Clean Coal Technologies

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Cover: Clean coal technologies now under development promise to keep coal at center stage in America's energy future. By enabling coal to be used cleanly and more cost-effectively, these technologies will help to resolve the conflicts between environmental and economic goals that have characterized the energy debate in recent years.

Clean Coal Technology: A Win-Win Proposition

Recent government initiatives to spur development and deployment of clean coal technologies offer welcome confirmation of the strategic importance these technologies hold for the utility industry and the nation. After more than a decade of rising electricity costs and unresolved debate over acid rain control measures, it is clear that we need technologies that use coal more cleanly and economically.

These goals must be pursued simultaneously. Our economic competitiveness in the global market depends on the continued availability of low-cost electricity from coal. And environmental improvements are sustainable in the long run only if they are part of an economically viable system. An intelligently planned and developed program in clean coal technology can provide a win-win solution—one that responds to the legitimate environmental concerns of society, while keeping the cost of electricity low.

EPRI and the utility industry have already spent more than a billion dollars ushering clean coal technologies toward commercial maturity. The approach is broad, encompassing improved methods of extracting impurities from coal before it is burned and innovative designs for new power plants that will produce fewer emissions, while improving the cost-effectiveness and productivity of coal utilization. Less costly and more-effective retrofit emission control options are also being developed in the event that environmental science indicates the need for their application. Equally important as these process developments are the rapid advancements being made in power plant materials and in harnessing the microprocessor revolution for improved monitoring and control. Ultimately, we may witness the evolution of coal refineries capable of producing virtually no wastes and extracting chemical feedstocks, fuels, strategic metals, and other coproducts from coal in addition to generating electricity.

The utility industry thus stands at the threshold of fundamental change in its technologic base. But this change does not come easy. New technologies must be developed, tested, and refined in the laboratory, at pilot scale, and in commercial-size demonstrations under a range of conditions before they will be accepted in the market. Such efforts require money, time, and a sustained commitment from utilities, equipment vendors, regulators, and government. The shared commitment to both the Cool Water IGCC facility and the demonstration of an array of commercial fluidized-bed combustion power plants reflects the progress that can be achieved.

The current pause in capacity expansion offers the United States an opportunity to bring to commercial readiness the next generation of coal-based power technologies. They must be clean, modular, quick to build, and cost-effective. EPRI and the utility industry will continue to support work in this field but cannot succeed alone. Only with national support for demonstration and deployment and with cooperation from all sectors in encouraging commercialization of innovative technologies can the full promise of clean coal technology be realized.

Kurt E Yeager

Kurt Yeager
Vice President, Coal Combustion Systems Division

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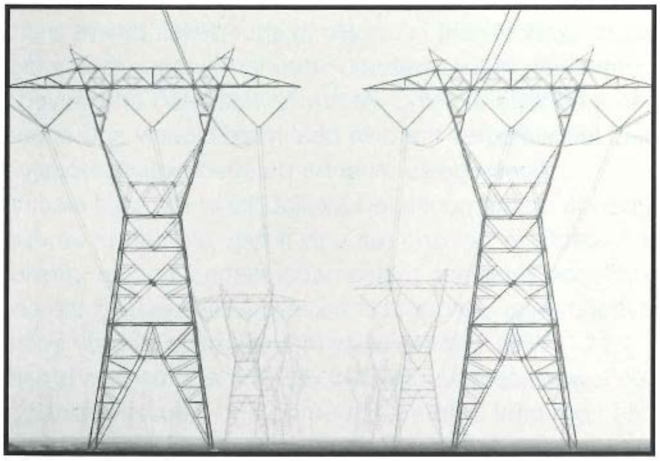

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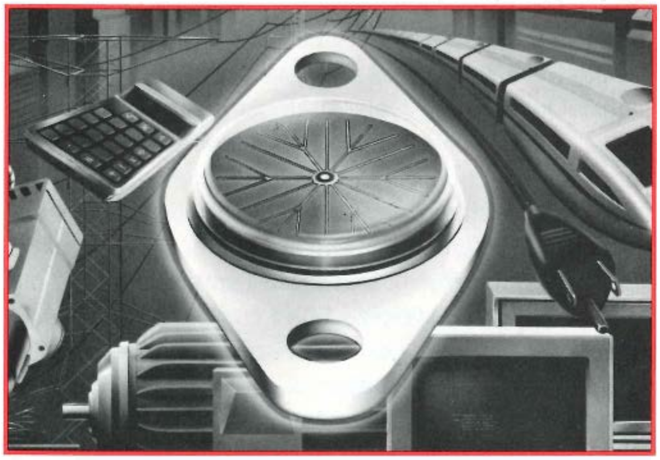

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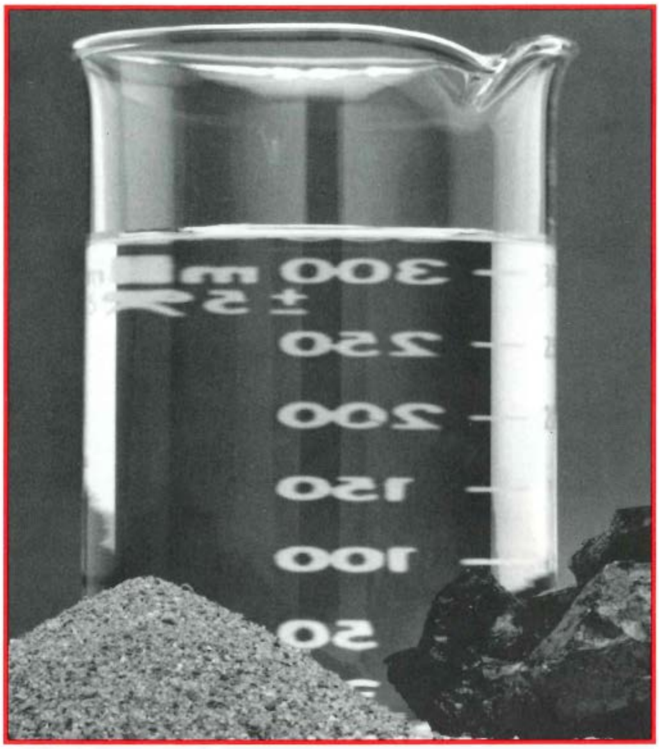

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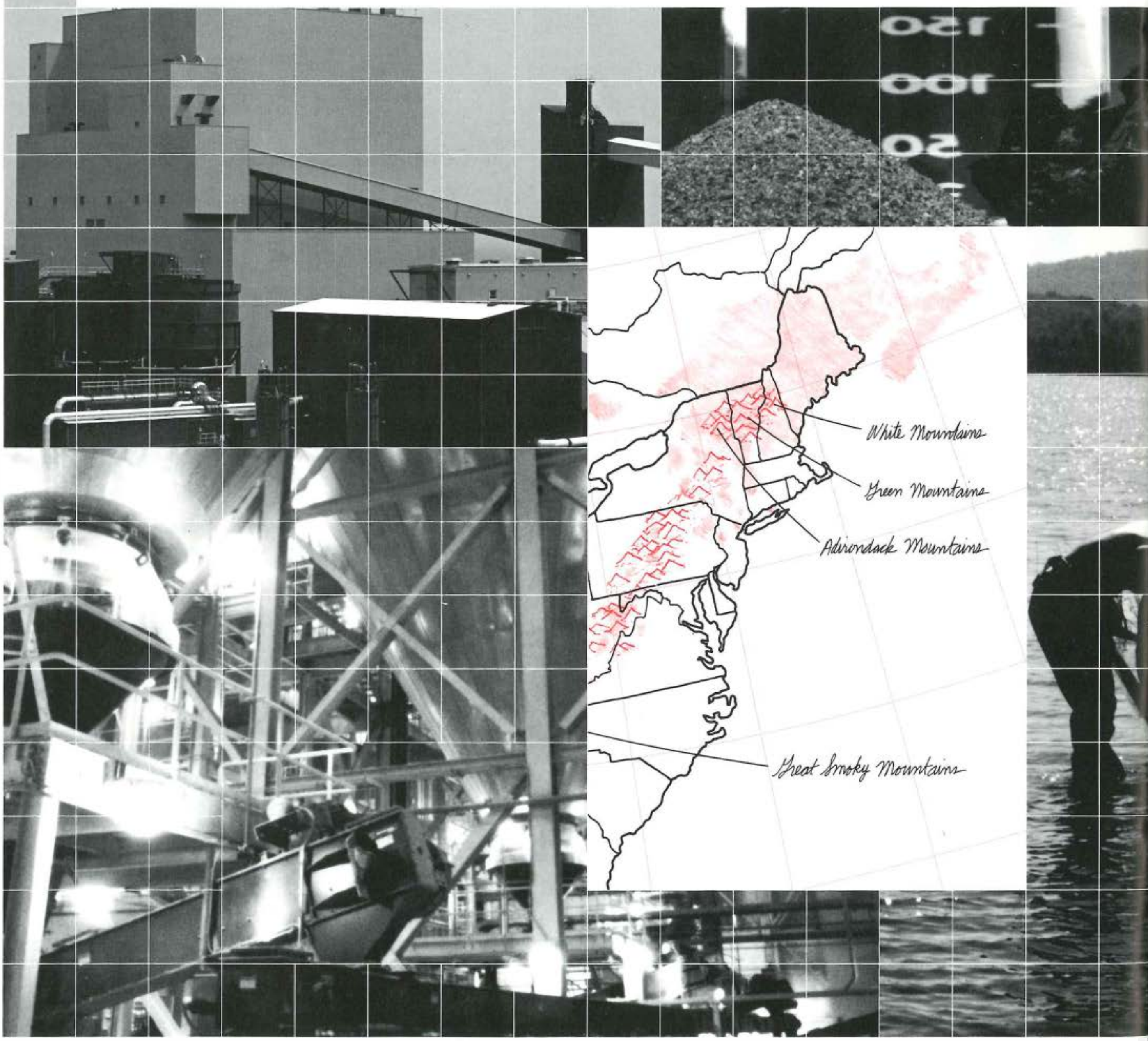
Coal Technologies for



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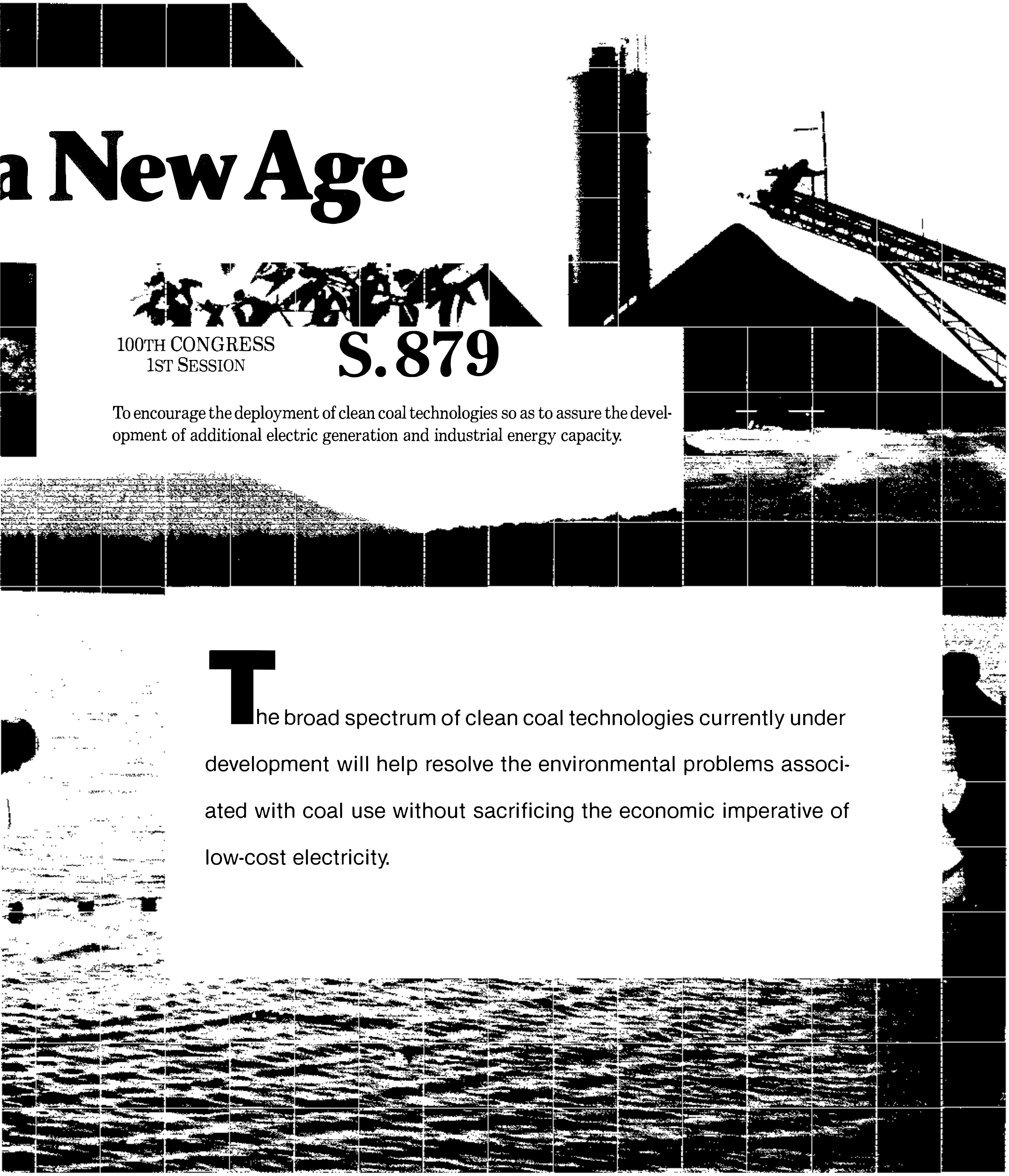

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To encourage the deployment of clean coal technologies so as to assure the development of additional electric generation and industrial energy capacity.

The broad spectrum of clean coal technologies currently under development will help resolve the environmental problems associated with coal use without sacrificing the economic imperative of low-cost electricity.

America has some tough decisions to make about coal. New Englanders, Canadians, and others concerned about acid rain are calling for stricter emission standards and additional air pollution controls on hundreds of factories and older coal-fired power plants, particularly those in the Ohio Valley. Appalachia and the Midwest are fighting new controls, maintaining that emissions are diminishing under existing programs, damage from acid rain is overstated, and the costs of new controls would hurt the region's economy. Several bills before Congress propose clean coal technology demonstration and deployment as an alternative to new standards, asserting that this approach would generate greater emission reductions at lower cost in the long term. Meanwhile, electric utilities, who depend on coal to generate more than half of the nation's power, are caught in a squeeze as they search for ways to simultaneously sustain environmental improvement, control costs, maintain productivity, and meet the need for new generating capacity when it arises.

The debate is often heated, and it reveals a lot about the difficulty this country has in balancing economic and environmental goals and planning for the orderly development and deployment of new technologies to help us achieve those goals.

