results were published in four volumes covering the following topics: Vol. 1, Engineering Analysis; Vol. 2, Graphical Analysis Handbook; Vol. 3, Computer Program User's Guide; Vol. 4, Field Verification of Horizontal Wire Mitigation Method (EL-3106).

The most significant result of this project was the development of the computer program ACPIPE, which computes the current(s) and voltage(s) induced on nearby parallel pipeline(s) by overhead transmission line(s). The computer program permits modeling of multiple power lines and pipelines as well as insulated pipe joints, bonds between pipes, and pipe grounds. ACPIPE runs on an IBM mainframe and on an IBM PC. Vol. 4 of EL-3106 documents a novel mitigation method for areas of high soil resistivity, where traditional grounding of the pipe may not be effective in reducing its induced voltage. In a field demonstration of the method in the Mojave Desert, the pipe voltage was reduced from 47 to 5 V.

In late 1987 EPRI and AGA will release a new computer program named ECCAPP (electromagnetic and conductive coupling analysis of power lines and pipelines). The new program will be able to carry out the following functions.

▫ Perform a steady-state analysis

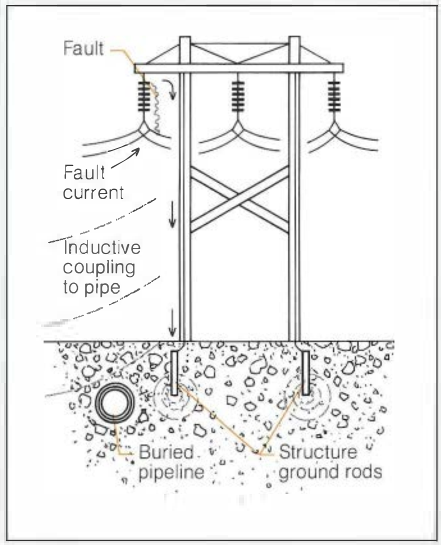
▫ Calculate the effects of a power line fault on the pipeline

▫ Model various mitigation methods and calculate their effects

Analysis of the effects of a power line fault on a nearby pipeline is of great interest to designers, and the computer program will be a valuable tool for siting, design, and safety analysis. In the event of a flashover, part of the fault current will return to the source through the overhead ground wire, and part will travel down the tower into the earth (Figure 1). Some portion of the earth current will likely penetrate the pipe coating and flow along the pipe line. In addition, the much-higher-than-normal current flowing on the faulted conductor will be inductively coupled to the pipe if the powerline and the pipeline run parallel to each other. This complex interaction requires a considerably more sophisticated solution than the steady-state situation does.

Since this work began in 1977, we have progressed from a hand-held calculator program to a steady-state computer program to a versatile, user-friendly computer program capable of performing virtually any interference calculations the designer requires. Although the computer programs supply important and useful technical tools, of equal importance is the spirit of cooperation exemplified in this research effort. Engineers from EPRI member utilities and representatives of the Pipeline Research Committee of AGA are jointly guiding this research. There have been many long, sometimes heated discussions on research

Figure 1 During a fault on the transmission line, current will flow into the nearby pipe from the transmission line structure to ground. Current will also be induced on the pipe by the abnormally high current on the faulted conductor. For the duration of the fault, greater-than-normal voltages will appear on the pipe, and high currents may penetrate the pipe coating, causing arcing at the pipe wall. Computer program ECCAPP will assess this situation.



priorities and proposal evaluations, but there has never been any lack of dedication to the goal of developing accurate and user-friendly tools for engineering analysis. This project serves as a model of cooperative research to solve technical problems of mutual need. *Project Manager: John Dunlap*

PLANT ELECTRICAL SYSTEMS AND EQUIPMENT

Polymeric hydrogenerator insulation

Shrinkage of conventional polymerics that are used as hydrogenerator coil groundwall insulation, wedges, spacers, or packing is a classic problem, since virtually all monomers shrink when they are converted into functional polymeric insulation systems. Shrinkage can occur during both processing (curing) and aging and can result in void formation or cracking. In hydrogenerator coils such shrinkage causes loosening and vibration within the stator slots. The result is premature equipment failure caused by either coil abrasion by vibration or coil erosion by sparking of slot discharges. The problem is minimized by suitable care in handling during manufacture and coil installation, but it is never fully eliminated.

If it were possible to reduce or eliminate resin shrinkage and achieve better bonding between the core, the coil armor, and the groundwall insulation, a more effective total insulation system would result. More effective insulation would lead to decreased coil vibration and subsequently to less downtime for large hydrogenerators in utility applications. *Project Manager: Bruce Bernstein*

DISTRIBUTION

Arcing fault detector

The use of 480Y/277-V, three-phase, four-wire service is common in the utility industry and is economically attractive for serving large electrical loads in commercial, industrial, and sometimes multifamily residential facilities. The customer receives the service either from individual transformers or as part of a spot network using multiple transformers.

Although the use of 480Y/277 V is common, 277-V equipment has some undesirable characteristics. One is that once an arcing fault has been initiated, the fault may not self-extinguish. In addition, the fault impedance is sufficiently high that the fault current is insufficient to trigger overcurrent protection. The fault current for a 277-V, line-to-ground fault can be the same order of magnitude as normal load current. Cases of substantial damage by a 277-V arcing fault have been reported.

In recognition of this problem, EPRI has started a research project with Westinghouse Electric Corp. to develop a detector capable of determining the existence of a 480Y/277-V arcing fault (RP2617). The project seeks to develop a detector that is reliable, usable on a multiple-grounded system, easy to retrofit onto existing installations, and cost-effective. *Project Manager: Harry Ng*

Dc arc furnace for destruction of PCB capacitors

Since the mid 1970s, the utility industry has been phasing out PCB equipment. The Toxic Substance Control Act of 1976 set strict guidelines for the management of PCBs, and EPA regulation has steadily become more stringent. Recently a deadline of October 1, 1989, was mandated for phasing out and destroying PCB capacitors in public areas. Many utilities, even before the deadline was imposed, had removed all PCB capacitors. In addition, many others plan to remove their remaining PCB capacitors after the mandated public exposure units have been disposed of.

The currently acceptable process for disposing of PCB capacitors is to remove the capacitor from the case and shred it. The shredded material is then destroyed in one of the three or four incinerators in the country licensed for PCB disposal. An EPRI contractor, Arc Technologies, a company formed by Chemical Waste Management, Inc., and Electro-Pyrolysis, Inc., has developed a dc arc furnace as an alternative process for destroying capacitors (RP2701). In the new process, unopened capacitors will be fed through several purged air locks and then punctured to prevent rupture from internal pressure. The capacitor is then fed into a pool of molten metal at 1500°C at the bottom of the furnace. Pyrolyzed gases leaving the decomposing capacitor are exposed to the high-intensity ultraviolet emission of the arc and finally must pass through the 5000°C arc and hollow electrode to reach the exhaust scrubber. The process has these advantages.

- It eliminates exposure of personnel and the environment to PCBs because there is no opening or shredding process.
- Exposure to decomposition conditions far exceeds those required by EPA for PCBs.
- The process uses pyrolysis rather than oxidation to eliminate the need for air flow, greatly reducing the volume of gas flowing to the scrubber.

A plant site at Model City, New York, near Niagara Falls has been approved. EPA has granted a permit for an experimental run. Construction has started, and the research run is planned for the spring of 1987. If no problems develop, full-scale operation should commence in mid 1987. *Project Manager: Gilbert Addis*

Distribution transformer with an electrohydrodynamic (EHD) pump

The movement of insulating liquids by the application of electric fields has been investigated as a unique approach to enhancing the heat transfer rate in convectively cooled transformers. In this application, EHD pump elements would be placed at strategic locations in the transformer to speed the oil flow through coil ducts and cooling radiators.

EHD pumping of insulating fluids is based on the fact that as an ion travels between two locations under a high electric field, the surrounding fluid is dragged along in the same direction. For this project, researchers conducted bench-scale experiments to determine suitable electrode design and power supply requirements (RP2589). Figure 2 shows the experimental apparatus used. An appropriate EHD pumping system was then fitted to an off-the-shelf 167-kVA distribution transformer. Figure 3 shows the EHD pump installed in one location in the transformer. This prototype transformer was then extensively tested to determine the benefit from EHD pumping.

Thermal heat runs were conducted at loads varying from 70 to 140% of rating. Investigators also varied the pump parameters to achieve

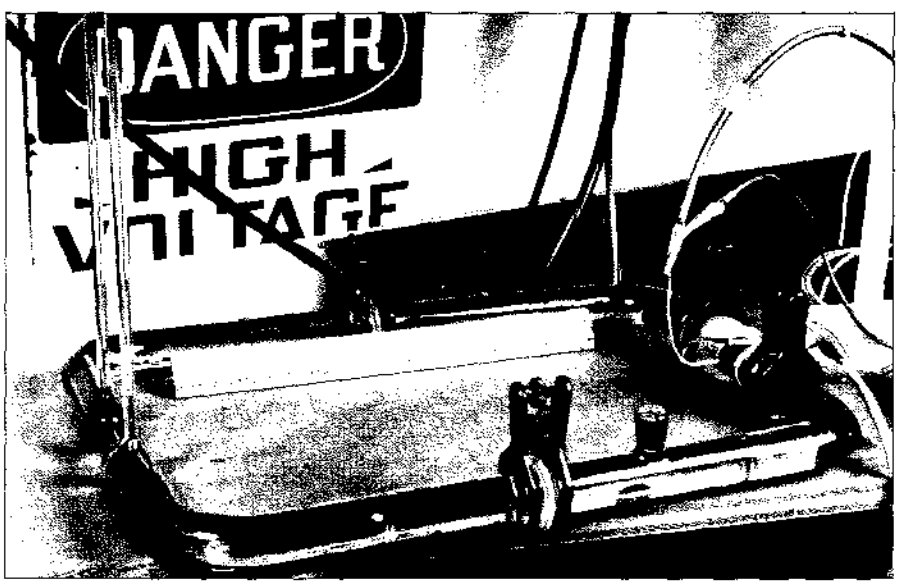
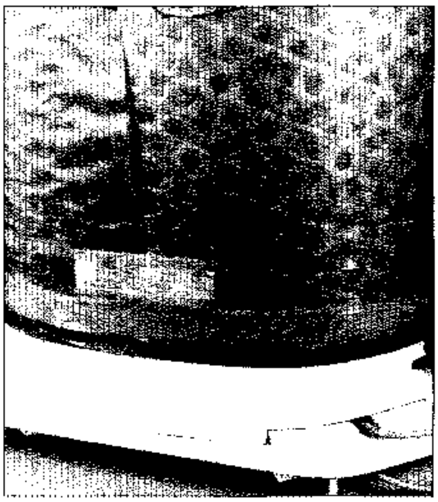


Figure 2 View of bench-top experimental pump showing the apparatus used to determine pump configuration and power supply requirements.