"If we want to transcend the adversarial nature of energy and environmental policymaking in this country, while enhancing our competitiveness in the global economy, we need technologies that resolve the present conflict between productivity, environment, and cost," says Kurt Yeager, an EPRI vice president who directs the Coal Combustion Systems Division. "That's not a utopian dream; it's a valid goal and one that we can achieve over time. The key is to bring all the major concerns into the engineering process as explicit design criteria. For utilities that means minimizing cost and environmental impact, while maximizing factors like reliability, performance, and modularity.

"And we have to think holistically about environmental controls. Rather than focusing on methods that capture air emissions but create water and solid-waste problems, we have to develop ways to minimize total environmental impact."

These are the kinds of principles that have guided EPRI's work in clean coal technology over the past 15 years. "It's our job to see that the industry is prepared technologically to respond to the policies that society chooses," says Yeager. Because those policies are continually changing and the industry is so diverse, utilities need an array of adaptable options, from better retrofit emission controls to clean, cost-effective, modular technologies for new power plants.

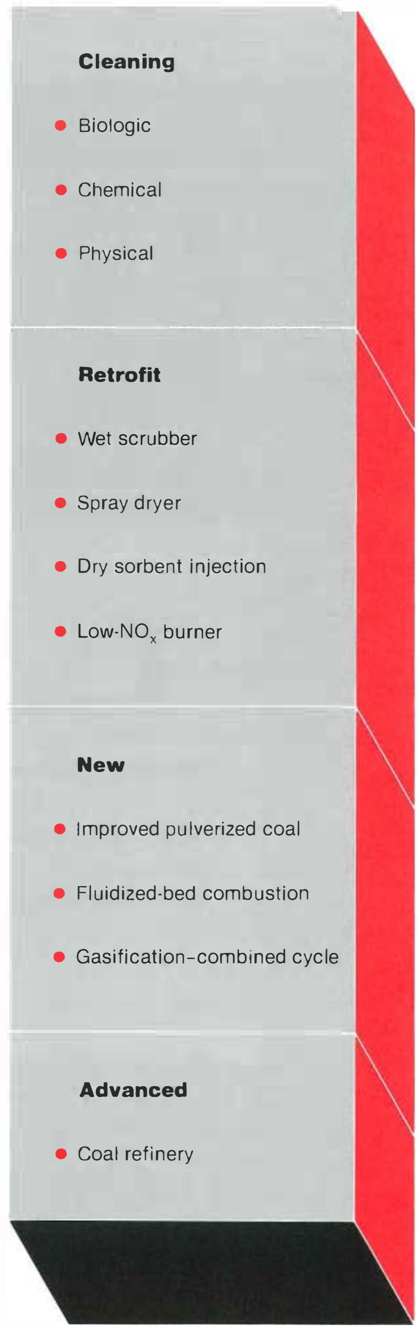
"We can reduce the cost of power and improve both productivity and environmental performance with the technologies being developed for new plants and for repowering existing facilities," says Yeager. "While we can't expect retrofit control options to enhance productivity, by improving them we can hold cost increases in check and offer the industry some technologic insurance against further regulation of existing plants."

Although EPRI and individual utilities have spent more than a billion dollars on clean coal technology, far more will have to be invested in development, demonstration, and deployment before the bugs are worked out and utilities are confident enough in the technologies to put them into commercial use.

Legislative proposals from the Reagan Administration and from Senator Robert Byrd would give this process a shot in the arm with government cost sharing for demonstration and deployment. But even with this help, utilities will be

Clean Coal Technologies

EPRI is pursuing clean coal technologies in four principal areas—coal cleaning, retrofit emissions controls, new generating options, and the integration of various advanced processes into the coal refinery of the future.



cautious about being the first to commercially apply a new technology. This caution stems in part from the fear that if the plant does not perform as expected—a common risk with new technologies—regulators might disallow part or all of the investment from the utility's rate base.

Such disincentives to innovation can be reduced. In Ohio, for example, utilities and state officials work together under a state-supported clean coal program to select candidate technologies for demonstration. The state shares part of the cost, expedites the permitting process, and ensures the utility a reasonable rate of return by guaranteeing to allow the utility's investment into the rate base.

Whatever emerges from Washington in terms of acid rain bills and clean coal programs, EPRI and the utility industry will continue to improve coal-based power technology. "We have to," says Yeager. "Right now there's a lot of surplus power capacity in parts of the system, but that won't always be the case. Even if aggressive load management and conservation keeps our load growth down below 2%, the nation is going to have to begin adding new, more-productive capacity in the near future. And much of that must come from coal."

Starting with the raw material

EPRI is approaching the clean coal challenge on many fronts. Perhaps most obvious and fundamental is an ambitious program on fuel quality and cleaning. This effort focuses on removing the impurities from coal before it even enters the power plant. The $15.2 million Coal Quality Development Center (CQDC)—formerly known as the Coal Cleaning Test Facility—built by EPRI, with cosponsorship from Pennsylvania Electric, New York State Electric & Gas, and Empire State Electric Energy Research, has been advancing the art of physical coal cleaning since it began operation in 1981. CQDC is characterizing the costs and benefits of cleaning the wide variety of major steam coals, developing and demonstrating new and improved coal-cleaning technology and instrumentation, creating a national coal quality data base, and designing a model to enable engineers to better extrapolate from inexpensive laboratory-scale tests the cleanability of specific coals.

Although 40% of utility coal is cleaned to some extent—mostly through physical processes that use differences in particle density to separate coal from its impurities—there is far greater potential for cost-effective coal quality improvement, according to Fred Karlson, who manages EPRI's Fuel Quality Program. "Part of the problem is that utilities have never had good information on what cleaning can and cannot accomplish," says Karlson. CQDC is working to alleviate this dilemma. The center has characterized more than 25 major coal types, compiling the results in a coal quality information book. The book tells users how much of the sulfur and other problem minerals is removed and how much of the fuel's Btu value is retained under various cleaning methods. This information can help utilities to design the most cost-effective means of complying with SO_2 emission standards because a combination of coal cleaning and partial flue gas desulfurization is often more effective and less costly than total reliance on flue gas scrubbing.

Although physical coal cleaning can effectively remove up to half of the sulfur in some coals, it's not the only game in town. EPRI is exploring both biologic and chemical means of getting the sulfur out of coal. "We're exploring some very interesting developments in bacterial desulfurization," explains Linda Atherton, a project manager in the Advanced Power Systems Division. "Several groups are finding that bacteria called *Thiobacillus ferrooxidans,* when mixed in a broth with finely ground coal, change the surface properties of pyrite particles, causing them to sink more readily. In some tests this process has doubled sulfur removal. The use of biologic surfactants thus may prove to be a very inexpensive and easy way of enhancing pyritic sulfur removal."

Although better pyritic sulfur removal is important, it won't be enough to allow utilities to meet stringent sulfur emission standards without further control methods. To do so would require that organic sulfur be removed as well. But organic sulfur is chemically bound into the coal molecule and cannot be removed by physical separation techniques. Several new techniques offer hope for organic sulfur removal, however.

A genetically altered form of Pseudomonas bacteria has been shown to remove organic sulfur by breaking sulfur bonds in the coal's molecular structure. And a new chemical solvent process still in the experimental stage appears to remove organic sulfur at 110°C, far cooler than was previously thought possible. Biologic and chemical desulfurization techniques like these are at very early stages of development and have yet to be proved at commercial scale, but they are advancing rapidly and hold promise as complements to more tried-and-true physical cleaning techniques.

Sprucing up existing plants

One of the more controversial issues in utility planning and environmental policy these days is the question of what to do with pre-1970s coal-fired power plants. For example, depending on the rate of plant retirements, up to 54,000 MW of coal-fired capacity may exceed 40 years of age between now and the turn of the century, and up to another 68,000 MW may join the over-forty set in the following decade. Because load growth has slowed and new plant construction is both expensive and risky, many utilities see performance upgrading and continued use of existing facilities as an important element in the strategy to reduce generation costs.

But those older plants generally emit at a higher rate than plants built under the Clean Air Act's New Source Performance Standards (NSPS). With the aim of reducing emissions as quickly as possible, proponents of acid rain control are pushing to have these facilities retrofit with wet scrubbers or equivalent technology.

Utilities are opposed to the retrofit proposals for several reasons. Cost is a major concern. In some cases scrubber retrofits would exceed the original cost of the plant: \$200–\$300/kW in capital cost alone. Across-the-board scrubber retrofits would cost utilities and their customers as much as \$12 billion per year over the remaining life of the plants. Moreover, say the utilities, such a massive investment in retrofit scrubbers would reduce the incentive for and the funds available to demonstrate and deploy new clean coal technologies—technologies that would lead to larger and more-sustainable emission reductions and productivity improvements in the long run.

Another argument against universal scrubbing is that emissions are falling under existing regulations. National SO_2 emissions from all man-made sources fell 28% from their peak of 29 million metric tons per year in 1973 to 21 million tons in 1985. Emissions from coal-fired plants, which peaked in 1977 at 17 million tons a year, fell 16% by 1985 to 14.2 million tons. Even more significant than the absolute drop in emissions is the fact that this occurred while utility coal use rose 45%, from 434 million tons a year in 1977 to 631 million tons in 1985.

There are several reasons for the decline in emissions. Demand for new generating capacity is shifting to the western half of the United States, where local coal contains less sulfur. Utilities in all regions are burning more low-sulfur coal. And scrubbers or other SO_2 control technologies are being used on all new plants and on more than 13,000 MW of pre-NSPS capacity.

Citing the fall in emissions and the recently released interim report of the National Acid Precipitation Assessment Program (NAPAP)—which concludes that acid rain is not causing widespread ecologic damage—utilities, manufacturers, and the Reagan Administration argue that there is no justification for a massive investment in retrofit scrubbers.

But the debate on acid rain's effects is far from settled, and although there is general agreement on historic emission levels, projections of future emissions are debated as well. The coal and utility industry argue that the drop in SO_2 emissions will continue as growth in coal use slows, new plants with strict controls become an ever-larger fraction of the generation fleet, and demand shifts toward low-sulfur coal. EPRI estimates that the industry could extend the service life of more than half of the pre-1971 NSPS coal-fired fleet to 60 years without increasing national SO_2 emissions.

But what do others say about future emissions? NAPAP surveyed the major emissions projection models now in use and found that the models produce similar results when the same assumptions are made about factors like demand growth, plant lifetime, fuel sulfur levels, and changes in technology. Because different investigators make different assumptions about these parameters—all of which entail some uncertainty—their projections vary somewhat. Some show a slight rise in emissions early in the next century (although not as high as the peak levels reached in the 1970s) followed by a steady decline. Whether or not they foresee such an emissions hump, virtually all models show a general long-term trend of declining emissions.

If their position on costs, emissions trends, and environmental effects does not hold sway, and the nation insists on curbing emissions from existing plants, utilities still maintain that a blanket requirement for wet scrubbing is the wrong approach. As insurance against the possibility of further control mandates, utilities—individually and through EPRI—are funding extensive R&D on a wide range of retrofit emission control technologies.

Developing retrofit options

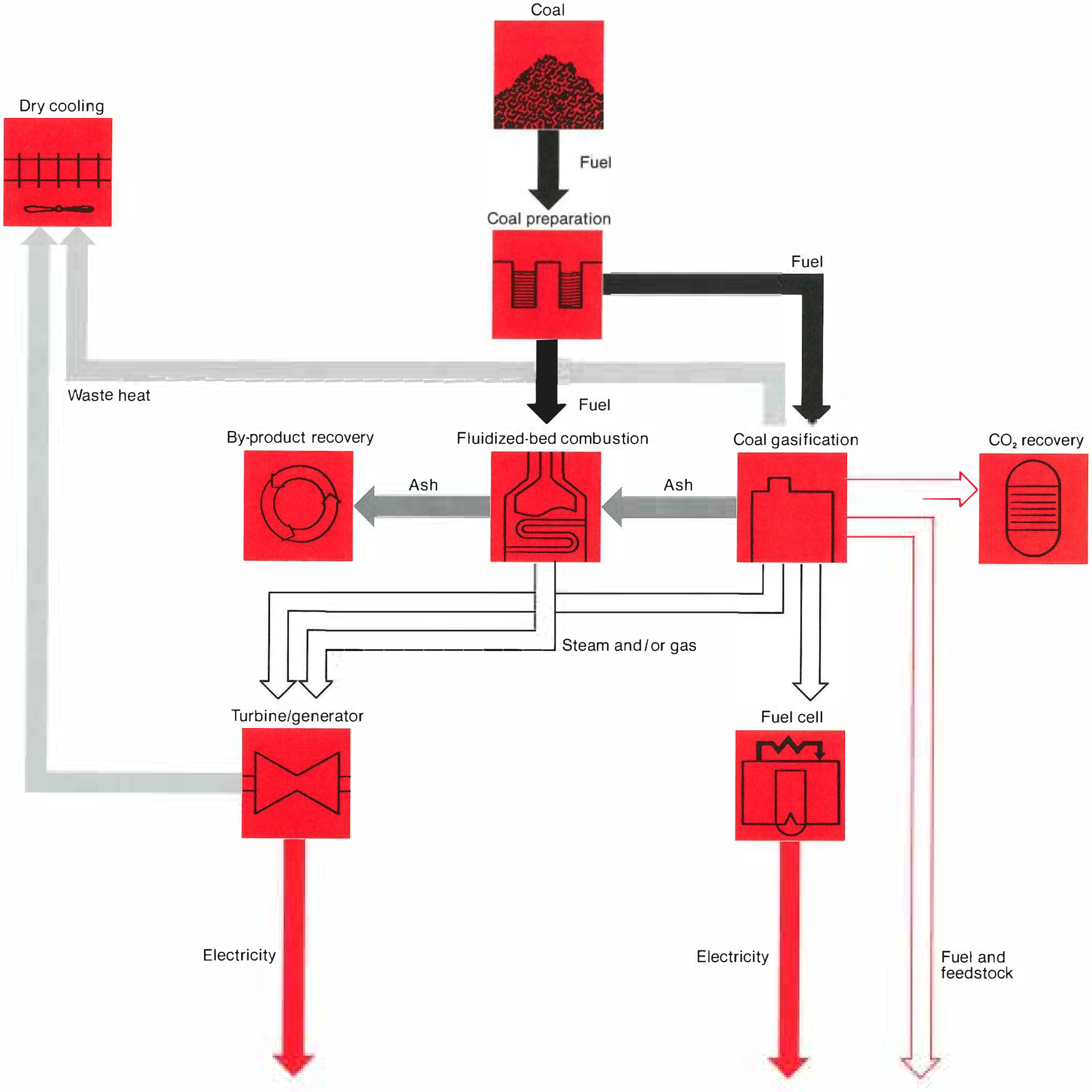
EPRI and others are working to provide the industry with a palette of retrofit controls to choose from. That means improving the conventional wet lime or limestone scrubber, as well as developing other technologies to control sulfur emissions. More important, it means transcending the historic approach of controlling one pollutant at a time and striving for more-integrated systems that tackle a number of environmental constraints at once.

EPRI's recently opened \$21 million High-Sulfur Test Center (HSTC), located at the Somerset station of New York State Electric & Gas, some 45 miles northeast of Buffalo, New York, will dedicate much of the first five years of its operation to testing and scaling up a number of techniques for improving the performance of wet scrubbers.

One area receiving considerable attention is the chemistry and consumption of water in the scrubbing process. Scrubbers use vast amounts of water, (up to 1000 gallons per minute for a 1000-MW plant) to create the alkaline slurry that reacts with and removes sulfur from flue gases. Because utilities are being pressured to minimize or eliminate their wastewater emissions, researchers are studying the options for recycling water repeatedly through the

Conceptual Coal Refinery of the Future

The advances now under way in clean coal technology will ultimately enable coal-fueled power plants to evolve from relatively resource-inefficient, mechanical combustion units into fully integrated coal refineries producing numerous products in addition to electricity. The process begins with coal preparation to remove mineral impurities. Next comes coal gasification, producing coproducts like elemental sulfur, chemical feedstocks, and CO_2 as well as fuels. The fuels can be burned to generate process steam and electricity or used directly to feed a fuel cell. Gasification residues, together with the coal cleaning by-product, are then burned in a fluidized-bed boiler to capture their residual heating value. The ash is mined for valuable trace metals, like chromium, cobalt, and manganese, leaving a beneficiated inert aluminum silicate ash that can be used in applications from road construction to the production of plastics.



scrubber. How far they can go in this direction without building up levels of chlorides and other impurities that will corrode materials or interfere with the sulfur-capturing chemistry is a question that the HSTC researchers plan to resolve.

Another area being investigated is the way scrubber by-products crystallize under different operating regimes and the implications of those crystallization patterns for dewatering, handling, and disposal of the scrubber sludge. Disposal is a very important issue, as a conventional scrubber on a 1000-MW plant can produce enough sludge each year to cover a square mile one foot deep. At many existing plant sites, particularly in urban settings, space for sludge disposal is severely constrained, so the by-product's settling properties and other physical parameters become very important. EPRI is also looking at ways to produce commercial products from scrubber sludge—products like gypsum, sulfur, and sulfuric acid.

HSTC researchers will also be studying the use of additives and process changes like forced oxidation to improve scrubbing chemistry, as well as ways to reduce the number and size of scrubber components and their electricity demand.

Ultimately, however, utilities would like to get away from wet-scrubbing processes because of their high water use, inherent process complexity, and cost. Consequently, a number of dry-scrubbing approaches are being investigated. One alternative, known as spray drying, is already being applied commercially at several power plants burning low-sulfur coal. Spray drying uses a slurry (typically calcium hydroxide) that dries as it reacts with SO_2 in the exhaust stream. Some of the powderlike by-product falls to the bottom of the spray tower, and some is captured in a fabric filter or electrostatic precipitator downstream of the spray dryer.

EPRI researchers are working on two pilot applications of this technology for retrofit on high-sulfur systems. HSTC is studying the spray dryer–baghouse combination, while the spray dryer–electrostatic precipitator combination is being evaluated at a pilot facility cofunded with TVA and Ontario Hydro at TVA's Shawnee steam plant.

Other desulfurization systems being studied involve injection of dry calcium-based sorbents either directly into the furnace or into the ductwork downstream of the furnace. The furnace sorbent injection process has reached the prototype demonstration stage with an EPRI- and EPA-funded project at the 70-MW Whitewater Valley station of Richmond Power & Light. In another effort, dry injection of lime downstream of the existing particulate device (typically an electrostatic precipitator) and upstream of a new, small baghouse is being studied at pilot scale at HSTC. These dry-injection technologies still need substantial development and demonstration, but early signs are that they will offer considerable capital and operating savings and will reduce the water and solid waste problems involved in wet scrubbing.

NO_x also an issue

Sulfur compounds aren't the only airborne impurities utilities may have to put a lid on. Nitrogen oxides (NO_x) are also hot on the legislative agenda because of their role as a precursor to acid rain, oxidants, and upper atmospheric effects. Utilities generate slightly less than one-third of the nation's 24 million tons of annual NO_x emissions (the rest come from other stationary sources and automobiles). Several bills now before Congress would require utilities to retrofit all their pre-NSPS fossil-fuel-fired plants with NO_x control technologies. NO_x emissions on newer plants are already regulated under the Clean Air Act.

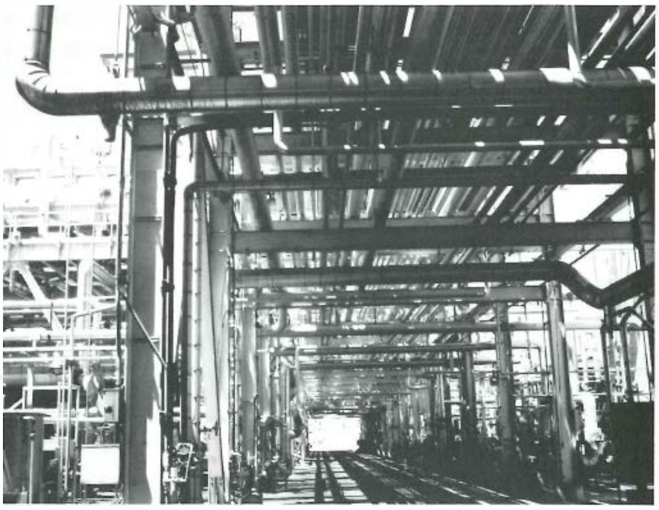
Although NO_x control on new plants has been achieved through the design of low-NO_x boilers with a typical cost premium of less than \$5/kW, cost estimates for retrofitting NO_x controls on older facilities range from \$3/kW to more than \$100/kW, depending on the technology used, the level of control required, and site-specific conditions. Two basic approaches are being explored: modification of the combustion process to reduce NO_x production, and removal of NO_x from the flue gas before it leaves the stack.

Combustion modification is the less-expensive approach. It is based on the fact that NO_x formation is largely a function of the temperature, fuel-air mixture, and fluid dynamics in the furnace. In general, the aim is to mix fuel and air more gradually to reduce the flame temperature and to stage combustion, initially using a richer fuel-air mixture, thereby reducing oxidation of nitrogen in the fuel. EPRI is funding low-NO_x burner retrofit demonstrations on four of the most widely used kinds of coal plant boilers. Scheduled for completion in 1991, "these demonstrations should resolve important questions about reliability that cannot be answered through pilot-scale research," says David Eskinazi, a project manager in the Air Quality Control Program.

A number of approaches to capturing NO_x after it is produced have been studied, but few have advanced beyond the laboratory workbench. One technique that has been applied recently in Japan and West Germany is selective catalytic reduction (SCR). SCR works by mixing ammonia with flue gas in the presence of a catalyst to transform the NO_x into molecular nitrogen and water. Virtually all applications and tests of SCR have been with low-sulfur coal, however, so there is still considerable uncertainty about the effectiveness of SCR in plants that burn medium- and high-sulfur coal. One of

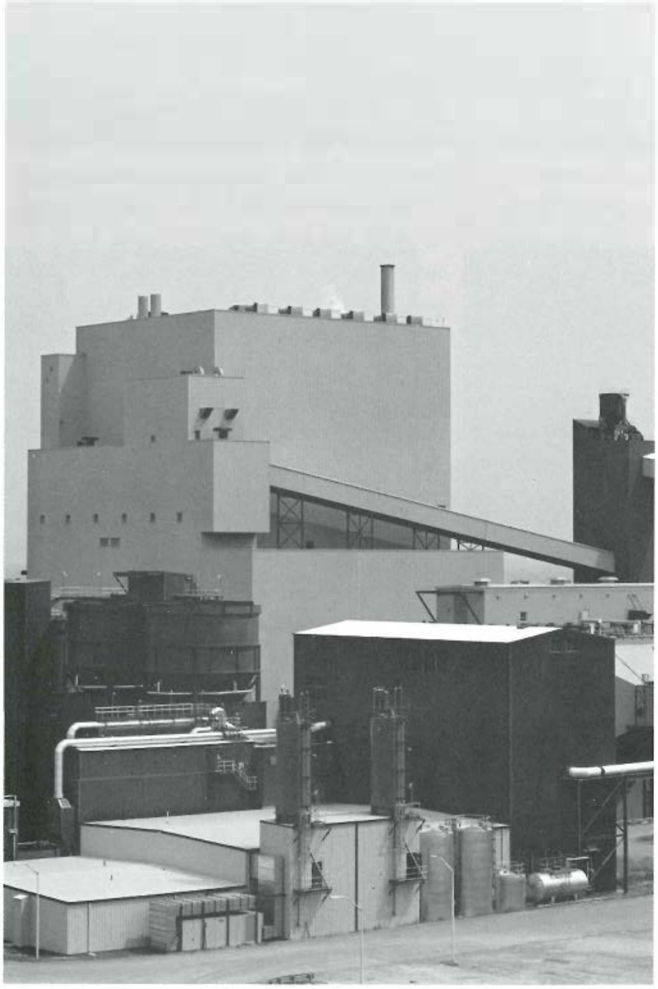
Clean Coal Technology for New Plants

EPRI is focusing on three clean coal options for new generating capacity: improved pulverized coal, fluidized-bed combustion, and gasification–combined cycle. Each approach seeks to minimize environmental impact, cost, and risk with design criteria like modularity, fuel flexibility, shop fabrication, and the integration of state-of-the-art environmental controls. Improved pulverized-coal technology involves material and design improvements on the conventional coal-fired systems now in use. Fluidized-bed combustion is a new approach, which captures sulfur in the furnace by burning coal in the presence of limestone; several utility-scale demonstrations are operating or under construction. Gasification–combined-cycle technology has been successfully demonstrated at the Cool Water station of Southern California Edison. The cleanest coal-fueled technique yet developed, this process converts coal to a gas, strips out particulates and elemental sulfur for resale, and produces electricity both by burning the syngas in a combustion turbine and by using waste heat to boil water and drive a steam turbine.

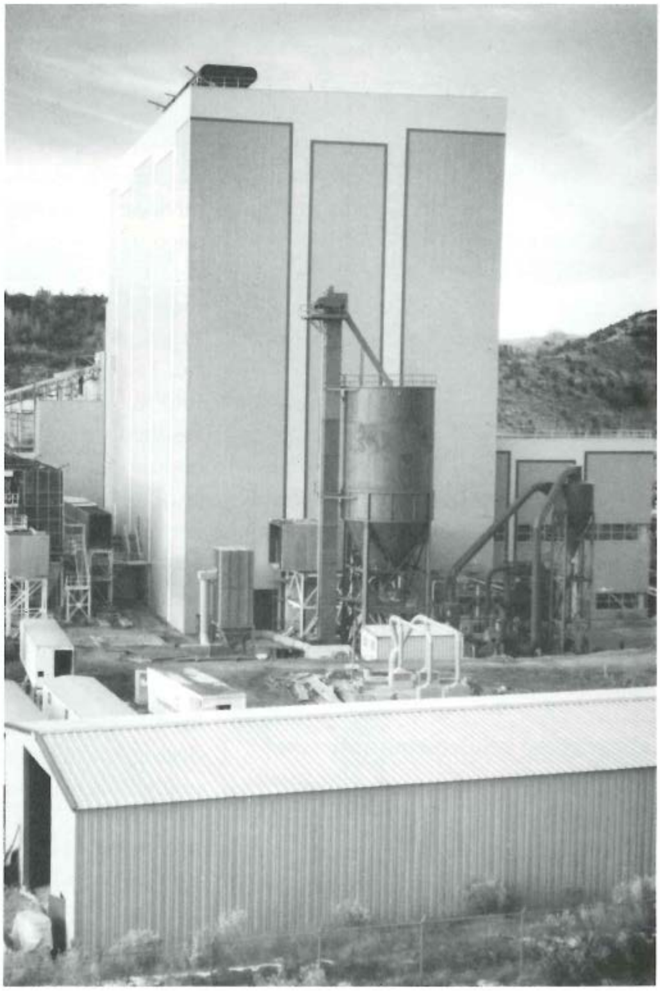


Gasification–combined cycle

Improved pulverized coal



Fluidized-bed combustion



the key questions is how long the catalyst can remain effective (it can become contaminated with fly ash and sulfur). And because the catalyst dominates the process costs, its longevity is an important element in determining the cost-effectiveness of the entire SCR system. Another concern is that the catalyst promotes conversion of SO_2 to SO_3, which can then contribute to deposition or contamination problems in downstream equipment and waste disposal, as well as affecting other plant emissions. Other possible difficulties with SCR include the production of potentially hazardous nitrosamine compounds under load-cycling conditions and competition with the fertilizer industry for available ammonia supplies. Research on these issues and further evaluation of the technology's application in Europe and Japan is needed before SCR's potential for the U.S. market can be clearly assessed.

Combustion modification appears to be more reliable than SCR and costs about one-tenth as much, both in capital expense and operating cost per ton of NO_x removed. Because of these apparent advantages, EPRI researchers feel that combustion modification (if it works out in the four demonstrations now getting under way) is apt to be the industry's most cost-effective option for NO_x control on new and, if required, older coal-fired plants. But to keep the industry's options open, EPRI is updating its technical and cost assessment of SCR, as well as combined SO_2–NO_x control techniques, and is planning pilot-scale tests of SCR at plants burning medium- and high-sulfur coal.

Integrating environmental controls

Although individual emission control technologies are improving rapidly, their piecemeal application to first one and then another kind of pollutant leads to unnecessary cost and inefficiency. To avoid this Band-Aid syndrome, the industry is searching for ways to streamline environmental control with fewer, multipurpose components that are designed to work integrally with the plant as a whole.

In some cases this means using the waste from one process as an input to another. For instance, cooling-tower blowdown (water used to flush chemical deposits from tower surfaces) can be recycled through a wet scrubber instead of being disposed of with mechanical evaporators and evaporation ponds. Waste heat recovery through the addition of low-excess-air burners and better seals can reduce flue gas flow by 15% and improve heat rate up to 200 Btu/kWh. With better heat rate, less coal can be burned, reducing flue gas volume and allowing controls to be made smaller and less expensive.

In addition to making existing components work together better, researchers are designing new multipurpose environmental control devices. For example, a 100-MW demonstration of combined SO_2-particulate control at the Nixon station of the Colorado Springs, Colorado, Department of Public Utilities has proved very successful. The injection of sodium bicarbonate into the fabric filter at the Nixon station resulted in over 70% sulfur capture, enough to place the station in compliance with the applicable New Source Performance Standards. Depending on alkali costs, EPRI estimates that sodium-based dry-injection technology (which is applicable principally in the western part of the country) may cost about \$95/kW less to build and up to 4 mills/kWh less to operate than spray-drying and wet-scrubbing systems. Colorado Springs and Public Service Company of Colorado now plan to use this dry-injection technology in plants scheduled to come on-line in the early 1990s. The rapid advances being made under EPRI sponsorship in high-temperature filtration also provide an important opportunity to combine SO_x, NO_x, and particulate removal in a single step.

Other processes being investigated include the use of electron beam irradiation, activated char, or chemical additives in conventional wet scrubbers to simultaneously collect SO_2 and NO_x from flue gas.

Given sufficient time and resources for development and demonstration, multipurpose, integrated environmental controls could help the nation retrofit its older power plants with greater reliability and less cost than would be possible with the retrofit technologies currently available. A legislative mandate for across-the-board scrubber retrofitting could slow or derail development work on many control options, however, so the commercial future of these technologies remains uncertain.