Figure 3 EHD pump installed in test transformer.



the most significant effect. The results were compared with the operation of a control transformer, which was not EHD-pump equipped.

The most significant reduction in winding temperature was obtained at 100% load. A drop of 5°C was recorded in the high-voltage winding and 3.5°C in the low-voltage winding. However, as tests progressed, the pump performance deteriorated. Researchers traced this phenomenon to contamination of the pump electrodes over a period of time. As the oil flowed through the pump, the suspended particulates and products in the oil were charged while traveling through the high-voltage screen electrode (negative with respect to ground). They were then attracted to and collected on the ground electrode. This buildup reduced the pumping efficiency and rendered the pump ineffective.

Because suspended particulates and products are always present in transformer oil, this problem is not easily surmounted. Any additional complexity or cost could not be justified for this application. The experiment was concluded and a final report is being prepared. *Project Manager: Joseph Porter*

UNDERGROUND TRANSMISSION

Underground obstacle detection and mapping system

Locating and accurately mapping underground facilities in city streets is of vital importance to utility companies. Such mapping would ensure against third-party damage to utility equipment and reduce or eliminate the possibility of dangerous gas pipeline or power cable incursions.

Unfortunately, because of the wide variations in soil conditions, a radar-only approach to detecting pipes is difficult. EPRI initiated a ground-penetrating radar project in hopes that the system would provide adequate signal strength in various soil conditions and overcome clutter problems by using filters and signal-processing techniques via a computer (RP7856). Digitizing sampled radar return signals and using a computer to enhance signal-to-noise values appeared to be the solution to pipe locating. Unfortunately, the system did not function up to expectations because of excessive soil moisture and mineral content, which caused drastic attenuation of the signal.

The computerized radar system worked only to a limited degree and only under ideal soil conditions. Although additional research could improve the technology, the costs outweigh the benefits to be gained and do not justify further pursuit of this technology at this time. *Project Manager: Thomas J. Rodenbaugh*

Aging of spacer insulators in gas-insulated bus

Gas-insulated substations (GISs) and transmission cables employ spacer insulators to support the high-voltage conductors and to provide the required voltage isolation from the grounded enclosure. These insulators are subjected not only to high electrical stresses but also to thermal and mechanical stresses. In designing GIS equipment and ascertaining that it, including the insulators, will meet these severe conditions, systems are subjected to extreme environmental and short-term overvoltage tests.

The overall experience with GIS testing has been good, but there have been instances of sporadic insulator failure after some period of satisfactory operation. Although the equipment is subjected to partial-discharge tests and to short-term overvoltage tests before commissioning, some early-aging phenomena appear to be responsible for these in-service failures. Unfortunately, long-term aging mechanisms are not well understood and data on long-term performance are simply not available.

The purpose of this project with Ontario Hydro is to develop an understanding of the aging mechanisms that act on insulators and to devise improved quality-control tests that will ensure reliable operation of the spacers over the required lifetime (RP2669). To adequately investigate the various aging mechanisms and to promote widespread acceptance of the tests that may result, EPRI contracted with numerous subcontractors: Alsthom Atlantique, ASEA, Brown Boveri, Inc., Siemens, the Technical University of Denmark, and the Institute of Materials Science at the University of Connecticut.

The project has four major areas of work. Researchers in the first will examine defects that exhibit partial discharges to determine whether the size of ionizable voids or cracks limits their detection by conventional instrumentation and to establish whether such defects can result in breakdowns. This hypothesis may suggest upper limits to design stresses.

The second area will be a study of defects that do not exhibit partial discharges. This study is to determine whether the operating field (voltage gradient) has an upper limit, including the effect of stress enhancements, at the surface of cast-in electrodes or conductive contaminants in the epoxy beyond which electrical trees can form and subsequently promote failure. This limit may suggest the level of quality control required for electrode surfaces and purity of materials.

The third area will be to examine the effects of multiple stresses in creating defects. The objective will be to determine if there are any conditions, such as mechanical stresses "frozen" into the spacer during casting, that may generate defects that lead to failure.

The fourth area will assess direct aging of spacer material by applied stresses to determine whether normal operating stresses applied to perfect spacers result in long-term degradation of the spacer. For example, will low concentrations of by-products that may be generated in SF_6 by low-level discharges or other mechanisms promote chemical changes on the spacer surface that could impair its voltage-withstand capability?

Ultimately, the quality control procedures and levels that these studies suggest will be applied to a large group of spacers of varying quality, which will be subjected to long-term statistical breakdown testing.

A companion project at Westinghouse (with the Institute of Materials Science at the University of Connecticut as a subcontractor) seeks to determine the limits of acoustic monitoring in the following areas (RP2669-2).

- Detection of ionizable voids
- Detection of the initiation and development of cracks and disbonding (of the electrode/epoxy interface)
- Determination of the spacer's state of cure during the manufacturing process
- Detection of mechanical stresses within the insulator

In addition, samples of spacers at all stages of the manufacturing process will be analyzed to determine those variables in the manufacturing process that are more critical to sample quality. Test spacers produced by Westinghouse will be included in the statistical test program. *Project Manager: Felipe G. Garcia*

R&D Status Report
ENVIRONMENT DIVISION

George Hidy, Vice President

EFFECTS OF SO_2 AND O_3 ON CROPS

In 1983 EPRI initiated a study of the effects of sulfur dioxide (SO_2) and ozone (O_3) on the growth and productivity of several important midwestern and eastern crop species. The study focused in particular on whether the two pollutants interact synergistically in affecting crops. The research was conducted at Pennsylvania State University (RP2371-2), Boyce Thompson Institute for Plant Research in Ithaca, New York (RP2371-3), and Argonne National Laboratory (also RP2371-3). Results to date indicate that the effects of SO_2 or of interactions between SO_2 and O_3 are minimal at the SO_2 levels to which crop plants are commonly exposed. This EPRI-sponsored research has been closely coordinated with work on the effects of O_3 on crops carried out under the auspices of EPA's National Crop Loss Assessment Network (NCLAN).

SO_2 and O_3 are among the most widespread gaseous air pollutants in the United States, and there has long been concern over their possible adverse effects on crops. Although considerable research into the effects of these pollutants on plants had been conducted before 1982, the information was of limited value for assessing effects on crop productivity under field conditions. For one thing, few field studies on economically important crops had been conducted because of the high cost of performing large numbers of treatments and replicates. And many of the existing studies had used unrealistic exposure regimes. In some cases, for instance, plants were exposed to SO_2 and O_3 simultaneously, whereas in nature high SO_2 levels tend to occur in the morning and high O_3 levels in the afternoon. Finally, some of the studies did not use common agronomic practices; thus the relevance of their results to crops grown according to such practices is questionable.

EPA's NCLAN program was originally designed to assess economic losses of major crops resulting from exposure to O_3, SO_2, and nitrogen dioxide (NO_2). Dose-response functions were to be generated for each pollutant alone and in combination with the others, and some physiological studies were to be undertaken. Subsequent federal funding reductions made it necessary to drop the research on SO_2 and NO_2 (and their interactions with O_3) and the physiological studies. The work sponsored by EPRI under RP2371 has helped fill this gap. At Boyce Thompson Institute (BTI) and Argonne National Laboratory (ANL), EPRI support enabled investigators to integrate SO_2-related research and certain physiological studies with the O_3-related work being supported by NCLAN. At Penn State EPRI sponsored an independent study.

The studies conducted at the three institutions were similar in many respects. All used open-top chambers (Figure 1) for the field exposure of crops. Such chambers are widely used in air pollution field studies and permit plants to be exposed to controlled concentrations of gases with minimal alteration of the existing ambient environment. The chambers can be placed over plants that are being cultivated according to standard field practices.

The chambers used in the work reported here are 3 m in diameter and 2.4 m high. Each is equipped with a blower that introduces air through a plenum surrounding the lower 1.2 m of the chamber. The blower system produces a positive pressure sufficient to drive air out through the top of the chamber and prevent the influx of ambient air. The airstream into a chamber can be modified by inserting a charcoal filter to remove a portion of the ambient pollutants. In this way plants in the chamber can be exposed to air that is cleaner than the ambient air. Similarly, controlled quantities of specific pollutants can be introduced into the airstream to expose the plants to higher than ambient levels. Because each research facility had 32 or 42 chambers available, the investigators were able to design experiments that involved several controlled levels of SO_2 and O_3

Figure 1 Open-top field chambers have been used in RP2371 to study the effects of SO_2 and O_3 on crops. These polyvinyl choride enclosures enable researchers to expose plants to controlled gas concentrations under field conditions.

alone and in combination, as well as two or three replicates of each treatment.

The techniques for exposing plants to O_3 were developed by NCLAN, and treatments were similar at all three institutions, with some variation in the number of hours of daily exposure. The treatments entailed either charcoal-filtered air (with O_3 at approximately 50% of the ambient level), ambient air, or air in which the ambient O_3 level was increased by 33, 66, or 99%. Thus, as the ambient concentration of O_3 fluctuated during the day, concentrations in the open-top chambers also varied. In this way plants were exposed to elevated concentrations of the gas, but the dosage kinetics were similar to those in the ambient air.

The studies differed more with respect to SO_2 treatments: a new exposure regime for SO_2 was developed at BTI and used in both the BTI and ANL studies, while the Penn State study took a simpler approach. The exposures at BTI and ANL simulated the concentration, duration, and frequency dynamics associated with point sources. Ambient SO_2 monitoring data for the Tennessee Valley Authority's Shawnee steam plant for the 1976, 1978, and 1982 growing seasons served as the basis for developing three SO_2 treatments. Each year's data represented a different degree of pollution control at the plant. The lowest SO_2 treatment at BTI and ANL reflected the 1982 levels near the plant; the highest treatment, the 1976 levels. At Penn State the exposure regimes were simpler and were designed to simulate acute episodes. Four times during the growing season, plants were exposed to SO_2 concentrations of either 140, 280, or 560 ppb from 9:00 a.m. until noon. These levels were meant to reflect possible worst-case scenarios around a point source, such as when a plume contacts the ground.

In all the studies, plants were exposed to the various levels of SO_2 and O_3 in separate treatments. They were also exposed to selected combinations of SO_2 and O_3 in order to test for interactions between the two pollutants.

The crops studied at BTI and ANL were soybeans, winter wheat, alfalfa, forage (timothy grass and clover), and corn. Only for soybeans did SO_2 reduce crop yield. Two soybean cultivars were tested, and the reduction in yield varied from 6.7% in the lowest SO_2 treatment to 32% in the highest. No SO_2-O_3 interaction effects were observed for soybeans, and O_3 alone resulted in yield reductions similar to those caused by SO_2: compared with results for charcoal-filtered air, yields ranged from 1% lower at ambient O_3 levels to 34% lower when O_3 was 199% of the ambient level.

In five experiments involving the other four crops, no negative effects of SO_2 on yield were observed. In contrast, in most cases O_3 did significantly reduce yield; this was true even at ambient levels. Only in the case of corn was there any evidence of an SO_2-O_3 interaction. For that crop there may be an interaction such that yields are stimulated by SO_2 at low O_3 concentrations but are reduced by up to 20% when O_3 is 199% of the ambient level.

At BTI the researchers monitored stomatal conductance, net photosynthesis, and chlorophyll content in the experimental plants in an effort to identify the mechanistic basis for any pollutant effects on overall yield. For both wheat and clover, exposure to the higher SO_2 concentrations caused stomatal closure during the exposure periods, but these effects were reversible and did not result in any change in growth or yield. For clover, the lowest SO_2 treatment actually caused stomata to open and increased photosynthetic rates during the exposure, but again no effect on ultimate yield was observed. Presumably, the reason these phenomena did not have any measurable effect on yield is that they occurred over such short periods of time.

O_3 often did have significant effects on physiological responses, and in some cases these were closely correlated with effects on yield. For instance, compared with data for charcoal-filtered air, net photosynthesis in clover and wheat decreased by approximately 20% at ambient O_3 levels and by up to 50% at the highest O_3 level. This study is one of the few to show good correlations between reductions in photosynthesis and reductions in yield.

The research at Penn State addressed only one crop, potatoes, but it involved more-detailed analyses of the response to SO_2 and O_3. Similar experiments were performed in successive years to increase the generality of the results. Potatoes were chosen because they are an important crop in many parts of the United States and because they are known to be sensitive to most stresses, including air pollution. As in the work at BTI and ANL, effects on total yield were evaluated. In addition, the Penn State investigators examined effects on the quality of the potato crop. They analyzed potato size distribution, total solids (a factor in determining the quality of table-stock potatoes), sugar content, and glycoalkaloid content (glycoalkaloids can impart a bitter taste and, if levels are too high, can be toxic).

Results to date indicate that only the highest level of SO_2 (560 ppb for three hours four times during the summer) affected potato yield or quality. This treatment resulted in a decrease of approximately 30% in the number and weight of the largest potatoes. There were no other effects on the quality parameters measured.

As with the crops studied at BTI and ANL, O_3 had a greater effect on yield than SO_2 had. O_3 exposure significantly reduced total weight but not the number of potatoes harvested; that is, there was a significant shift to smaller potatoes. The number and total weight of grade-one potatoes, the largest and commercially most important, showed a fairly linear response to increasing O_3: compared with the yield obtained with charcoal-filtered air, the yield at ambient O_3 levels was 15% lower and the yield at the highest O_3 level was 80% lower. O_3 reduced the total solids content but had no effect on sugar or glycoalkaloid content.

Most of the Penn State evaluations showed no interaction between SO_2 and O_3. The one major exception involved the weight of grade-one potatoes exposed to SO_2 in the presence and absence of 166% of ambient O_3. The highest level of SO_2 alone induced a decrease in the total weight of these potatoes, but in the presence of O_3 no effect of SO_2 was detected. This interaction may reflect the greater importance of O_3 as a stress on potatoes, with its effect overwhelming the SO_2 effect.

The Penn State results show that O_3 at levels commonly measured in ambient air can reduce the number, weight, and quality of field-grown potatoes. SO_2 affected potatoes only at the highest concentration administered. It is very unlikely that such a concentration would occur for four three-hour periods during one growing season.

Besides conducting the experiments on potatoes, the Penn State researchers developed a minicomputer-controlled system for delivering SO_2 and O_3 to the open-top chambers. The system allows the investigator to specify pollutant concentrations, starting and ending times of fumigations, treatment schedules during the season, frequency of measurement of pollutant concentrations in the airstreams, and the like. The system monitors the ambient O_3 level and then controls O_3 concentrations in the various treatments so that they track this level. Each chamber is independently controlled for both SO_2 and O_3 concentrations. This system greatly reduces the time spent in monitoring and controlling the experimental treatments.

The only work remaining to be completed under RP2371 is the analysis of data from the 1986 field experiments on potatoes. Assuming that the results are similar to those obtained in preceding years, it can be concluded that the field studies have yielded results of reasonable consistency for a diverse group of crop plants from three areas of the country. The EPRI-supported work, like the other NCLAN studies, shows that O_3 at common ambient levels can significantly reduce crop yield. In contrast, it indicates that SO_2 does not cause significant damage to crops at levels commonly encountered in agricultural settings in North America. Equally important, there is little evidence that SO_2 and O_3 act synergistically to cause greater damage when they occur together. It should be noted, however, that the results apply only to the specific crops and environmental conditions studied; moreover, not all of the possible effects of SO_2 were tested for in this work. *Project Manager: Louis F. Pitelka*

PCB HEALTH EFFECTS ASSESSMENT

Polychlorinated biphenyls (PCBs) have been widely used in the electric utility industry. Some members of the public believe PCBs to be potent toxicants that are associated with such adverse long-term health effects as cancer, spontaneous abortion, and birth defects. Although certain animal investigations appear to support these fears, studies of human populations who have been accidentally or occupationally exposed to PCBs offer remarkably little support. In view of the uncertainties about the nature and magnitude of the occupational hazards posed by PCBs, EPRI is sponsoring an objective, systematic assessment of the risk to utility workers (RP2374). In this project Clement Associates, Inc., and Washington Occupational Health Associates undertook to evaluate all relevant toxicity information in the published literature, to characterize the utility workplace with regard to occupational PCB exposure, and to estimate any human risk associated with such exposure.

Literature review

The scientific literature concerning PCBs is voluminous. The RP2374 researchers have focused on information relevant to risk assessment, including human clinical and epidemiologic studies, animal studies of dose-response relationships, animal studies of long-term and low-level exposure, and animal studies comparing the biologic effects of various PCB mixtures used in electrical fluids.

After screening approximately 3000 titles and abstracts, the researchers selected about 1600 for more-detailed review. The analysis of these papers has yielded 19 human and 18 animal studies containing information judged relevant and adequate for use in risk assessment. Excluded were papers with little relevance to assessing human risks (e.g., studies on environmental distribution or wildlife toxicity), studies known to have been superseded, and studies deficient in conducting or reporting chemical analyses of the PCB involved.

Animal studies, unlike studies of human exposure to PCBs, have revealed a wide range of toxic effects. One reason for this difference is that, in general, animal toxicologic work is conducted at PCB levels well above those experienced by humans; the relevance of such studies to the low-level exposure of humans is a controversial topic. Also, some animal experiments used single chemical forms of the PCB family that occur at only very low concentrations in commercial PCB mixtures.

Among the adverse effects observed in the animal studies were skin lesions (including chloracne-like lesions), depression of the immune system, reproductive disorders and offspring malformations, and some forms of liver toxicity. At very high doses, PCBs can cause death in animals. Some PCBs were shown to cause cancer or to enhance the potency of carcinogenic chemicals in rats.

The animal studies reveal that the range of toxic effects is not the same for all PCBs; those containing more chlorine are more toxic than those with less chlorine, and some act like the much more toxic polychlorinated dioxins or dibenzofurans. In addition, considerable differences in toxic potency were observed between animal species.

The literature on adverse human health effects associated with occupational PCB exposure includes studies of workers in PCB production plants, workers in capacitor manufacturing plants, and workers engaged in nonutility transformer maintenance activities. Also, several instances of nonoccupational exposure involving the long-term ingestion of PCB-contaminated fish have been documented.

In general, PCB levels in the blood of the populations studied are much higher than those of the general public, which implies exposure to much higher levels of PCBs and, most likely, exposure for longer periods of time. Nonetheless, the adverse effects in these populations are subclinical and are not associated with overt disease. Exceptions are sporadic cases of contact dermatitis and chloracne. Also, changes in blood chemistry consistent with liver changes have been observed. In some studies (but not others), there is clinical evidence suggesting involvement of the cardiovascular, the respiratory, or the nervous system. Evidence from these populations that PCBs cause cancer is inconsistent and at best weak. There is some evidence that the exposure of pregnant women to high dietary PCB levels results in shortened gestation and in reduced birth weight in the offspring.

Studies of workers whose jobs closely resemble jobs in the utility industry, such as transformer maintenance workers, have reported skin and eye irritation, sporadic chloracne (one study), and some minor but statistically significant changes in blood chemistry not associated with manifest disease.