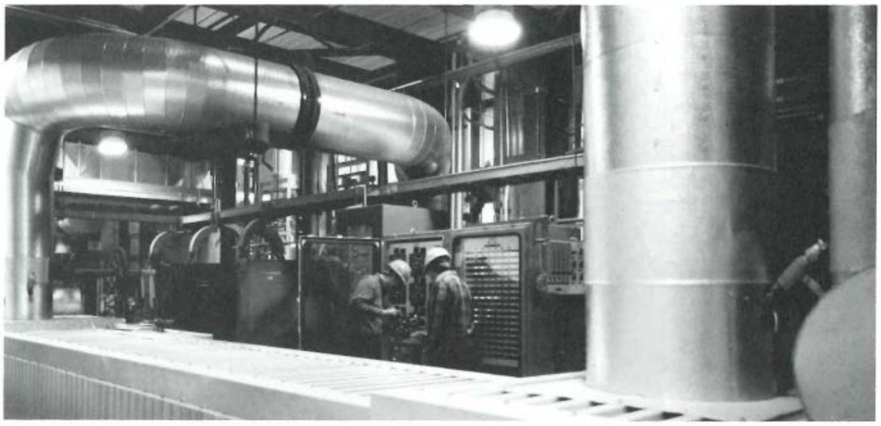
Cleaner options for new plants

Whatever happens with regard to older plants, utilities must continue to develop advanced options for new power supply. Not only must the new technologies minimize environmental impact, but they should also minimize cost and risk. This means shop-fabricated, modular designs that can be built and brought on-line quickly in a range of sizes to better match uncertain demand growth and reduce capital requirements. To ensure flexibility within volatile fuel markets, these advanced technologies should also be able to run on fuels of varying quality.

EPRI is pursuing three basic options for new coal-fired capacity: improved pulverized coal, fluidized-bed combustion (FBC), and integrated gasification–combined-cycle (IGCC), all aimed at combining stringent environmental control with higher productivity. The improved pulverized-coal approach entails materials and design modifications on a tried-and-true technology that has long been the workhorse of America's electric power fleet. "By improving the

Retrofit Clean Coal Technologies

The utility industry is developing a number of retrofit emission control technologies, in part as insurance against potential acid rain legislation. EPRI's High-Sulfur Test Center is testing methods for improving wet scrubber performance and recycling waste water through the scrubber. Utilities also are investigating several dry scrubbing options. Spray drying uses a slurry that dries as it reacts with SO_2 in the exhaust stream. It is used commercially at a few plants burning low-sulfur coal and is being evaluated at pilot scale for retrofit on plants burning high-sulfur coal. Other dry systems now in the prototype demonstration stage inject calcium sorbents directly into the furnace or ductwork downstream of the furnace. The most promising retrofit option for reducing NO_x emissions is modification of the burners to mix fuel and air more gradually, reduce flame temperature, and stage combustion so as to minimize oxidation of nitrogen in the fuel. EPRI is funding several low-NO_x burner retrofit demonstrations and is investigating a postcombustion NO_x control technology called selective catalytic reduction. SCR uses ammonia and a catalyst to remove NO_x from flue gases.



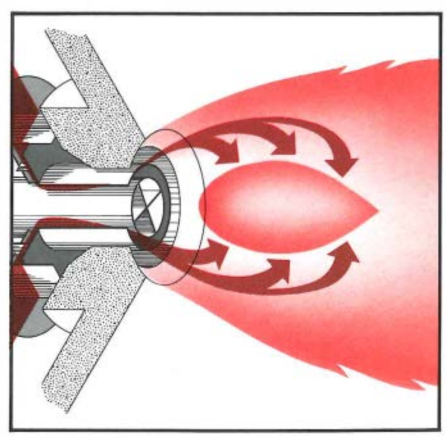
High-Sulfur Test Center

Wet scrubber

Dry sorbent injection

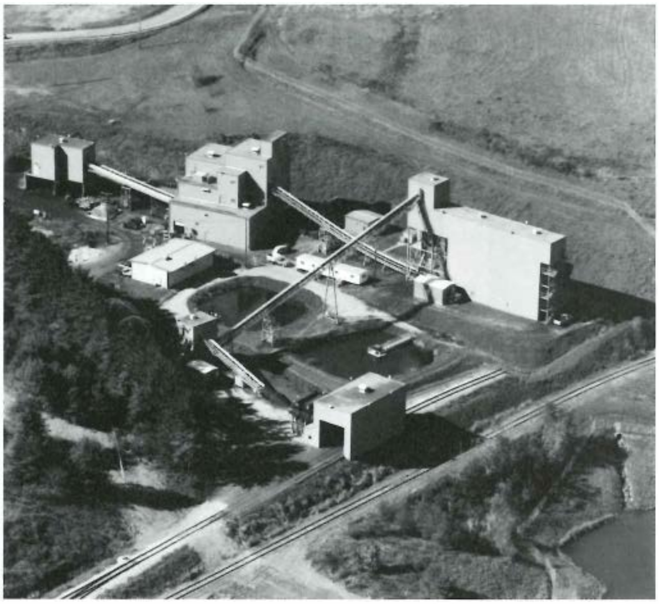
Spray dryer

Low-NO_x burner

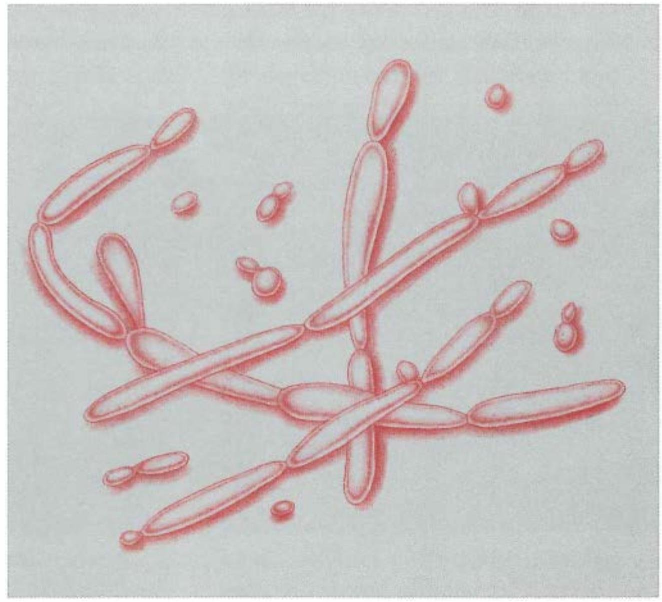


Coal Cleaning

About 40% of the coal used by utilities today is cleaned through physical separation processes that remove some of the sulfur and ash-forming impurities. EPRI's Coal Quality Development Center is developing improved physical coal cleaning methods and documenting the effectiveness of cleaning for the major steam coals. In the past few years, dramatic advances have been made in the experimental use of bacteria and chemical solvents for extracting the molecularly bound sulfur that physical cleaning cannot remove. If cleaning can remove enough sulfur in a cost-effective way, it may reduce or eliminate the need for certain emission control technologies.



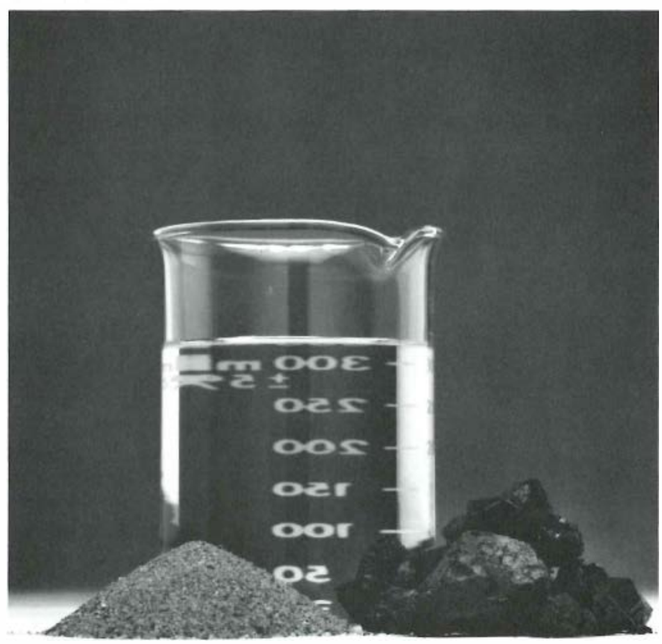
Coal Quality Development Center



Biologic cleaning

Physical cleaning

Chemical cleaning



heat rate of new plants 15–20%, incorporating more-durable materials, and integrating the most advanced environmental control technology, the improved pulverized-coal plant will offer a clean, reliable, and highly efficient option for utilities that are considering new capacity," says Tony Armor, who manages the Fossil Fuel Plant Performance Program. State-of-the-art diagnostics and monitoring equipment will enable plant operators to keep facilities fine-tuned for optimal performance under varying conditions. For instance, on-line measurement of key coal constituents, such as carbon, sulfur, and moisture, will allow the boiler and environmental control system to be adjusted for compliance with emissions limits and for maximum plant efficiency and availability. And newly emerging adaptive controls will enable plants to be cycled safely and reliably with minimal wear on equipment by keeping a close watch on boiler and turbine temperatures and stresses.

"These kinds of developments that harness the microprocessor revolution to power plant instrumentation and control are the mortar that will hold the building blocks of clean coal technology together," says Yeager. "The ability to monitor and fine-tune plant processes is critical to realizing the full potential of advanced technologies."

While the improved pulverized-coal program focuses on familiar technology, the work in FBC is breaking new ground in an area that was only conceived of for coal utilization within the last 20 years. FBC's greatest advantages are its fuel flexibility and its ability to deal with combustion pollutants right where they are formed—in the furnace. Coal and limestone are floated and mixed in the furnace by jets of air, creating a combustible fluidized bed. As the coal burns, the limestone particles react with sulfur impurities and are removed as a dry waste product. FBC units are capable of removing up to 95% of the coal's sulfur without the need for a scrubber.

Because FBC systems operate at relatively low temperatures (1500–1600°F) their NO_x emissions are also low. Pilot tests have shown that FBC boilers typically emit about half the NO_x allowed under EPA standards and that with staged firing, emissions can be reduced even further.

FBC technology has advanced over the past 15 years from pilot-scale facilities to more than 70 industrial applications in the United States alone, burning a variety of fuels, from cow manure and tree bark to coal and oil shale. EPRI has been active in the scale-up of coal-burning units, starting with 2- and 20-MW pilot plants and moving on to several commercial utility demonstrations in the range of 100–200 MW.

The first large-scale utility application came at Northern States Power's Black Dog station. There, a 30-year-old, 100-MW pulverized-coal boiler was converted by Foster-Wheeler to bubbling-bed atmospheric FBC operation. The new system was started up in 1986 and is meeting NSPS for both SO_2 and NO_x while burning low-grade subbituminous coal. Ultimately, the plant is expected to generate 25 MW more than the original unit and to operate for an additional 25 years.

Montana-Dakota Utilities has followed a similar course by converting its 75-MW lignite-fueled Heskett No. 2 unit from stoker firing to atmospheric pressure FBC in the spring of 1987. Before conversion, the unit suffered from slagging problems because of the high sodium content of the Beulah lignite being fired and was operating at capacities as low as 50 MW. Since the conversion by Babcock & Wilcox, the Heskett unit has run consistently at 66-MW capacity and is expected to achieve nameplate rating of 75 MW by May of 1988.

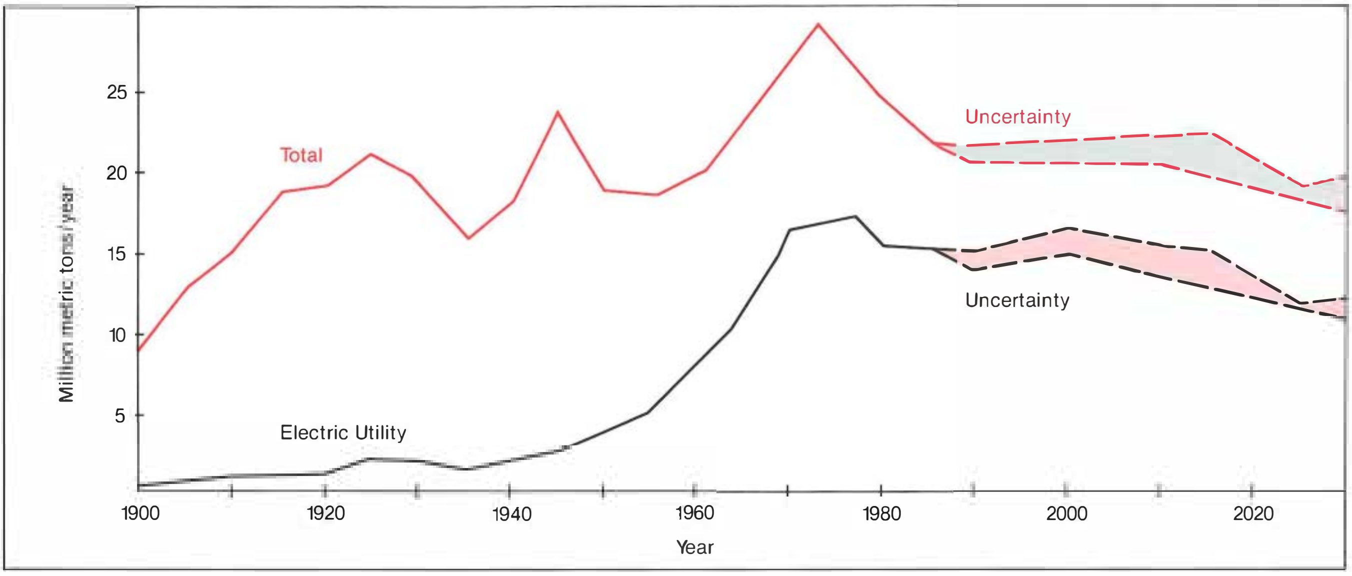
Other utility applications of FBC include the Colorado-Ute Association's 110-MW circulating FBC demonstration unit (using a European design provided by Pyropower) at its 25-year-old Nucla plant and the new 160-MW Combustion Engineering FBC demonstration boiler the Tennessee Valley Authority, Duke Power, and a number of cosponsors (including EPRI) are building at the Shawnee steam plant. "The fact that these demonstrations have been funded by the private sector indicates that the industry is serious about developing new clean coal options," comments Kurt Yeager.

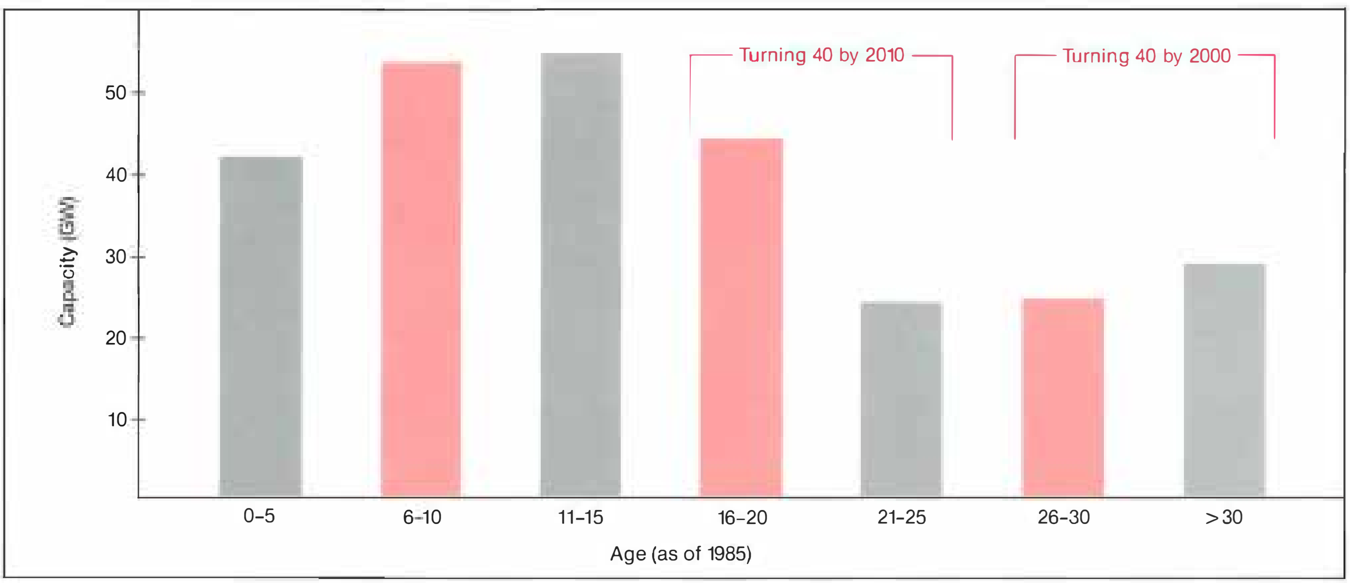
EPRI believes that at least 20,000 MW of aging coal plants are potential first-generation candidates for FBC retrofits and repowerings like those conducted at the Black Dog and Heskett stations as utilities look for ways to extend the life and increase the power output of existing facilities, and at the same time improving environmental performance. EPRI is also working to understand the environmental character and the potential for commercial recovery and use of the by-products generated by FBC.

FBC is not limited to retrofit application. The fact that the technology can be built in a range of smaller unit sizes without sacrificing the economy of scale of large plants makes it potentially attractive to utilities that want to meet uncertain demand growth with small increments of new capacity. Because they can be shop-fabricated and shipped to the plant site, pressurized-FBC units can significantly reduce construction time. These are important criteria for utilities trying to minimize cost and risk. American Electric Power (with support from the state of Ohio and the U.S. Department of Energy) is repowering the 35-year-old 80-MW unit at its Tidd station with a pressurized-FBC–combined-cycle system employing Swedish technology. The unit will be almost entirely shop-fabricated by

SO_2 Emissions Expected to Continue Decline

Sulfur dioxide emissions grew early in the century, peaked in the mid 1970s, and have been declining steadily since passage of the Clean Air Act. As a result, SO_2 emissions today are about 25% lower than in the mid 1970s, although coal use has increased by 70%. Projections of future emissions vary with assumptions about electric demand growth, plant lifetimes, fuel sulfur levels, and technologic changes. On the basis of current and projected industry trends, most analyses foresee an overall decline in SO_2 emissions over the next 30 years.





Coal Fleet Age Profile

Much of the debate over acid rain and clean coal legislation centers on the question of whether older (pre-1970s) coal-fired power plants, which are not covered by federal clean air standards, should be retrofit with additional emission controls or whether resources should be concentrated on developing and demonstrating new clean coal technologies. Depending on the rate of plant retirement, up to 54,000 MW of coal-fired capacity will become 40 years old between now and the end of the century, and another 68,000 MW may reach 40 between 2000 and 2010.

Babcock & Wilcox and then shipped to the plant site by barge.

Moving toward coal refineries

Fundamentally different in a technologic sense from FBC but sharing the attributes of modularity and superior environmental performance, integrated gasification–combined cycle is a third important and complementary option for new coal-based generating capacity. An IGCC plant consists of four basic elements: a gasifier that reacts coal with oxygen and perhaps steam to produce a mixture of combustible gases, a particulate and sulfur removal system to produce a clean-burning fuel gas (syngas), a combustion turbine that burns the syngas to produce electricity, and a steam turbine powered by waste heat from the combustion turbine and the gasifier.

IGCC systems evolved from coal gasification technology that was popular before and during World War II but fell out of favor in the postwar period because low-cost oil and natural gas were readily available. Utility interest in gasification was renewed in the 1970s because it offered a clean way to burn coal without scrubbers. That potential has been borne out in the 100-MW Cool Water IGCC plant near Barstow, California—the world's cleanest coal-fired power facility. Even when burning high-sulfur coal, Cool Water easily meets the most stringent government standards for SO_2, NO_x, and particulates. And the slag that the plant generates as solid waste has been judged nonhazardous under a very rigorous test conducted by the California Department of Health.

The Cool Water plant has operated for over 18,000 hours since June 1984 and in the past year achieved a 65% capacity factor. On the basis of the Cool Water experience, Potomac Electric Power Co. (Pepco) is in the licensing stage of a 750-MW, two-unit combined-cycle plant at its Dickenson site in Maryland. The Pepco project will capitalize on one of combined cycle's main advantages: it can be built in phases, as conditions warrant. A utility can install gas turbines for peaking capacity, then add steam bottoming cycles as the need for baseload power grows. If natural gas or distillate prices rise, the utility can then build a gasifier (or buy syngas from a third-party-operated gasifier). This approach minimizes capital risk and enables the utility to expand capacity in increments as demand warrants.

"IGCC represents more than a technologic change in power plant engineering—it provides the basis for a fundamental change in electric utility planning," comments Dwain Spencer, vice president for the Advanced Power Systems Division. Fossil-fuel-fired power plants have traditionally been conceptually simple mechanical systems—fuel burns in a boiler to make steam that turns a steam turbine generator. But with IGCC, utilities have entered the world of chemical engineering, where coal is processed into many useful products in addition to electricity.

True to this vision, Cool Water is converting the problematic sulfur found in its fuel into a marketable product—99.9% pure elemental sulfur that is being sold for approximately $100 a ton. The coarse, sandlike slag is being tested for use in road construction and other bulk applications. Plans for future IGCC facilities envision the production—in addition to electricity—of various liquid fuels and chemical feedstocks, from methanol to ammonia.

In addition to the diverse capabilities of IGCC, utilities are looking at other ways to generate marketable coproducts. For instance, as the supply of strategic metals becomes increasingly problematic because of conflicts in South Africa and other regions, mineral industries are starting to look seriously at mining utility fly ash. EPRI has already funded an engineering design study for a fly ash processing plant, which would extract valuable metals, including aluminum, iron, silver, titanium, and gallium, leaving behind inert sandlike grit for use in building products, roads, and the like.

"Clean coal technology means more than controlling the airborne emissions that cause acid rain," says Yeager. "It means developing systems that extract in a commercially competitive manner the greatest possible value from coal, while producing virtually no wastes of any kind. Essentially, we are moving toward coal refineries in which power generation becomes one element of a broader, integrated resource-processing capability.

"We have to move down this road but we also have to realize that clean coal isn't the end of the line. It's a transition, really, that we'll need to get us through to even cleaner, more-sustainable energy sources. We can do it, but it will take a strategic commitment on the part of the nation, and really the whole world, to get the job done in an economically and environmentally productive manner by using the technologic tools at our disposal. The environmental and economic opportunities that result are tremendous." ■

Further reading

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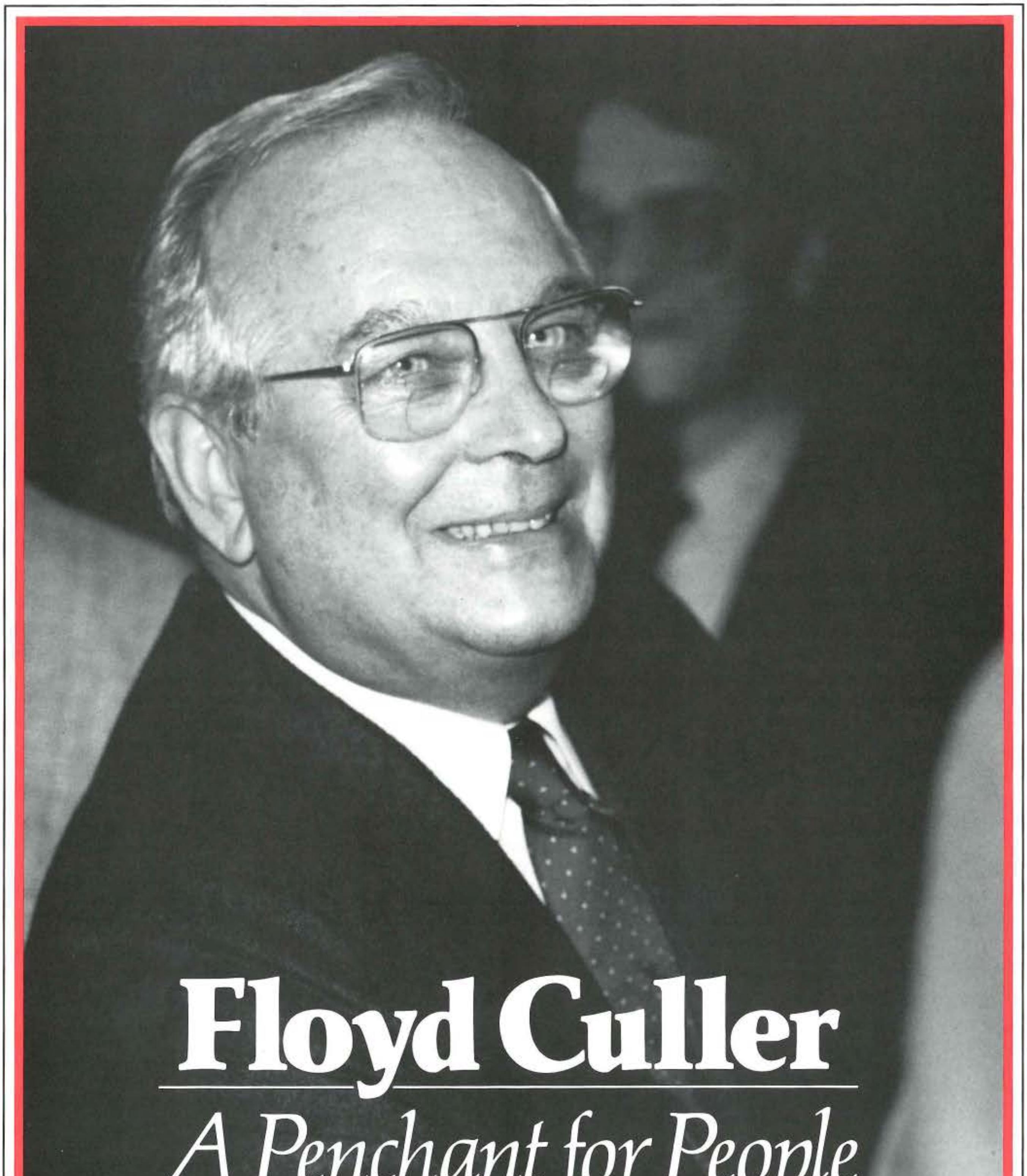
This article was written by Michael Shepard. Technical background information was provided by Kurt Yeager, Coal Combustion Systems Division. Additional support was provided by staff of the Coal Combustion Systems and Advanced Power Systems divisions.


Floyd Culler
A Penchant for People

Floyd Culler retired as EPRI's president in January, ending his administration but not his involvement with energy—especially not with electricity. During 10 years of leadership he emphasized the application of EPRI research results: near-term technical fixes for utilities, full-scale system demonstrations, new and better technologies for electricity end use, and many initiatives to speed the adoption of EPRI's output by its member utilities.

Now Culler's successor, former Executive Vice President Richard Balzhiser, is building on that legacy of R&D service, and Culler himself is turning again to the generation of ideas. "I'm going to explore those pieces of science where there are opportunities to add to EPRI's new exploratory program and to replenish the science on which future electricity technology will be based."

One thing is certain. As he turns over each of those pieces, cataloging the ideas they represent, he'll be exercising a unique gift for synthesis. That gift has been one half of Culler's skill as an R&D executive. The other half has been his personal warmth, a quality that pervades the comments of past and present staff members, as well as of colleagues and advisers from EPRI's member utilities.

Balzhiser points out that these characteristics are combined in Culler's inspirational leadership style. "Floyd is a people person. If there's anything I've learned in my association with him, it's his sensitivity to people. And there's little in science that he hasn't been exposed to, so he's quick to apply his knowledge to the problem at hand, synthesizing new opportunities or directions for others to consider."

As it turned out, such flexibility of mind was vital for the times. Culler's years as EPRI's president were marked by shifts in its R&D agenda and austerity in its budgets. He instituted changes in forthright response to difficult business circumstances for utilities and to increasingly tough technical requirements. As onetime EPRI Chairman Floyd Lewis phrases it, "Not only has EPRI been able to continue an R&D program during a period of fiscal constraint, but Floyd made that program something worth supporting."

Again, his personal touch often made the difference in consolidating support for EPRI and its work. Milton Klein, EPRI's vice president for industry relations and information services, says, "Floyd brought the Institute much closer to its members—developing relationships and strengthening them by his personal involvement. And he reached out effectively to many other constituencies that impinge on EPRI and the utility industry."

Ric Rudman, Klein's predecessor and now president of a technical publishing company, sees that personal diplomacy as a survival skill for EPRI. "He kept the wheels from falling off. He bolstered the R&D resolve of many utilities at a time when technology didn't seem an important institutional concern."

EPRI's president is retiring after 10 years of dedicated and inspiring direction. With a talent for catalyzing people as well as ideas, he brought the Institute to its members and new technologies to commercialization.

Bob Bell of Consolidated Edison points to the maturation of EPRI's advisory groups during Culler's tenure and to the professional growth of EPRI's staff. Bell was a member of the industry goals task force whose 1971 report led to EPRI's establishment, served on the Research Advisory Committee thereafter, and concluded that service as RAC chairman at the end of 1987. He traces the changes in EPRI to Culler's inspirational style. "He's turned on by his vision of the electric utility industry—the configuration of our next-generation plants, the future of nuclear power, the ability of EPRI to anticipate change in the industry and continue to be vital to it."

Building content and style

Culler's leadership at EPRI had its roots in his earlier technical and management experience with nuclear power technology. He spent a total of 34 years at Oak Ridge, Tennessee, first with a wartime Manhattan Project contractor on the design and construction of nuclear fuel processing facilities and thereafter with Oak Ridge National Laboratory, particularly in work on the nuclear fuel cycle, reactor research, and radioactive waste management.

A design engineer when he began at ORNL in 1947, Culler became director of the Chemical Technology Division 6 years later at the age of 30. He held the position for 12 years, then was named assistant laboratory director for nuclear technology in 1965. Five years later, Alvin Weinberg, the longtime director of ORNL, picked Culler as his deputy director. Culler continued in that post until he joined EPRI, working for both Weinberg and his successor, Herman Postma, and during 1973 serving as acting director of ORNL.