Characterizing utility industry exposure

Estimates of utility workers' exposure were developed in RP2374 on the basis of information supplied by electric utilities—specifically, detailed information on past and present work practices from four utilities and the responses to a questionnaire sent to over 100 utilities. From this information it was possible to determine the jobs likely to involve work with equipment containing PCBs, the time spent annually on particular activities, and the number of workers in the industry engaged in those activities. Also collected were industrial hygiene data on PCB levels in the work environment and, in some cases, measurements of PCB levels in the blood of utility workers.

The researchers have estimated that about 115,000 utility workers in 13 major job categories are involved at one time or another in work on PCB-containing equipment, such as capacitors and transformers. Their activities include changeouts, routine repair, and spill cleanup. The major categories of workers engaged in activities involving PCB-containing equipment are overhead line mechanics (75,000) and transformer repairmen and testers (10,000). Estimates are that shop repairmen spend 20–50% of their working time on these activities; for most other job categories, the time spent is 10% or less. The main routes of exposure are inhalation and dermal absorption.

PCB levels in the blood of utility workers by and large reflect their job activities. The levels are usually higher in underground mechanics and shop repairmen than in overhead line mechanics, members of cleanup crews, and workers in substations. The measured values range widely and are heavily skewed to values found in the general public. In fact, the largest series of PCB blood measurements in the utility industry yielded mean values for exposed workers that were not significantly different from levels for the general population. The data indicate that past work practices have led to the deposition of relatively small amounts of PCBs in the bodies of utility workers. It is reasonable to expect that today's stricter work practices will lead to even lower body levels.

The researchers concluded that it was not feasible to use existing human studies as a basis for quantitatively assessing health risks associated with occupational PCB exposure in the utility industry, since the results are insensitive (of low statistical power) and inconsistent. And estimating human health risks from animal data can introduce conservative assumptions that overestimate the risks involved and result in large confidence intervals.

Another way to estimate risk is to compare the background levels of PCBs in members of the general public with those in workers in the utility industry. Assuming that risk is proportional to PCB levels in the body, it would appear that utility workers have little excess risk over the risk of the general public. The study suggests that significant exposures under current work practices are small and that today's health risks are lower than those resulting from past environmental exposure. *Project Manager: Walter Weyzen*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

VALVE STEM PACKING IMPROVEMENTS

The leakage of process media through valve stem packing is a major concern in nuclear power plants, and a great deal of attention to maintenance is required to achieve acceptable packing performance. Similar considerations apply in fossil fuel plants, but there the acceptable level of leakage is higher and the consequences of a leak are significantly less severe. In nuclear applications even minor leakage can have implications in terms of radiation exposure, housekeeping problems, labor costs, and possibly a plant load reduction or shutdown. Thus EPRI initiated a research project in early 1984 to develop improvements in valve stem packing systems that would enhance performance, minimize maintenance requirements, and increase plant availability (RP2233-3). This effort is part of EPRI's project on key valves and builds on previous research reported in EPRI NP-2560; it aims to provide utilities with detailed information for designing and implementing valve stem packing improvements.

The work under RP2233-3 was divided into two phases. The first focused on determining the root causes of valve stem packing leakage, on identifying and developing corrective actions, and on the preliminary laboratory evaluation of these actions; it also entailed the design and construction of a full-scale test facility for evaluating corrective actions under closely simulated plant operating conditions to establish their validity. The second phase of the project covered the testing and evaluation of selected corrective actions, the in-plant implementation of corrective actions, and technology transfer and commercialization.

On the basis of a competitive solicitation, Foster-Miller, Inc., was selected as the prime contractor for the research effort. EPRI designated the Chalk River Nuclear Laboratory of Atomic Energy of Canada Ltd. (AECL) as a major subcontractor to take advantage of its in-depth experience and testing capability and establish a strong research team.

Valve stem packing performance is affected by many factors, including the frequency of stem movement, system pressure and temperature, stem and stuffing box surface finishes, stuffing box depth, accuracy of stem guidance, fluid medium, vibration, packing composition and configuration, and packing gland pressure.

Many of these factors (e.g., system pressure and temperature) cannot be changed in an operating system, whereas others (e.g., stuffing box depth) can be altered to achieve improved performance. Previous research by AECL indicated that packing composition/configuration and gland pressure have the greatest effect on stem seal performance. The project focused on these and other areas offering opportunities for retrofit measures in installed valves.

The principal causes of poor valve stem packing performance in LWRs in the United States were determined to be the extensive use of braided asbestos stem packing, excessive stuffing box depth, and insufficient packing gland loading force to achieve a stem seal throughout the maintenance interval of the equipment.

Braided asbestos valve stem packing is relatively permeable and requires significant compressive force to achieve a seal. During prolonged exposure to high-temperature service conditions, the material tends to dry out, shrink, and harden. As a result, additional compaction is required to reduce stem seal leakage to an acceptable level. Excessive stuffing box depth tends to emphasize the problem because the packing rings near the bottom of the box cannot be sufficiently compressed to contribute to the stem sealing capability but merely add to the friction load needed to open or close the valve. The depth of the stuffing box can be reduced, however, by installing a spacer sleeve at the bottom of the box. This provides at least four advantages: (1) the total friction load on the valve stem is reduced; (2) the magnitude of in-service consolidation (compaction) of the packing material is reduced; (3) the replacement of packing rings is simplified; and (4) the quantity of replacement packing materials is minimized. Developmental testing of selected stem packings in the second phase of RP2233-3 was successfully conducted by using (nominally) only five rings of packing.

Litigation and government regulations regarding asbestos products and their potential carcinogenic effects can be expected to result in the unavailability of these products within the next few years. Therefore, a suitable substitute must be found. Flexible graphite stem packing materials have been commercially available for many years and have been used in limited applications with good results. Because previous research results indicated that this material would be an excellent substitute for braided asbestos packing, developmental testing of it was undertaken in the second phase of this project.

Live loading of valve stem packing glands has been successfully implemented over a number of years by AECL in its Candu reactor systems and by Electricité de France in its PWR systems. Live loading involves adding stored energy (usually in the form of springs) to the valve stem packing gland so that a compressive load of sufficient magnitude to achieve a stem seal can be maintained on the packing material for an extended period of time. Without live loading, the compressive load on the packing drops rapidly as the packing consolidates during use, since very little energy can be stored in the gland bolts.

The test matrix in the second phase of the project consisted of testing a conventional square-cross-section graphite packing and an innovative wedge-shaped packing developed in the first phase. These were tested with and without live loading at BWR and PWR conditions of pressure, temperature, and chemistry. The test configuration simulated a large gate valve with a stem about 3 in (7.6 cm) in diameter; the stem travel was about 14 in (35.6 cm), full open to full closed.

The test sequence consisted of fully inserting the stem through the stuffing box into a chamber containing the hot, pressurized test medium and holding it in that position about

5 min to allow the stem to heat up. The stem was then fully withdrawn and maintained at that position for about 10 min, while the exposed portion of the stem was cooled by circulating air fans. This cooling created a thermal gradient in the stem—with a resulting reduction in stem diameter in the cooler region—as would occur in actual service. The stem was then reinserted to start another cycle; at least 1500 cycles were run for each configuration.

The test medium leakage was condensed, collected, and measured. The results indicate that the application of live loading to conventional square packing significantly reduces leakage under both dynamic and static conditions.

The successful use of live loading with valve stem packing requires appropriate attention to a number of factors, including the following.

- Design of the spring stack to provide sufficient force throughout the maintenance interval to achieve an effective stem seal
- Alignment and guidance of individual springs in the stack to ensure that no binding occurs to diminish the delivered force
- Lubrication of components
- Correct installation and adjustment

The wedge packing (Figure 1) performed well during the second-phase laboratory tests. Without live loading, it achieved leakage rates that compared favorably with those achieved by the square packing with live loading. The wedge packing effectively uses system pressure together with packing gland pressure to radially load the packing against the stem and the stuffing box wall. Only a nominal improvement in leakage rate was obtained when live loading was applied to the wedge packing.

Corrosion tests conducted during the second phase of the project generally indicated that valve stems made of austenitic (e.g., type 316) and precipitation-hardening (e.g., type 17-4 PH) stainless steels showed no signs of pitting from contact with the graphite packing materials. On the other hand, all specimens of martensitic stainless steels (e.g., type 410), which are hardenable by heat treatment, showed some pitting. Tests of packings incorporating corrosion inhibitors (passive and active) indicated that inhibitors that are relatively insoluble in the process media, and therefore relatively immobile, provide better protection against pitting than those that are not. No inhibitors, however, provided complete protection against pitting of the martensitic valve stem material.