Culler himself looks to the late 1950s as the time when he first grappled seriously with what would become his R&D management style. "I got out of my construction period, where I ran things like a construction and design manager, when I realized that an executive isn't better than any other participant in the intellectual exchange of ideas. You try to be an executive in a research and development setting," he says almost excitedly, "and you're going to bomb out!"

Moving the intellectual direction of things has to be handled in a more subtle way, according to Culler. He values the ability to synthesize, that is, to assemble ideas in a possible solution, or just point them toward a solution. "The introduction of ideas is so important. In the long run, our whole R&D trade is ideas—ideas that become substance, and substance that moves and does things."

Culler's range of interests, the stuff of synthesis, strikes nearly everyone. Merrill Eisenbud, a two-time Advisory Council member and former director of a laboratory for environmental studies at NYU Medical Center, recalls, "Floyd isn't at all hesitant about discussion in the biologic sciences. His knowledge is broad," Eisenbud says flatly, "and deep, too. He's no dilettante."

Culler himself is quick to mention biology. "If I were starting over, I'd be a molecular biologist," he says, and the student's excitement takes over as he recalls technology crossover teams organized at Oak Ridge in the 1950s. In part they stemmed from ORNL's (and Culler's) pioneering work in chemical separations, which led to his expansive suggestion at the time, that "we could separate anything from anything, including the big macromolecules—things like RNA, amino acids, and such." Small wonder that genetic engineering, unheard of then, easily captures his fancy today.

But beyond the discrete appeals of many individual scientific domains, even beyond the occasional opportunities for synthesis they present, the universals of scientific endeavor beckon to Culler. Jack Pfister says this is what made his work with Culler memorable. "We have a common interest in philosophy, especially the philosophy of science and technology." Pfister, general manager of the Salt River Project, was EPRI's Board chairman a few years ago, as well as chairman of a task force that evaluated EPRI's effectiveness. "I worked very closely with Floyd then. It was one of the better professional relationships I've known in our industry."

EPRI staff members were most frequently exposed to Culler's surprising intellectual range in the context of program reviews that brought him together with each EPRI technical division. Chauncey Starr, EPRI's founding president, recalls the way Culler posed questions, framing them not only to learn what was being done but also to find soft spots as a basis for policy reinforcement and guidance. Starr points out that Culler's encyclopedic mind alone wasn't sufficient. "You need enough knowledge to open up the topic," Starr explains from personal experience, "but you must ask about what you don't know. Floyd pushed, he explored—sometimes dead-end alleys, sometimes opening something. But he wasn't afraid to present what might be unsound thoughts of his own. If he had been afraid, he wouldn't have made a contribution."

Serving up R&D in a real world

Culler's mind and style draw hearty affirmations from everyone who has worked with him. Perceptions of his specific accomplishments as EPRI president are more varied, depending on the vantage point of the observer and the frequency of contact. Still, there are pointers to be found among the different actions that draw comment.

In fact, much of Culler's accomplishment *was* his style. Certainly, that was an essential element of his success in holding and ultimately building EPRI membership in the 1980s. But Jack Pfister traces that success, as does Floyd Lewis, partly to another accomplishment: Culler's conscientious reprogramming of the Institute's R&D to acknowledge a plateau in utility fortunes.

EPRI's response after Three Mile Island was an unprecedented turn of research capability into needed real-time service, especially, says Merrill Eisenbud, the establishment of the Nuclear Safety Analysis Center. Crediting Culler's understanding of nuclear issues, Pfister also remarks on his thoughtful, knowledgeable guidance of NSAC "in that very dark time for nuclear utilities."

Floyd Lewis speaks of technology transfer, of Culler's identifying it as a key

need and working to help utilities put research results into practice. This was another instance of outreach, taking R&D into the community. "You'd think utilities would be waiting with bated breath to use new technology, but it doesn't work out that way," Lewis concludes. "Floyd saw the reality and he dealt with it."

Charles Hitch, emeritus president of the University of California and another past member of the Advisory Council, was an early advocate of energy demand-side and end-use research at a time when much industry advisory wisdom still tilted to power generation and other supply-side technologies. Hitch measures Culler's accomplishment primarily mainly in behavioral terms—"how open he was in taking ideas from the Council, such as our recommendation to increase the end-use research allocation, as well as in briefing us on EPRI's work."

End-use R&D marks an outreach beyond electric utilities themselves, a move to carry technology all the way to electricity users. But even more important in EPRI's newly outgoing push for technology application under Floyd Culler was technology demonstration, showcasing and proving completed products and

systems of every size in on-line utility use.

Demonstration projects were a major accomplishment in Culler's own assessment. They were a task he set for himself at the beginning, saying in 1978, "We must convert our technology to practical use and our processes to production. We must get on with the industrialization of technology. The big question will be how and when to fund large pioneer and demonstration plants."

This was a point on which Chauncey Starr didn't agree at the time. "I objected that their cost could detract from our primary research responsibility. Floyd thought that if we didn't bring our results to the demonstration stage, then the industry couldn't grasp their full value. I was wrong and he was right."

Culler set a pattern early in his term, using funds EPRI had accumulated, as well as contributions and in-kind services of cosponsors and coparticipants. "I think we've built most of the systems that were candidates at the time, plus even a few more. We've implemented about two dozen, by my count."

EPRI came of age as a result, Culler feels. "We were able to carry through with technology that seemed promising. We've become the focal point for cooperative work that leads to demonstrations, more so than anyone in the business." In a more generalized comment that encompasses all the Institute's R&D areas, Culler adds emphatically, "We're better positioned than any organization in the United States to transfer our technology to the people who sponsor us."

A barrel of new science

The future holds more of the same, but with several twists. Looking over his shoulder at EPRI, but at the same time looking ahead toward the Institute's future, Culler has some predictions of his own.

"Until there are some number of the new-technology plants in existence, EPRI must go beyond the demonstration stage and become a partner with the utilities who use them. EPRI must think about helping to train operators and maintenance workers for systems that are quite different—in effect, big chemical plants."

Culler describes such work as "a lengthened attention span for EPRI, not as a matter of choice but as a matter of necessity, because we are standing in the breach, where no one else happens to be."

For himself, Culler sees another kind of future. Referring again to the technologies being demonstrated and readied for commercial use today, he elaborates on his own plans. "We're finishing off the science we started with, the science of the 1930s, 40s, and 50s. I'm going to work along with the people doing EPRI's exploratory research. There are pieces of new science in laboratories around the United States that we should pay attention to. I want to help replenish the barrel."

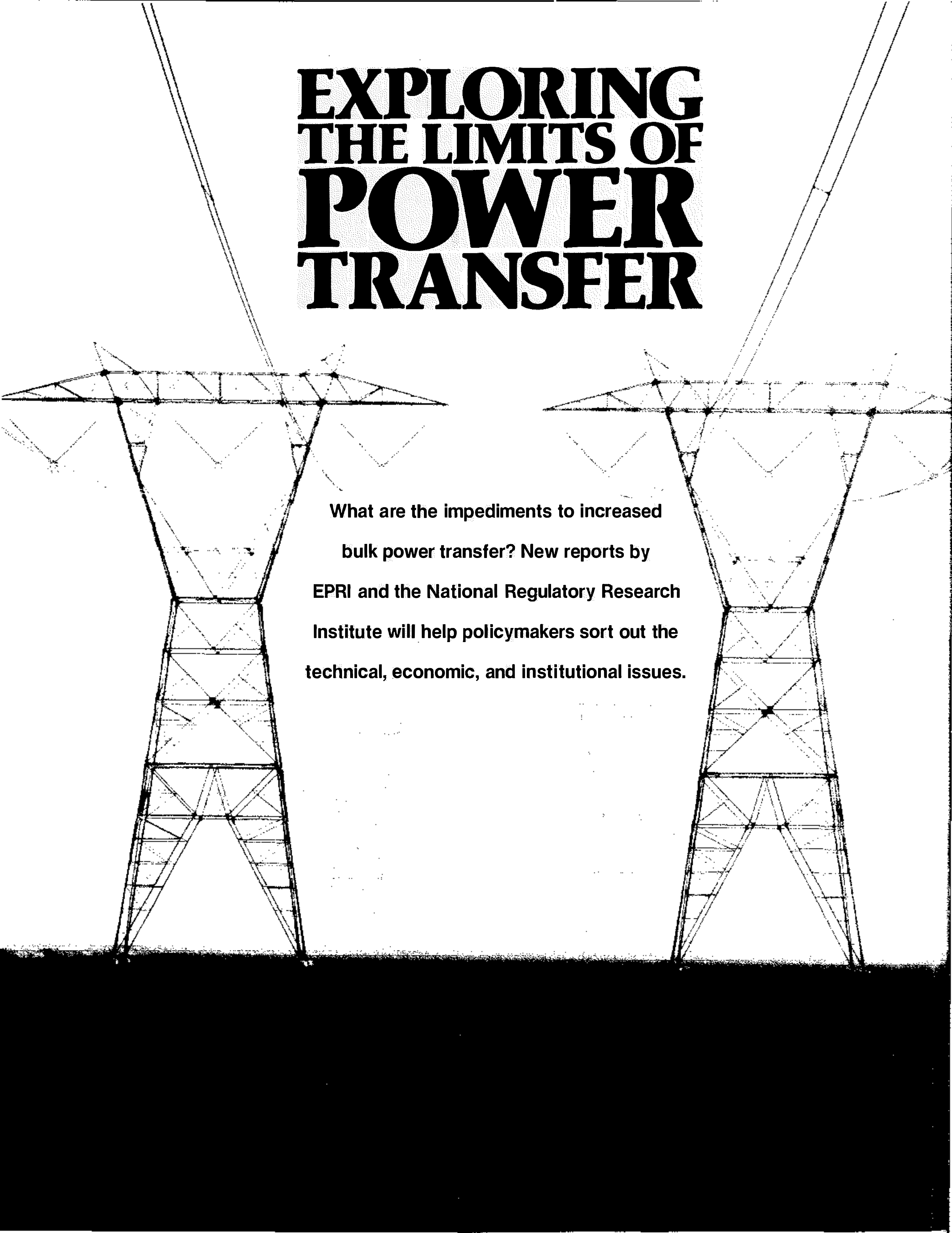
Now an EPRI president emeritus, Culler has only an EPRI consulting agreement to define his role. But as to his purpose, he adds, "I may also begin to think more about the revolution that will occur in the electricity industry in the next 30 to 40 years. It's really an evolutionary sequence that is already beginning with fuel cells and photovoltaic power—our escape from the Carnot trap of thermal cycles."

Clearly, the ideas are still flowing and the synthesis is taking place. As Charles Hitch says, "I can't imagine Floyd being idle. He's easy to turn on, he has such an interest in things. And for the same reason, I guess you'd say he's hard to turn off."

Dave Saxe, who served both Chauncey Starr and Floyd Culler as EPRI's vice president for finance and operations, says it a little differently. "Innovative ideas, scientific advances, and technical accomplishment all turn Floyd on. I guess the opposite turns him off. He doesn't want to hear that something can't be done when it hasn't been tried. He's positive in his approach; he's turned off by negativism."

Milt Klein returns to the quintessential in Culler. "People. Not just science. People turn Floyd on. He's always looking to see if he can help someone do better." And David White of MIT's Energy Laboratory, recently on EPRI's Advisory Council, concludes, "I don't know what turns him off. He hides that well. You're going to miss him." ■

This article was written by Ralph Whitaker, *Journal* feature editor, and is based on conversations with Floyd Culler and many of his former associates.



EXPLORING THE LIMITS OF POWER TRANSFER

What are the impediments to increased bulk power transfer? New reports by EPRI and the National Regulatory Research Institute will help policymakers sort out the technical, economic, and institutional issues.

At any given moment, on average, slightly more than 40% of the electricity flowing from the generators of major utilities in the United States is sold to other utilities. Such bulk power transfers may be wholesale transactions for resale or short-term economy exchanges that permit utilities to take advantage of lower-cost production at neighboring or nearby utilities. A growing number of these transactions now involve wheeling—the transfer of power from buyer to seller through the high-voltage transmission lines of one or more intervening systems.

Some 3500 entities (private and public utilities, government power authorities, cogenerators, and independent producers) sell electricity in this country, yet virtually all power that flows on transmission lines is scheduled and coordinated by dispatchers and system operators at about 150 control centers. With computers and automatic control equipment, operators maintain a careful balance between generation and loads, as well as ensure that the frequency of the power system will deviate little from its standard 60 cycles per second.

Growing use of the interconnected utility transmission systems for wheeling and bulk power transactions poses a host of technical, economic, and regulatory issues for an increasingly competitive industry. Nonutility generators are pressing for greater access to utility-owned transmission grids to route their power to the highest bidder. Some large industrial users are shopping for lower-cost energy beyond their local utility, yet demanding that the utility wheel the power to them over existing circuits. Capacity-short utilities look for opportunities for bulk power agreements with utilities enjoying ample reserves, often requiring agreement by intervening utilities to wheel the power for a fee.

Regulators and policymakers, meanwhile, are struggling to resolve matters of price, equity, and fairness on the assumption that power transfers ultimately serve the twin goals of increased efficiency and lower costs for everyone. Transmission-owning utilities and power system operators, on the other hand, worry about the impact on overall system stability and reliability of using power grids for purposes for which they were not designed. Add to this the changing nature of transmission technology that promises greater flexibility and control of bulk power flows, and the stage is set for transmission as a major area of policy and regulatory contention for years to come.

But the technical, economic, and regulatory dimensions of the debate have been significantly elevated and illuminated in recent studies intended to apprise regulators of the impediments to power transfers and options for reducing them. Prepared at the request of the National Association of Regulatory Utility Commissioners (NARUC), reports by EPRI and the National Regulatory Research Institute (NRRI) have laid a solid foundation for more-informed debate and decision making as transmission issues come to a head on the state and federal levels.

Focus on interconnections

Today there are an estimated 140,000 circuit-miles of alternating-current (ac) transmission lines in the lower 48 states, operating at voltages from 230 kV up to 765 kV. The majority are rated at 230 and 345 kV and are operated by investor-owned utilities. Most were built over the last 50 years to bring power from nearby or more-remote generating stations into urban load centers. Transformers at substations step down the voltage from transmission levels for local subtransmission and distribution to ultimate consumers.

With the advent of high-voltage transmission over long distances, gradually came system interconnections and the new dimension in electric service reliability they afforded. Neighboring utilities with different peak demand patterns could cooperatively share some reserve generation capacity, trading power back and forth, with each requiring less reserve capacity to meet contingencies than if each operated as an island. Moreover, through wholesale power transfers utilities could obtain greater use of existing capacity that might otherwise be idle or not operated at full production.

From the earliest days, the capability for bulk power transfers among interconnected utility systems has been constrained by both physical and institutional limits. For any transmission line at a given voltage, there is a finite maximum limit to the current-carrying capacity, above which it would overheat and sag.

Transmission lines are normally operated well below maximum limits both for safety and to provide some reserve margin for emergencies. Electrical losses from the resistance of conductors are linear and increase with greater line lengths, often requiring more generation at the selling end of a transaction than is actually needed at the buying end. Increased current loadings on a line that is already heavily loaded can result in resistance losses two to three times greater than average losses.

In addition, the electrical phenomenon of loop or parallel flows means that power on ac systems does not follow a contractual path but flows over all available paths in proportion to their impedances. This can greatly complicate a seemingly simple transaction between contiguous utilities, potentially affecting line loadings and power flows throughout a region and thus requiring notification and coordination with other utilities not party to a transaction.

Institutional limits to power transfers relate to the legal complexities of the regulated, franchised service areas in which utilities operate; issues of appropriate cost and price for transmission services and wheeled power, as well as possible discriminatory pricing; the diffuse and sometimes overlapping state and federal regulatory authority over transmission; widely varying rules and criteria among state utility commissions; and the considerable obstacles, cost, and delays that face any effort to construct new lines for increased transmission capacity.

A further institutional difficulty involving power transmission is the tendency in some quarters to view the nation's interconnected high-voltage systems as an integrated common carrier—a regulatory concept borrowed from such industries as trucking and natural gas transportation. Utilities generally and vigorously resist this notion because of the very different nature of the commodity involved, as well as the substantially greater technologic complexity in power transmission.

But in an era in which deregulation of economic markets is politically popular, some analysts note that many transmission lines are not operated at maximum capability and argue for regulatory treatment of transmission as a market-clearing mechanism, tending to equalize costs between buyers and sellers. Such a view assumes that power flows as intended, all parties gain equally from a transaction, and line losses are fully accounted for—none of which usually applies in power transactions.

Nevertheless, individual states and their utility commissions, as well as federal authorities and members of Congress, believe there remains significant potential for broad economic benefits from increased power transfers. Some states with ample generating capacity or fuel resources would like to export power to other states. Some states view the construction and financing of new generating capacity as a less desirable and more costly option than using transmission lines to bring in the power from somewhere else. Still others want to encourage more independent power production and view access to regulated utilities' transmission lines as a barrier to increased competition.

Reflecting these concerns and competing interests, state commissioners, through NARUC, asked EPRI and NRRI in 1985 to address the technical and nontechnical impediments to power transfers. Andrew Varley, chairman of the Iowa State Commerce Commission and head of NARUC's electricity committee, posed four basic questions: Is the best use being made of the existing transmission system? What and where are the physical constraints on the system? To what extent could an integrated direct-current (dc) system economically improve transmission capabilities? And what is a proper pricing mechanism for wheeling power?

Wheeling economics

NRRI undertook two studies to address the questions facing utility regulators. The first, published last August, examined the economics of power transmission. It applied tests of classical market economics to identify the theoretically most-efficient approach for setting prices that properly signal the aggregate economic cost of increased wheeling. A second, broader analysis that integrated nontechnical impediments to power transfers (economic, regulatory, legal, and institutional) within a policy context followed in September.

NRRI's economics study, in addition to extensive grounding in the dollars and cents of transmission costs and pricing, provides an insightful tutorial on the technology and operation of the interconnected high-voltage network. The institute, based in Columbus, Ohio, drew heavily from the electrical engineering perspective to explain the essential elements and effects of bulk power transactions, which are rarely confined to just buyers, sellers, and wheelers because of the physical nature of electricity. It sought to identify the principles of rate-setting that would encourage economically good decision making (i.e., transactions that further the equalization of marginal costs across the transmission grid and the economically optimal expansion of transmission capacity over time).

The analysis contrasts conventional transmission cost determination and pricing methodology based on the average or historical embedded cost of transmission facilities (sometimes coupled with a regulator-approved revenue requirement) with the more contemporary concept of marginal cost pricing. The latter approach is widely considered to more accurately reflect both the short-run and long-run incremental cost of additional power transfers to all parties affected by a transaction. It incorporates a wheeler's lost-opportunity costs (the costs of other possible transactions forgone because of the wheeling).

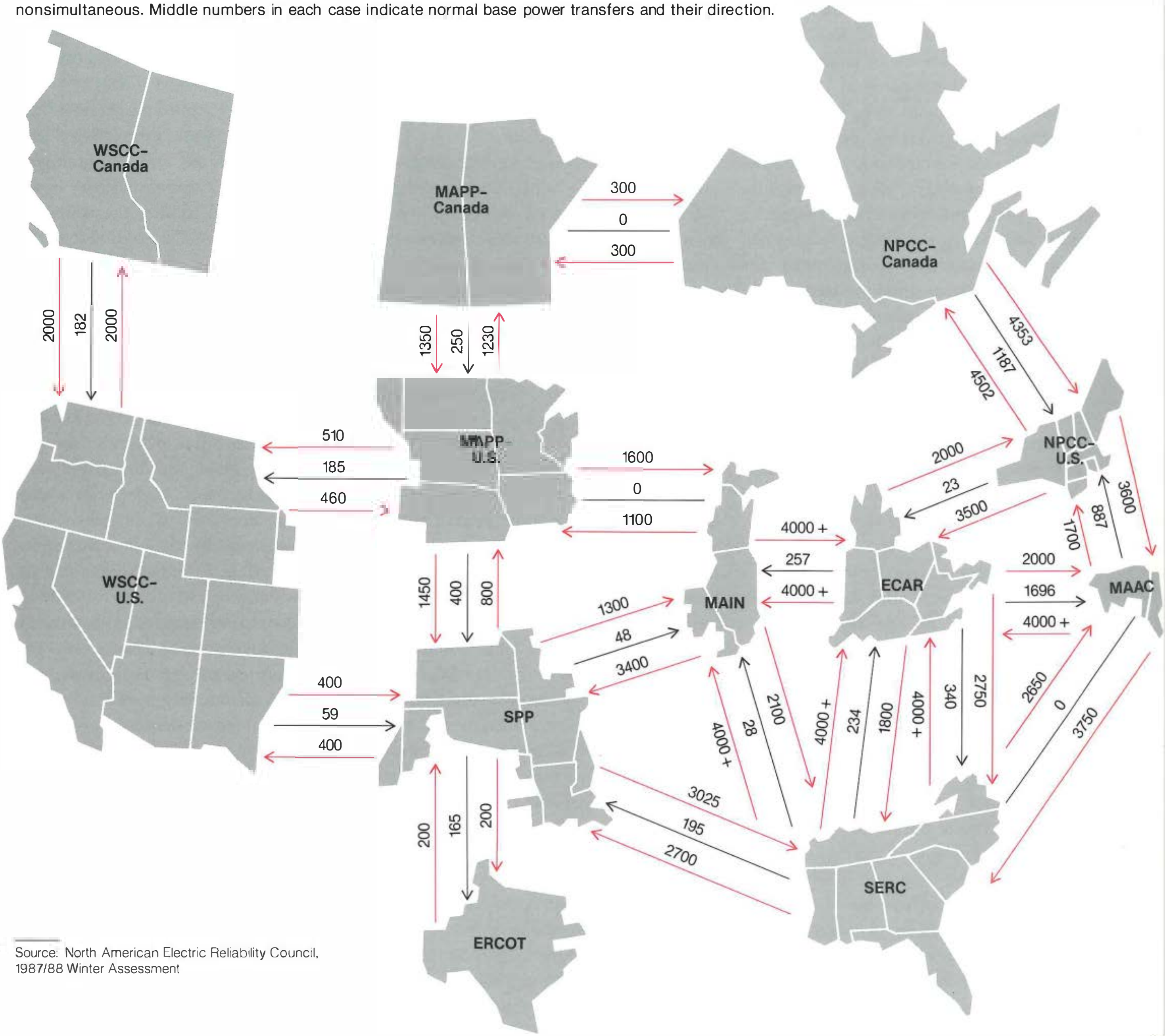
In most cases, marginal costs are higher than historical embedded costs because they properly signal to all parties to a transaction the cost of increasing transmission capacity to handle increased transfers. Short-run marginal costs, essentially the cost of moving a kilowatthour from one point in the network to another, including the cost of losses along the way, should theoretically provide the proper signals to users of transmission service, rising and falling as congestion or loading of the tie lines of interest in a transaction increases or decreases over several decades of cyclical system expansion.

But setting wheeling prices at short-run marginal costs may not achieve the equalization of long-run bulk power supply costs across the grid, for several reasons. Users may not correctly anticipate short-run price fluctuations, thus making incorrect economic choices. Customers may be averse to the financial risks of such a strategy or find that the added cost of continually competing for transmission capacity in a short-term interruptible market affects their investment decisions. Moreover, the transmission system may not be optimally configured over time because of a variety of other factors.

Alternatively, notes NRRI, prices based

Regional Power Transfer Capabilities

Available interconnected transmission capacity constrains the amount of power that can be transferred among regions in a reliable manner. Data reported by United States and Canadian utilities to the North American Electric Reliability Council indicate representative incremental power transfer capabilities in megawatts for the present winter season. In most cases, these values represent the amount above normal base power transfers that could be transmitted. Some values, however, represent the total amount of power that could be reliably transferred. Values in opposing directions are nonsimultaneous. Middle numbers in each case indicate normal base power transfers and their direction.



Source: North American Electric Reliability Council, 1987/88 Winter Assessment

Legend of regional councils:

ECAR—East Central Area Reliability Coordination Agreement

ERCOT—Electric Reliability Council of Texas

MAAC—Mid-Atlantic Area Council

MAIN—Mid-America Interconnected Network

MAPP—Midcontinent Area Power Pool

NPCC—Northeast Power Coordinating Council

SERC—Southeastern Electric Reliability Council

SPP—Southwestern Power Pool

WSCC—Western Systems Coordinating Council on the long-run marginal cost of transmission "encourage customers to compare correctly the total costs of various long-term energy supply alternatives and hence to make good investment decisions and long-run contractual commitments," though they may distort good decision making in the optimal near-term use of network facilities.

Thus, "the best practical cost-based pricing policy appears to be to divide the wheeling market, setting price equal to short-run cost for customers seeking energy economy and for customers willing to risk price variation in hope of greater gain, and setting price equal to long-run cost for customers facing major investment decisions and long-term power supply decisions," concludes the NRRI study. "Customers would decide for themselves into which category they fall on the basis of the service reliability level they require. Firm service would be priced at long-run cost, interruptible service would be priced at short-run cost, and customers would have the option of selecting either type of service."

Several issues stand in the way of implementing such a pricing policy, as the regulatory research group notes, such as determining a fair division of the gains from correctly priced transactions. Or, regulatory revenue requirements could constrain good decision making by requiring utilities, under today's costs, to wheel at a price below long-run cost, which not only fails to send the proper price signal but also fails to give a positive share of the gains to the wheeling utility. Moreover, calculation of cost-based wheeling rates is complicated by the loop flow phenomenon, requiring detailed and expensive computer load flow analyses of all potential transactions to obtain the sum of the costs of flows over all affected paths.

Summarizing the economic perspective on wheeling, the NRRI report concludes: "Pricing policy for the wheeling of electricity is best viewed within the context of how to optimally use and expand the nation's bulk power supply systems. An institutional difficulty is that [high-voltage transmission service] pricing policy is largely under federal control, and system expansion policy is under state control. This suggests that more federal-state cooperation is advisable, perhaps through a joint board of federal and state regulators, to fashion a coherent wheeling policy.

"Wheeling is one of several kinds of interutility transactions that can reduce the aggregate cost of delivering electricity to widely dispersed customers. Toward this end, all such transactions, including wheeling, should be priced so as to promote the equalization of both short-run and long-run marginal costs across the grid because, in such a condition, aggregate total supply costs are minimized.

"Such an equalization requires prices that are not distorted by embedded-cost revenue requirements, preference power allocations, cogeneration pricing rules, or arrangements that ignore loop flows through unaffiliated transmission systems. Prices based on incremental costs accomplish the equalization. Important implementation issues remain, but they should not obscure the basic point that to promote marginal electricity cost equalization across the grid and thereby supply the nation's electricity at least cost, the movement of power itself must be priced at marginal cost."

Nontechnical impediments

In a wide-ranging follow-on to its economic analysis, NRRI commissioned consultants to detail the four broad categories of nontechnical impediments to power transfers (institutional, legal, regulatory, and economic), as well as several recent case studies in which bulk power transfers have been impeded.

Perhaps the most important institutional impediment stems from the highly diverse structure of ownership and organization in an industry in which competition is on the rise. Noting the very large number of electric utilities of various sizes and degrees of integration, plus the growing ranks of industrial cogenerators and small power producers, the NRRI study points out that most utilities have an exclusive franchise from government to provide monopoly service to customers in a specified territory.

"An increase in power transfers often means more competition to serve a utility's historical retail and requirements customers. Such competition may be resisted as it tends to alter these institutional arrangements," according to Kevin Kelly, NRRI associate director, who is coauthor of the economic analysis, and editor of the nontechnical impediments survey.

Legal impediments to more power transfers relate to the limited authority of the Federal Energy Regulatory Commission (FERC) to order wheeling, as well as uncertain state authority over bulk power transactions. In recent rulings FERC has asserted sole authority over bulk power pricing, declaring that all interconnected high-voltage lines are directly or indirectly involved in interstate commerce. Other important legal barriers include federal antitrust laws and their interpretation by the courts, and other federal and state laws limiting the siting of transmission lines.

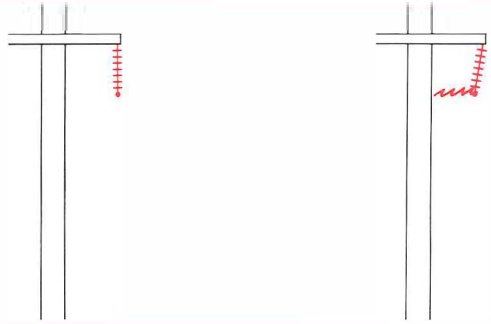
Regulatory agencies themselves can also create roadblocks to moving power, as the NRRI study notes, through burdensome filing and notification requirements. Uncertainty that even a voluntary agreement among parties for transmission service will be allowed by regulators to terminate after the contract term can also inhibit utilities' willingness to enter into such agreements. Moreover, regulatory hearing and approval procedures for new transmission lines are often used by opponents of projects to delay construction for very long times.

Incorrect pricing of transmission service is perhaps the most significant eco-

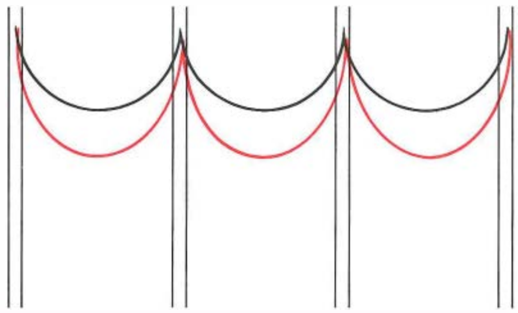
Limits to Power Transfers

The amount of power that can be transmitted over a given circuit is limited by four basic concepts governed by fundamental laws of electrical engineering.