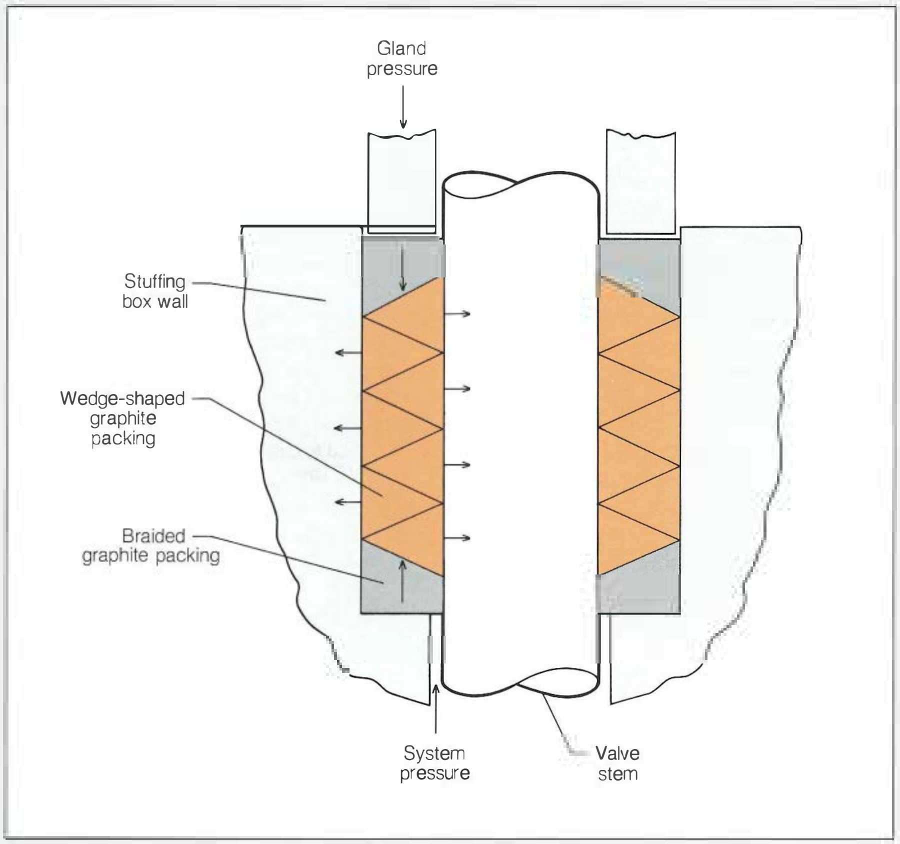


Figure 1 Force distribution with wedge-shaped packing. This design uses system pressure and packing gland pressure to radially load the packing against the valve stem and the stuffing box wall. Leakage rates without live loading are comparable to those for live-loaded square packings.

Technology transfer of the research results has been pursued in a number of ways. As information was developed, technical papers were presented at meetings of the American Nuclear Society, the Fluid Sealing Association, the Valve Manufacturers Association, and the Edison Electric Institute. Articles have also been published in trade journals (e.g., *Power, Nuclear News, Electrical World,* and *Power Engineering*). A patent application has been filed for the unique wedge-shaped packing developed early in the project, and licensing agreements for the manufacture and sale of this product have been negotiated with A. W. Chesterton Co. and Union Carbide Corp.

An interim EPRI report (NP-4255) describes the first phase of the project and presents its results. A final report covering both phases of the work is in preparation; it will include information on the in-plant demonstration of selected packing configurations installed at Duke Power Co.'s Oconee-2 nuclear power plant. A workshop was held at EPRI's Maintenance Equipment Application Center in Charlotte, North Carolina, to describe the activities of this project and other valve-related research. *Project Manager: Boyd Brooks*

PIPING INTEGRITY RESEARCH

A 1986 status report summarized the early work in this three-year project, which began in the spring of 1985 (RP1543-15; EPRI Journal, *March 1986, p. 51). This EPRI–NRC cooperative project was brought about by the belief that current design rules for nuclear piping produce piping systems that are excessively conservative for dynamic loading effects. In addition to the enormous cost of nuclear pipe systems compared with nonnuclear piping, the most obvious difference between the two types of systems is the use of large numbers of dynamic snubbers in modern nuclear plants. Because snubbers themselves are a source of piping unreliability, this project was designed to examine critically the current design rules by extensive testing that would permit optimization of those rules. This status report summarizes the results at approximately the midpoint of this research project.*

Although conservatism is prudent in the design of any component or system in a nuclear power plant, excessive conservatism can result in both excessive costs and less-reliable systems than could result from a more-optimal approach. It has become evident that nuclear power piping design procedures, combined with current NRC regulations, produce piping systems that have too many dynamic snubbers. Evidence accumulated over the years suggests that pipes and pipe components are capable of withstanding much larger dynamic loads than when the peak dynamic loads are applied statically.

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code developed rules for nuclear piping design that do not account for this difference between dynamic and static loading. Several nonlinear phenomena occur as a piping system is loaded dynamically toward failure.

- The apparent damping increases dramatically.
- The stiffness of the piping decreases, which causes a detuning effect.
- Even after one cross section of the pipe system becomes plastic, redundancy results in redistribution of additional dynamic load to other cross sections.

These technical reasons explain why piping is so resilient to dynamic loading, and yet until now, no one has put this information into a systematic approach for changing the ASME nuclear code.

The piping reliability project was designed to fill this need. The main technical objective is to demonstrate once and for all that one of the several failure modes assumed by the ASME code—that of plastic collapse—simply does not occur in piping, provided the frequency content of the dynamic load is sufficiently high. The lowest-frequency dynamic loading of significant interest for piping design is that associated with seismic effects. The other two types that commonly occur in LWR plants are containment-related hydrodynamic effects and water hammer effects. Any ASME code rule changes for dynamic effects must address the entire range of loading frequencies that may be encountered; therefore, although testing emphasis in this project is on seismic loading (because it has the lowest frequency content and therefore produces effects closest to static loading), the other two types are also being tested and evaluated.

Component tests

To provide the necessary experimental data base that would support design rule changes, the project calls for 40 tests on such components as elbows, tees, nozzles, reducers, and welded attachments. All test components are pressurized with water at room temperature. Two pipe materials, carbon steel and stainless steel, are being tested in 6-in-diam nominal pipe sizes with wall thicknesses corresponding to schedules 10, 40, and 80. Strain gages, accelerometers, and displacement gages on the test assembly carefully track component and material dynamic response from initial plastic deformation to a leakage crack that breaches the pressure boundary. A leakage failure has historically been the point at which piping is considered to have failed. Each test component is mounted on a specially designed shake table, and a high-powered hydraulic actuator applies the dynamic loading to the table. The test dynamic loading is a 20-s computer-modified time history record that has frequency characteristics like those found in an actual nuclear plant piping support system. The amplitude of this test loading is scaled up to produce a pipe failure in only a few applications of the 20-s loading. Normal-amplitude seismic loading produces no measurable damage to piping.

Another potential failure mode, plastic collapse, which is the basis for the most limiting part of the present ASME code, could theoretically distort a pipe section or component so severely that the pipe would be unable to carry fluid and would become nonfunctional. The most familiar example of this phenomenon is a soda straw that is bent so severely that the drinker can no longer suck the soda through it. If collapse failure can occur before leak failure in nuclear pipes under dynamic loading, then the current ASME rules would be correct and no major improvements can be made. However, if leak failure always occurs before collapse failure, then present ASME code rules for fatigue failure will protect against the damaging effects of dynamic loads and no plastic collapse rules are necessary or appropriate.

The component tests are ideally suited to demonstrating whether leakage failure or static collapse failure occurs first, because the test components are cantilevered pipes without redundant support and hence represent the worst case for plastic collapse. Project personnel contend that component tests can demonstrate that leakage failure precedes collapse failure, not that 40 such tests can conclusively prove this point. However, if engineering analysis demonstrates why collapse does not occur first, then one can generalize the results to other situations not tested. The strategy of this research project is to perform enough key experiments so that when the test results are sufficiently analyzed, researchers can conclusively describe the failure mode of piping under any dynamic loading situation of interest. On the basis of this information, the ASME code rules can be changed to eliminate much of the excessive conservatism.

By the end of 1986, 19 of the 40 component tests were completed, and all 19 clearly showed that fatigue ratcheting failure or ratcheting collapse occurs before static plastic collapse. Table 1 highlights results from the first 12 tests. The most significant column is the ratio of the input dynamic load to the load that would just reach the allowable ASME code stress under level D faulted conditions. The ASME code requires a 1.4 safety factor for this stress limit; therefore, because the observed ratios varied from 15 to 27, the code safety margin is too high by about an order of magnitude.

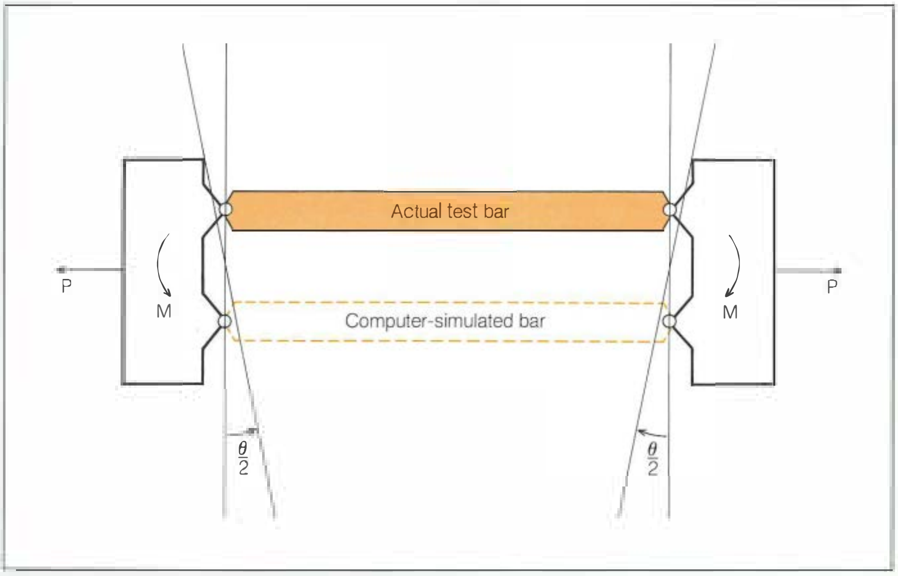
Although researchers observed incremental or ratcheting-type plastic collapse in many of the tests, the ratchet collapse did not block pipe flow or render the pipe nonfunctional. In

Table 1
COMPONENT TEST SUMMARY FOR SEISMIC INPUT

Test Number	Pressure (psi)	Ratio of Dynamic Moment to Static Collapse Moment	Ratio of Input Load to Load at ASME Level D	Failure Mode
1	2600	1.21	15	Fatigue ratcheting
2	2600	1.04	15	Fatigue ratcheting
3	400	2.36	21	Fatigue ratcheting
4	1000	1.83	18	Fatigue ratcheting
5	1700	2.06	21	Fatigue ratcheting
6	1700	2.00	19	Fatigue ratcheting
7	1000	1.8	23	Fatigue ratcheting
8	0	1.8	24	No failure
9	1700	2.5	21	Fatigue ratcheting
10	1000	2.4	21	Fatigue ratcheting
11	400	1.0	16	Fatigue ratcheting
12	1700	2.3	27	Fatigue ratcheting

fact, for the pressurized tests the ratcheting to date has caused pipe swelling, which has actually opened the pipe to flow during these tests. If the 21 component tests to be run in 1987 continue to verify the occurrence of ratchet fatigue as the dominant failure mode, researchers will be well on the way to achieving the project's objectives.

Figure 2 In the two-bar simulation, an on-line computer calculates the forces to be applied to the actual tested bar by applied force *P* and by the deflection-controlled rotation θ caused by some computed moment *M*.



Pipe system tests

Although the component tests represent the worst case in the demonstration that static collapse is not the failure mode of concern for piping, they are not necessarily the worst case in the measurement of apparent plastic damping effects. Damping is an extremely important engineering parameter used in piping design, and it promises to be one of the best ways to predict dynamic pipe response accurately in engineering analysis. Therefore, another objective of RP1543-15 is to quantify the apparent damping in pipe systems that are dynamically overloaded. Apparent damping of 40–50% has been observed in the component tests. This is an order of magnitude higher than the currently acceptable design values of 5%.

Three small pipe system tests will be performed in 1987 to clarify how much of this apparent damping will be present in an actual pipe system. NRC has joined forces with EPRI in this research project and is funding two of the three system tests. NRC has also funded half of the component tests.

The three planned system tests will provide an important data base for verifying that engineering understanding of the component tests can be accurately extrapolated to pipe systems. Two of the three tests will be performed at a new DOE testing facility in southern California, which is believed to have sufficient capacity to cause a small pipe system to fail with only a few applications of a 20-s simulated and magnified earthquake. Results of these tests will enable researchers to determine which of the competing engineering theories best describes pipe system response and failure behavior. The third system test will simulate the effects of a large water hammer and will generate pipe failure data in the high-frequency response region.

Pipe materials tests

The system tests will allow researchers to properly extrapolate their understanding of pipe component behavior to pipe systems, and a third type of experiment, a materials test, will provide details of the failure process itself. At the present time, there is no satisfactory engineering theory to accurately forecast a fatigue ratchet type of failure, which is how pressurized piping generally fails when it is dynamically overloaded to failure. Project personnel have planned approximately 110 materials tests of four pipe materials to obtain the basic data for a new theory.

In its proposal for this project, General Electric Co. developed an ingenious testing concept, which involves a two-bar simulation test (Figure 2). The test simulates the behavior of the pipe wall with a simple beam that responds to a steady force (representing pressure in the pipe) and an alternating strain or displacement (representing the seismic bending stress in the pipe). The beam will have a variable stress and strain field in its interior that can be simplified if the beam is idealized as a two-bar assembly, with each of the two bars having a different but uniform state of stress and strain at any particular time. Thus researchers can study the complex state of stress and strain in the pipe wall that results from the simultaneous action of steady pressure and alternating seismic forces.

The test can be further simplified by taking advantage of the computer control capabilities of modern materials testing machines with a computer that tracks the material behavior of the test bar. By using the cyclic changing material behavior recorded for the bar actually being tested, the computer simulates the presence of a second, parallel bar.

This novel idea has now been developed and tested, and actual data have been obtained on a few specimens. One surprise has been the lack of an end to the ratcheting behavior. Researchers expected a shakedown after a limited number of strain cycles when ratcheting would ease, but a time-dependent creep phenomenon is apparently occurring even under room-temperature testing conditions. The creep behavior slightly complicates the tests but does not present a significant obstacle to the project's objectives. The materials tests will quantify the conditions under which ratcheting takes place and determine the effect this ratcheting has on the fatigue life of the pipes.

At this point, the 19 component test results show convincingly that fatigue ratcheting is the correct failure mode for dynamically overloaded piping. These raw data have been used several times in the past year to help convince regulators and industry experts that piping has an excessive margin for dynamic effects. The major benefit so far has been to help keep present snubber reduction programs on track in spite of vigorous questioning by regulators about the acceptability of code case N-411, which permits up to 5% damping. Project personnel expect that when completed, RP1543-15 will not only reconfirm the basis for this code case but also show that even higher damping can be justified and even more snubbers can be safely removed. *Project Managers: S. W. Tagart, Jr., and Y. K. Tang*

R&D Status Report
PLANNING AND EVALUATION DIVISION

Richard W. Zeren, Director

MIDAS: Multiobjective Integrated Decision Analysis System

Utility decision makers are confronted with a wide range of strategic demand and supply options. Because the payoffs for demand and supply strategies interact, these decision makers need integrated planning tools that can assess both types of strategies and that recognize their mutual interdependence. In addition, uncertainties—which cloud expected decision payoffs in all areas—are frequently neglected in the analysis. The objective of the MIDAS project is to develop a decision framework for integrated demand-supply planning. This framework, implemented in the form of an easy-to-use microcomputer model, will enable utility decision makers to quickly obtain information that will help them determine which decisions are more robust over a wide range of uncertainties and which specific planning alternatives should be analyzed in more detail.

MIDAS is an integrated decision support system that will help utility managers examine a broad range of supply, demand, and financial options in the presence of uncertainties. MIDAS contains a model within a model, a simulation system within a decision system (Figure 1). The two are fully integrated and are linked by a powerful data management system.

The decision system, which uses a generalized decision analysis approach, significantly enhances the capability of the utility manager to incorporate risk into decision making. The model calculates the expected value of "perfect" information and produces risk profiles for multiple planning objectives. The simulation system is a flexible corporate planning model that enables utility managers to address a wide range of integrated demand and supply planning issues. Although the model is flexible enough to be used as a high-level screening tool, it can also provide substantial quantities of accurate and detailed information if certain of its options are activated. The completed MIDAS system runs on a microcomputer with user-friendly, menu-oriented features.

Generally speaking, the analysis of a decision problem under uncertainty requires that the decision maker follow six prescribed tasks.

- Define available options for action and for gathering information
- Identify uncertain events whose outcomes will affect the consequences of actions taken
- Arrange the information acquired, and the choices that can be made, in chronological order
- Evaluate the consequences that might result from various courses of action
- Assess the chances that any particular uncertain event will occur
- Select the best decision strategy on the basis of preference for the consequences, judgment about uncertainties, and understanding of the problem's structure

The unique features of MIDAS make it possible to perform a decision analysis (involving all six tasks) in a self-contained and integrated framework, a capability that is made possible by recent advances in microcomputing.

The MIDAS systems

The decision system is an advanced utility planning tool that facilitates decision analysis. It organizes scenarios for the simulation system and analyzes the results. A decision problem is described graphically as a decision tree that contains two types of nodes, decision nodes and chance nodes. The decision nodes represent action choices, and the chance nodes represent uncertain events. A probability is assigned to each branch emanating from a chance node. On the basis of these probability assignments, the model performs the expected value and risk-profile calculations for any output variable of the simulation system.

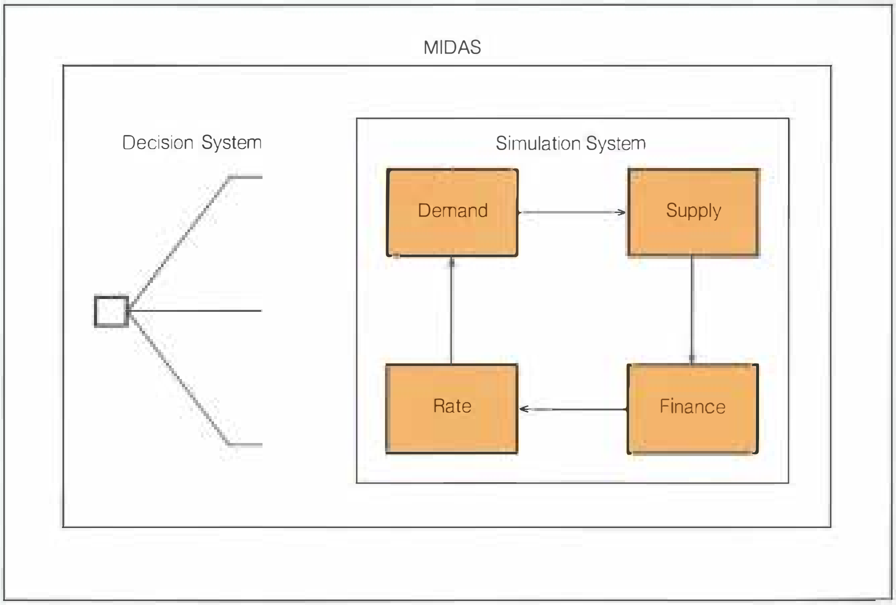


Figure 1 MIDAS contains two nested models—a simulation system within an enveloping decision system.

The decision tree provides a useful framework for analysis. Each endpoint of the tree represents a single scenario—a specific combination of decision and chance event outcomes—for which the simulation system is run. When every endpoint has been simulated, decision analyses can be performed easily for multiple objectives defined from output variables of the simulation system.

The idea of valuing information is extremely powerful in decision analysis. By comparing the expected value of a decision based on (assumed) perfect information with that of a decision based on less-than-perfect information, the decision maker can estimate the incremental value of perfect information. In MIDAS the expected value of perfect information can be easily calculated. This capability will help utility decision makers identify those uncertainties whose resolution would have the greatest value. Consequently, it can help decision makers bring their information-gathering resources to bear.

The multiobjective capability of the decision system allows one to examine how a decision might change when viewed from the perspective of different objectives. In specifying an objective function, the user can apply any of several functions—minimum, maximum, average, sum, or present value—to any variable computed by the simulation system over any subset of years. In addition, different objectives can be linearly combined into a compound objective function.

The simulation system is a planning model that integrates demand, supply, financial, and rate-planning components. The model is run for each scenario in the decision tree, and the results are collected in a three-dimensional results matrix in which each variable is defined by variable, time, and scenario. Running the simulation for each scenario is the most time-consuming task in MIDAS. Once this task is complete, however, the results matrix permits rapid selection of reports and repeated decision analyses with alternative objectives and probability assignments.

The simulation system model performs all functions in one year before proceeding to the next year. Feedback loops between demand and prices alter load shapes in response to rate structures, as well as to long-term, lagged-price response. The model is self-contained and can be run on a stand-alone basis or as part of a decision analysis exercise. It comprises four modules: demand, supply, finance, and rates.

The demand module projects patterns of daily, monthly, and annual load shapes based on input historical load patterns, peak and energy forecasts, demand-side management program effects, and price elasticities. Analysis can be performed at three levels: end use, customer class, or total system.

The supply module calculates the additions of new generating units necessary to meet the specified planning reserve margin and mix of baseload, cycling, and peaking capacity. It also computes generation, fuel use, and total production cost by generating unit and for the total system. For production cost analysis, both a probabilistic and a deterministic approach are allowed, taking into account both capacity-limited and energy-limited units.

The finance module calculates revenue requirements, cash flow, and financing needs, and provides complete financial statements, including balance sheets, income statements, and fund flow statements. The rates module computes customer-class average electricity prices. Revenue requirements are first classified into energy, demand, and customer components on the basis of input specifications and are then allocated to each customer class on the basis of contributions to peak, energy, and demand, as computed in the demand module.

Using MIDAS

MIDAS is a general planning tool that can be applied to a wide range of decision problems. It is particularly well suited for certain types of problems at a corporate level at which a broad perspective is required and at which the consideration of uncertainties and multiple objectives is important.

Three studies have been conducted to test MIDAS and to demonstrate its applications. The first was conducted in cooperation with Union Electric Co. (UEC). MIDAS was used to evaluate the relative benefits of the supply and demand options available to UEC. The supply options included a coal power plant and combustion turbines. The demand options were all conservation programs, including high-efficiency air conditioners, infiltration control, and external shading for residential customers, as well as high-efficiency lamps for commercial customers. The key uncertainties were the cost of the coal unit, customer acceptance of conservation programs, and future load patterns.

In this UEC application, MIDAS proved highly complementary to existing planning tools. It broadened the planning perspectives, provided additional insights, and showed the robustness of alternative strategies under conditions of uncertainty. The model was subsequently used by UEC to provide insight for the development of its energy resource plan. This study, conducted at a relatively early stage of the model's development, provided an extensive test of MIDAS's capabilities.

In a second study, which was cofunded by Virginia Power and DOE, MIDAS was used to make an economic evaluation of the life extension of Virginia Power's Surry-1 nuclear plant. Preliminary results showed that MIDAS was extremely useful in performing sensitivity analyses, in identifying key uncertainties for further analysis, and in suggesting new considerations for decision making. The third study was recently undertaken with Puget Power & Light Co. to further test the model and to demonstrate its usefulness as an analytic tool for developing an integrated resource plan for the company.

A preliminary version of MIDAS has been completed and prereleased for beta-testing to over 20 utilities. Version 1.0 of the model is scheduled to be released in June 1987. *Project Manager: Hung-po Chao*

New Contracts

Project	Funding / Duration	Contractor / EPRI Project Manager
Advanced Power Systems		
Review of Japanese R&D on Dry, Low-NO_x Combustion Systems for Utility Combustion Turbines (RP1657-9)	$33,000 4 months	Intech Incorporated/ *L. Angello*
Analysis of the Aggflotherm Process (RP2655-13)	$54,600 6 months	Praxis Engineers, Inc./ *L. Atherton*
IGCC Site-Specific Study (RP2773-3)	$225,000 11 months	Baltimore Gas & Electric Co./*J. Fortune*
Development of Software to Convert NERC/GADS Data for Direct Input to the UNIRAM Code (RP2921-4)	$199,900 12 months	Arinc Research Corp./ *J. Weiss*
Coal Combustion Systems		
Study for Converting Baseload Unit to Cycling Duty (RP1184-20)	$399,900 32 months	Pacific Gas and Electric Co./*M. Divakaruni*
Feed Pump Operation and Maintenance Guidelines (RP1884-23)	$768,400 29 months	General Physics Corp./ *S. Pace*
Steam Line Inspection and Monitoring (RP1893-4)	$502,800 17 months	Babcock & Wilcox Co./ *S. Gehl*
Integrated Approach to Life Assessment of Boiler Pressure Parts (RP2253-10)	$3,284,300 47 months	G. A. Technologies, Inc./ *R. Viswanathan*
High-Sulfur Test Center Operations (RP2604-3)	$2,047,700 17 months	Gilbert/Commonwealth, Inc./*R. Glover*
Tangentially Fired Dry Sorbent Injection Prototype (RP2786-2)	$1,597,700 52 months	Energy and Environmental Research Corp./ *M. McElroy*
Urea Injection Demonstration: Report Preparation (RP2869-5)	$34,000 8 months	KVB, Inc./*D. Eskinazi*
N_2O Formation in Combustion and Environmental Control Systems (RP8005-4)	$222,000 24 months	University of California at Irvine/*G. Offen*
Electrical Systems		
GEMS: Generator Expert Monitoring System (RP2591-3)	$1,628,300 (Canadian) 39 months	Ontario Hydro/*D. Sharma*
Aging of Extruded-Dielectric Power Cables (RP2713-2)	$3,089,700 74 months	Conductor Products, Inc./ *B. Bernstein*
Algorithm for Detecting Energy Diversion (RP2739-1)	$953,100 47 months	Boeing Computer Services/*H. Ng*
Photovoltaic Generation Effects (RP2838-1)	$551,200 18 months	New England Power Service Co./*H. Songster*
Composite-Insulation BIL Guide (RP2874-1)	$71,900 17 months	Mississippi State University/*J. Mitsche*
Alternative-Cable Evaluation (RP7898-10)	$161,400 12 months	Power Technologies, Inc./ *J. Shimshock*

Project	Funding / Duration	Contractor / EPRI Project Manager
Energy Management and Utilization		
Electric G-Van Feasibility Study (RP2664-3)	$238,900 7 months	C&C Incorporated/ *L. O'Connell*
Appraisal of Cooling Alternatives (RP2732-8)	$69,300 11 months	Regional Economic Research, Inc./*R. Wendland*
Optimizing Power Use in the Process Industries (RP2783-8)	$310,600 10 months	ICI Tensa Services/ *A. Karp*
Vapor Compression System Improvements via Cycle Modifications (RP2792-2)	$237,500 11 months	Arthur D. Little, Inc./ *C. Hiller*
Development of Price-Responding Control Algorithms (RP2830-5)	$178,500 17 months	Massachusetts Institute of Technology, Inc./ *L. Carmichael*
Direct-Fired-Coil Studies (RP2868-4)	$223,100 11 months	Battelle Memorial Institute/ *C. Hiller*
Electric Transportation Technical Assistance (RP2882-1)	$124,500 12 months	Bevilacqua-Knight, Inc./ *L. O'Connell*
Environment		
Study of Telephone Linemen to Determine Leukemia Risks From Electromagnetic Fields (RP799-23)	$353,000 24 months	Johns Hopkins University/ *R. Black*
Microcomputer Modeling of the Interaction of Low-Frequency Electromagnetic Fields With Biologic Objects (RP799-25)	$31,500 24 months	University of the South/ *S. Sussman*
Lake Quality and Mercury in Fish (RP2020-5)	$200,100 22 months	Tetra Tech, Inc./ *D. Porcella*
Survey of Trace Metal Chemistry in Phase 2 Lakes of the National Lake Survey (RP2020-7)	$31,500 12 months	Indiana University Foundation/*D. Porcella*
Nuclear Power		
Auxiliary Feedwater Spreading Test (RP1845-10)	$53,600 12 months	Science Applications International Corp./*J. Kim*
Evaluation of Moderator Temperature Coefficient for Westinghouse Cores (RP2420-47)	$88,000 8 months	Science Applications International Corp./*J. Chao*
Geologic and Geophysical Characterization of Site of Parkfield Dense Seismic Array (RP2556-40)	$108,600 3 months	Geomatrix Consultants, Inc./*C. Stepp*
Planning and Evaluation		
Fuel Supply Business Strategies (RP2359-24)	$99,200 11 months	Applied Decision Analysis, Inc./*S. Chapel*
Integrated Energy Services (RP2379-14)	$150,000 9 months	Integrated Communications Systems, Inc./ *P. Gupta*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. For information on how to order one-page summaries of reports, contact the EPRI Technical Information Division, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2411.

ADVANCED POWER SYSTEMS

Biologic Coal Beneficiation: Literature Review
AP-4834 Final Report (RP2606-2); $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: L. Atherton

Low-Rank Coal–Water Slurries for Gasification: Phase 2 Analytic Studies
AP-4905 Final Report (RP2470-1); $32.50
Contractor: University of North Dakota
EPRI Project Manager: G. Quentin

High-Efficiency Axial Compressor
AP-4943 Final Report (RP2544-1); $47.50
Contractor: General Motors Corp.
EPRI Project Manager: A. Cohn

Reliability, Availability, and Maintainability Assessment of a Zinc Chloride Battery System
AP-4948 Final Report (RP370-29); $32.50
Contractor: Arinc Research Corp.
EPRI Project Manager: W. Spindler

Battery Energy Storage Test (BEST) Facility, Summary Report: 1976–1986
AP-4982 Final Report (RP255-2); $25
Contractor: Public Service Electric & Gas Co.
EPRI Project Manager: W. Spindler

Chemical Structure and Liquefaction Reactivity of Coal
AP-4995 Final Report (RP2147-4); Vol. 1, $25; Vol. 2, $25
Contractor: Rockwell International Corp.
EPRI Project Manager: L. Atherton

Carbon Conversion–Ash Agglomeration Study for KILnGAS Coal Gasification
AP-5004 Final Report (RP1601-1); $25
Contractor: Allis-Chalmers Corp.
EPRI Project Manager: R. Frischmuth

Pyrolysis of Coal for Production of Low-Sulfur Fuel
AP-5005 Final Report (RP2051-2); $40
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: R. Frischmuth

COAL COMBUSTION SYSTEMS

Advanced Dry-Cooling Demonstration: Summary
CS-4862 Final Report (RP422-2); $25
Contractor: Union Carbide Corp.
EPRI Project Manager: J. Bartz

Water Blowing of Fireside Deposits in Coal-Fired Utility Boilers
CS-4914 Final Report (RP1650-1); $47.50
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: D. Broske

Development and Testing of Equipment for Removal of PCBs From Porous Surfaces
CS-4925 Final Report (RP1263-25); $25
Contractor: Quadrex HPS, Inc.
EPRI Project Managers: R. Komai, M. McLearn

1985 Fossil Plant Water Chemistry Symposium: Proceedings
CS-4950 Proceedings (RP1886-8); $62.50
Contractor: Jonas, Inc.
EPRI Project Manager: B. Dooley

Proceedings: 1986 Joint Symposium on Dry SO_2 and Simultaneous SO_2/NO_x Control Technologies
CS-4966 Proceedings (RP2533-12); Vol. 1, $55; Vol. 2, $62.50
Contractor: Radian Corp.
EPRI Project Manager: G. Offen

Economic Evaluation of Microfine Coal–Water Slurry
CS-4975 Final Report (RP1895-29); $25
Contractor: Stone & Webster Engineering Corp.
EPRI Project Managers: C. Derbidge, F Karlson, R. Manfred

Demonstration of the Combustion Engineering 100-MBtu/h Burner for Coal-Water Slurries
CS-4987 Final Report (RP1895-25); $32.50
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: R. Manfred

Wet-Dry Cooling Demonstration: Transfer of Technology
CS-5016 Final Report (RP422-3); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: J. Bartz

ELECTRICAL SYSTEMS

Conductor Fatigue Life Research: Eolian Vibration of Transmission Lines
EL-4744 Final Report (RP1278-1); $62.50
Contractor: Auburn University
EPRI Project Manager: J. Porter

The HARMFLO Code, Version 4.0: User's Guide
EL-4920-CCM Computer Code Manual (RP2444-1); $32.50
Contractor: Purdue University
EPRI Project Manager: J. Mitsche

Practical Methods to Integrate Load Management Into Normal Operations of Power System Control Centers
EL-4927 Final Report (RP2202-1); Vol. 1, $32.50; Vol. 2, $40
Contractor: ECC, Inc.
EPRI Project Manager: C. Frank

Literature Review of Pyrolysis and Combustion Products of Selected Utility Materials
EL-4939 Interim Report (RP2028-15); $32.50
Contractor: Midwest Research Institute
EPRI Project Manager: G. Addis

Radio Interference From HVDC Converter Stations: Modeling and Characterization
EL-4956 Final Report (RP1769-1); $32.50
Contractor: International Engineering Co., Inc.
EPRI Project Manager: S. Wright

Methods for Mitigating Corrosion of Copper Concentric Neutral Wires in Conduit
EL-4981 Final Report (RP1771-1); $32.50
Contractor: Pacific Gas and Electric Co.
EPRI Project Manager: T. Kendrew

HVDC Converter Stations for Voltages Above 600 kV: R&D Needs and Priorities
EL-4984 Final Report (RP2115-5); $32.50
Contractor: Institut de Recherche d'Hydro-Québec
EPRI Project Manager: S. Nilsson

ENERGY MANAGEMENT AND UTILIZATION

Evaluation of Near-Term Electric Vehicle Battery Systems Through In-Vehicle Testing
EM-4701 Interim Report (RP1136-27); $32.50
Contractor: Tennessee Valley Authority
EPRI Project Manager: L. O'Connell

Heat Pump Experiments Using Crawl Spaces as Ground-to-Air Heat Exchangers
EM-4908 Final Report (RP2033-14); $32.50
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: C. Hiller

Solar Hot Water Manual for Electric Utilities: Domestic Hot Water Systems
EM-4965 Final Report (RP2237-1); $32.50
Contractor: Burt Hill Kosar Rittelmann Associates
EPRI Project Manager: G. Purcell

Industrial End-Use Planning Methodology (INDEPTH): Demonstration of Design
EM-4988 Interim Report (RP2217-1); Vol. 1, $40; Vol. 2, $40; Vol. 3, $32.50
Contractor: Battelle, Columbus Division
EPRI Project Manager: C. Gellings

Directions for Future Commercial Survey Research: A COMSURV Monograph
EM-4989 Final Report (RP1216-9); $25
Contractor: Applied Management Sciences, Inc.
EPRI Project Manager: L. Lewis

ENVIRONMENT

Round-Robin Evaluation of Regulatory Extraction Methods for Solid Wastes
EA-4740 Interim Report (RP2485-8); $40
Contractors: Ethura; Battelle, Pacific Northwest Laboratories
EPRI Project Manager: I. Murarka

Micro-Surface-Analytical Techniques for Characterizing Fly Ash
EA-4820 Interim Report (RP1625-1); $32.50
Contractor: University of Wisconsin at Milwaukee
EPRI Project Manager: J. Guertin

Western Regional Air Quality Studies: Visibility and Air Quality Measurements, 1981–1982
EA-4903 Interim Report (RP1630-11); $62.50
Contractor: AeroVironment, Inc.
EPRI Project Manager: P. Mueller

Strategies for Coping With Drought: Problem Identification
EA-4944 Final Report (RP2194-1); Vol. 1, $32.50
Contractor: University of Washington
EPRI Project Manager: E. Altouney

Investigation of Methodologies for Estimating Human Carcinogenic Risk Using Nonhuman Data
EA-4973 Final Report (RP2027-4); $32.50
Contractor: K. S. Crump and Co., Inc.
EPRI Project Manager: A. Silvers

Proceedings: Workshop on Instream Flow Research Needs
EA-5007 Proceedings (RP2380-14); $25
Contractor: EA Engineering, Science & Technology, Inc.
EPRI Project Manager: J. Mattice

NUCLEAR POWER

Compilation of Corrosion Data on the CAN-DECON Process
NP-4222 Final Report (RP2296-3); Vol. 3, $25; Vol. 4, $40; Vol. 5, $25
Contractors: Ontario Hydro; London Nuclear, Ltd.
EPRI Project Manager: C. Wood

ARMP-02 Documentation: NORGE-B2 Computer Code Manual
NP-4574-CCM (Part II, Chap. 12) Computer Code Manual (RP1252-9); Vol. 1, $25; Vol. 2, $32.50; Vol. 3, $32.50
Contractor: S. Levy, Inc.
EPRI Project Manager: O. Ozer

Assessment of ASME Code Section XI Ultrasonic Testing Techniques
NP-4928 Final Report (RP1570-3); $25
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: M. Behravesh

Chemical Cleaning Waste Disposal
NP-4954 Final Report (RPS305-19); $32.50
Contractor: Duke Power Co.
EPRI Project Manager: L. Williams

Comparison of QUANDRY and PDQ Analysis of Zion Unit 2, Cycle 1
NP-4955 Final Report (RP1936-5); $32.50
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: W. Eich

The Source Term Experiments Project Deposition Sample Characterization
NP-4967M Interim Report (RP2351); $25
Contractor: Argonne National Laboratory
EPRI Project Manager: R. Ritzman

Application of the Leak-Before-Break Approach to Westinghouse PWR Piping
NP-4971 Final Report (RP1757-55); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: B. Chexal, D. Norris

Evaluation of Empirical Aerosol Correlations
NP-4974 Final Report (RP2684-1); $32.50
Contractor: Rockwell International Corp.
EPRI Project Manager: R. Ritzman

Transient Failure of Zircaloy Cladding: State-of-the-Art Study and Model Development
NP-4976 Final Report (RP1117-4); $25
Contractor: Anatech International Corp.
EPRI Project Manager: C. Lin

Simulator Qualification Plan
NP-4977 Interim Report (RP2054-2); $40
Contractor: General Physics Corp.
EPRI Project Managers: R. Colley, J. Sursock

Evaluation of Intergranular Attack on Alloy 600: Evaluation of Causes
NP-4978 Final Report (RPS302-13); Vol. 1, $40
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: P. Paine

Application of the Leak-Before-Break Approach to BWR Piping
NP-4991 Final Report (RP1757-56); $32.50
Contractor: General Electric Co.
EPRI Project Managers: B. Chexal, D. Norris

Postaccident Chemical Decontamination: Method Development
NP-4999 Final Report (RP2012-8); $32.50
Contractor: Pacific Nuclear Services
EPRI Project Manager: R. Shaw

PLANNING AND EVALUATION

TAG: Technical Assessment Guide
P-4463-SR Special Report; Vol. 1, $50; Vol. 3, forthcoming
EPRI Project Manager: S. Vejtasa

Evaluating the Effects of Time and Risk on Investment Choices: A Comparison of Finance Theory and Decision Analysis
P-5028 Final Report (RP2379-4); $25
Contractors: Applied Decision Analysis, Inc.; Charles River Associates, Inc.
EPRI Project Manager: S. Chapel

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

JUNE

9–10
Computerized Cost Estimating: Flue Gas Desulfurization Retrofit
Denver, Colorado
Contact: Robert Moser (415) 855-2277

JULY

7–9
Seminar: Gas-Insulated Substations
Newport Beach, California
Contact: Vasu Tahiliani (415) 855-2315

20–22
International Conference: Hardfacing and Wear
Golden, Colorado
Contact: Howard Ocken (415) 855-2055

AUGUST

25–26
Symposium: Power Plant Valves
Kansas City, Missouri
Contact: Stanley Pace (415) 855-2826

SEPTEMBER

9–11
Annual Review: EPRI's Demand-Side Planning Program
Houston, Texas
Contact: Terry Oldberg (415) 855-2887

15–17
Workshop: Generator Retaining Ring Inspection
Charlotte, North Carolina
Contact: Jan Stein (415) 855-2390

23–25
Seminar: Meeting Customer Needs With Heat Pumps
New Orleans, Louisiana
Contact: Sharon Luongo (415) 855-2010

OCTOBER

6–9
1987 PCB Seminar
Kansas City, Missouri
Contact: Gilbert Addis (415) 855-2286

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