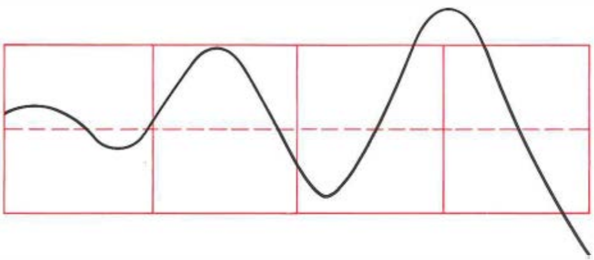
Voltage limit The potential for flashover increases when lines are uprated to higher voltage. The distance between the conductor and the tower structure must often be increased to guard against such occurrences.



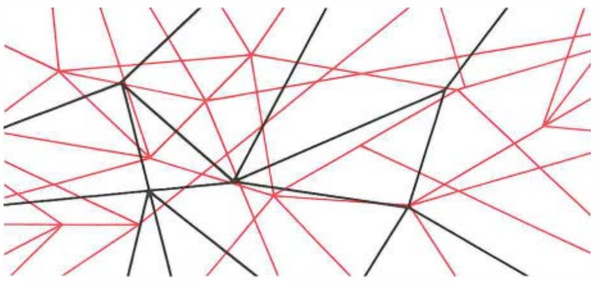
Current-temperature limit There is a maximum amount of current that can be transmitted on a circuit of given voltage before it will overheat and possibly sag below minimum clearance levels prescribed by the National Electrical Safety Code.



Stability or operating limit All generators on a transmission system must operate in synchronism to maintain proper voltage and current flow. Sudden changes in loads, or a transmission line outage, can cause the system to become unstable and prevent it from functioning normally.



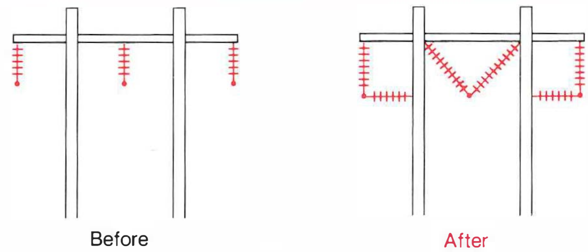
Network limit Kirchoff's Law governs how current flows over the many circuits in a large transmission network. Current will take the paths of least resistance and divide along the paths according to their individual impedances.



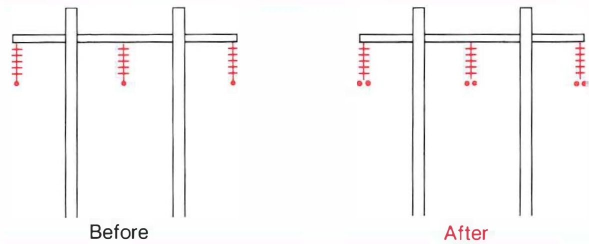
Technical Fixes to Transmission Limits

Technical recourses are available for boosting power transfer limits, but they, too, are constrained by the laws of electricity. Some approaches are routinely used by utilities to increase transmission capability, while others require further research to develop or demonstrate.

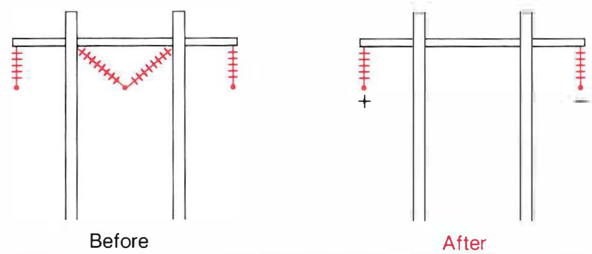
Voltage uprating To protect against flashover when existing circuits are uprated, insulator strings are generally lengthened and bracing insulators added to keep the conductors from swinging close to the tower.



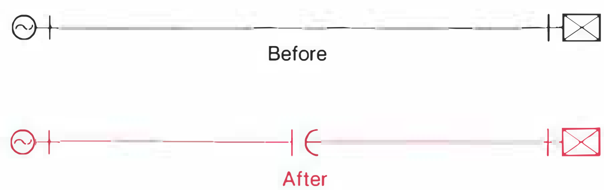
Conductor bundling Single-conductor circuits can be upgraded by adding conductors to form a bundle. Towers may also require reinforcement.



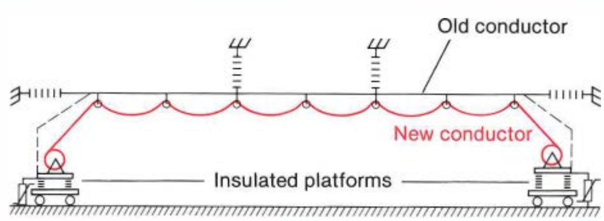
Conversion to dc Typical ac circuits can be converted to dc circuits for major gains in transfer capability using existing conductors but would require terminal equipment to change ac to dc.



Series capacitors The addition of series capacitors at transmission substations can improve the dynamic stability of a circuit (or transmission line) by negating the effect of the impedance that would normally limit transfer capability.



Live-line uprating Often conductors in strategic circuits that can not be taken out of service for uprating conceivably could be replaced with higher-rated conductors using live-line construction techniques involving insulated platforms and equipment. Though explored, this practice has not actually been applied and requires further R&D to develop.



nomic impediment to bulk power transfers, the NRRI study found. "Traditional ratemaking for wheeling services does not provide the economic incentives for utilities to wheel power voluntarily," it concludes. "Given the choice, utilities will not choose to transmit electric power unless transmission service is economically attractive." Uncertainties surrounding the economic aspects extend from the approach to the determination of the costs of wheeling to the setting of wheeling rates to the treatment of utility revenues and profits from transmission service.

For some real-world indications of the relative importance of various impediments, NRRI commissioned three case studies of transmission conflicts. One involves long-standing attempts by investor-owned utilities to construct a new transmission line in Maryland. Another deals with the wheeling needs of a municipal utility in Louisiana that wants to offer retail service to an industry outside the municipal service territory. A third case involves numerous attempts to obtain transmission service by a relatively new agency formed to increase the market buying power of some two dozen municipal utilities in Wisconsin.

Among conclusions drawn from the case studies are that in practice many nontechnical impediments are almost inseparable from important technical issues, including loop flows. Further, transmission access issues often involve dividing existing savings instead of creating new savings. And decisions about transmission service are often regional, affecting several states, and have to be addressed at a level appropriate to the region affected.

Overcoming technical impediments

EPRI's transmission study represents a comprehensive review of the technical limits to power transfers and the techniques used by utilities around the world to overcome or work around them. Prepared by Power Technologies, Inc., under the guidance of Frank Young, associate director of EPRI's Electrical Systems Division, the study drew from extensive surveys of utility practices, as well as the insight of an industry advisory committee.

"The study represents a broad view of both the standard and unique ways engineers have approached the problems of eliminating bottlenecks and increasing transmission capabilities where new lines cannot be built," explains Young. "Most of the resources cited for enhancing power transfer are ideas currently in use by some utility systems.

"But the study also looks ahead to research that may be needed to achieve further improvement in the industry's effective use of transmission capacity. Aspects of system planning and engineering, equipment design, and operating philosophy and procedures are covered, and hardware, software, and informational needs are identified," Young adds.

The focus of EPRI's study is on maximizing the use of transmission facilities as they exist today, although that can include adding substation equipment, modifying existing lines or replacing them within existing rights-of-way, relaxing operations criteria, and other improvements to power plants and system operation.

The study details why varying thermal limits on different lines of the same voltage often result in far-from-maximum current loadings on certain circuits. Loadings closer to thermal limits are typically found on shorter lines (50 miles or less) in relatively compact and mature systems, such as around major population centers, while longer lines from remote generation sources are usually much more lightly loaded for reasons involving safety, stability, and line losses. Losses alone can cause the economic loading of some lines to be as low as 25% of their thermal capability.

Dynamic limits related to the physical locations of generators and load centers can constrain a grid and force some systems to operate well below the thermal rating of equipment. Certain equipment may be sized for short-circuit capability, giving it more power-handling capacity than is normally useful to the network. A growing cause of transfer limits involves voltage support and reactive power flows as larger blocks of energy are exchanged through systems.

Most systems have more than one of these limitations, the study found, and the dominant limits can change over time. Geographically large, weakly interconnected systems may outgrow stability limits as they mature, while more-compact systems that add new long lines can develop stability limits, sometimes sacrificing the loadability of other lines.

"There will always be some practical limitations to transmission network capability," says Young, "but the goal has long been, and remains, to achieve an economic balance between capability and potential use. For a large bulk power system with a reasonably homogeneous pattern of loads and generation that is planned and operated strictly on a least-total-cost basis that takes into account the economic cost of unreliability, transmission limitations do not exist. In fact, a system designed strictly from a consumer economics point of view can ill afford to impose limits on transfers that are economically attractive."

Still, a curious parallel has emerged for U.S. utilities, where transmission limits generally arise from restrictions and time delays or a lack of capital for construction of new lines, with transmission problems faced by developing countries, the study notes. "Both are concerned with transfers over relatively long distances, and both have difficulty building new lines: the United States because of environmental and regulatory concerns, and the developing countries because of severe credit limitation. Both systems therefore seek innovations to extend their existing transmission capabilities while planning the construction of new circuits."

Technology for boosting transfers

Recourses for enhancing transmission capability fall into three basic types: intelligence-based, including software, control, and operating methods that require minimal hardware investment; solutions based on the addition or replacement of major apparatus, such as series capacitors, static VAR (reactive power) compensators, and circuit breakers, which, though more expensive, can bring major gains in transfer capability; and the modification or upgrading of existing lines to higher voltage or compact double circuits, with corresponding changes in substation equipment. The third category tends to be the most costly but also the most effective in strengthening transfer capacity.

Within the intelligence-based category, the study found that utilities generally agree that data acquisition systems for more-detailed information on network conditions and state-of-the-art control center software are the most cost-effective means for improving transfer capability. The software includes programs for system load flows, state estimation, contingency ranking, and other types of security analysis.

System control software represents another intelligence-based option to the extent it can be improved cost-effectively. Examples of how control programs could play a greater role include automatic redispatch of generation on the basis of changing network constraints, automatic startup of combustion turbines and control of pumped-hydro storage, and improved response and stability of controls on steam boilers for faster ramping of generation. All can be exploited for higher loading of the transmission network.

Planning and operating criteria of individual utilities, power pools, and the industry at large have extremely significant influence on transmission loading, the study notes. "Although no utility is interested in enhancing transfer capability by weakening criteria, unrealistic criteria put artificial limits on transfer capability and can be removed with no cost and little sacrifice in reliability."

Among major apparatus options, the addition of series capacitors on long lines is perhaps the most common utility recourse for boosting transmission capacity. These reactive power compensation devices cancel some of the inductive reactance on a line and improve the stability at higher loadings. But in circuits that are heavily compensated with capacitors, unwanted low-frequency oscillations can feed back into the grid, possibly damaging generators. The emergence and anticipation of advanced protection systems and improved ability to predict and damp subsynchronous resonance, however, make growing use of series capacitors most likely.

A relatively recent device, the static VAR compensator (SVC), can provide an almost continuous range of reactive power compensation and enable the loading of lines up to their thermal limits. Based on semiconductor, light-fired thyristor switches, SVCs can sense changes in voltage and reactive power, switching on or off many compensation devices, as needed.

The ultimate hardware improvement to increase transmission capability remains the use of dc transmission, which does not share with ac what engineers call the curse of reactive power and where the flow of power is readily controlled. Dc circuits can inherently carry more power than ac conductors of the same size. Ac circuits can be converted to dc lines for major gains in transfer capability, but if a dc line is to serve loads along the way, costly converter terminals must be added to change the current back to ac. To date, the cost of dc transmission and associated terminal equipment has been difficult for utilities to justify unless it involves a new line.

Hardware options are also available for overcoming dynamic limitations to system transfers. These include neutral resistors to reduce the severity of circuit faults and fast-acting, strategically located braking resistors.

Surveying recourses that involve modifying or rebuilding existing transmission lines, the EPRI study found that "U.S. and Canadian utilities have developed an invaluable pool of techniques and experience." Line options include both voltage and current uprating (with larger and higher-rated conductors) and compacting more circuits on existing towers and within existing rights-of-way.

"Perhaps the most valuable and least publicized are methods for constructing a new circuit while leaving an existing circuit in service," the study notes. Live conductors can be temporarily removed from tower supports for tower modifications to increase the number of conductors, and grounded new conductors can be suspended and pulled alongside the energized conductors. Use of live-line restringing, however, requires further research on safe and practical techniques, as well as special hardware.

The challenge for R&D

Despite the availability of numerous options for increasing transmission capabilities today, the trend toward greater dependence on transmission for meeting regional power needs in the future poses several challenges for research and development. The EPRI study identified some options that are only at the prototype stage: advanced protective relays, sophisticated on-line security analysis software, and state-of-the-art communications and control technology. Apparatus options at the prototype stage include thyristor-controlled phase-angle regulators and dc circuit breakers, while such line options as bundled circuits and high-phase-order configurations remain proved but largely unapplied.

Among new ideas that could significantly alter the technology of power transmission but which are not yet ready for prototype application are high-temperature superconductors. The recent discovery of rare-earth ceramic oxides that conduct electricity with zero resistance loss poses one of the most promising areas of research for underground transmission cable systems in decades.

In the 1970s superconducting transmission research confirmed the potential economic attractiveness of resistanceless underground cables. But the work then focused on metallic superconductors that require expensive and difficult-to-maintain liquid helium temperatures. The new materials, operating in the temperature range of less costly liquid nitrogen and possibly even higher, could eliminate most of the economic obstacles to superconducting transmission.

Superconductors also promise the potential of advanced generators, megawatt-scale energy storage systems, and faster, more-powerful, and affordable large computers, all of which have a potential bearing on the ability of system operators to exert more-active control over the transmission system.

Narain Hingorani, an EPRI vice president and the director of the Electrical Systems Division, says that superconducting and advanced semiconductor technology, along with advances in system automation with digital control and protection, expert systems and artificial intelligence, robotics, and other new technology, presage the beginning of a major technologic transition.

The transmission system today is controlled somewhat crudely and slowly by mechanical means, but Hingorani foresees a day in the not-too-distant future when advanced electronics will permit precise, real-time, high-speed control of power flows by operators, possibly aided by on-line expert systems at their side suggesting the best course of action.

"I am confident that down the road, all electric power, from its production to its end use, will flow through several power semiconductor devices," predicts Hingorani. "We are in the midst of several revolutions in technologies related to power systems—conductors, electronics, computers, and software. Together, they promise an increasing degree of flexibility and control of the bulk power system."

Transmission in the spotlight

The studies by NRRI and EPRI lend technical and economic substance to a growing body of ongoing analysis of the role of transmission in a competitive bulk power supply market. They will complement the work of other groups as transmission issues emerge in the national energy policy spotlight.

Among those other studies, a recent report from the electricity transmission task force of the National Governors' Association concludes that state and federal governments should encourage development of a broader and more integrated transmission system. Governors recommended a five-point plan, including simplified, expedited state approval for transmission projects; more-comprehensive regulatory review of electricity supply and transmission planning; greater interstate coordination for multistate projects; removal of rate disincentives to develop new transmission facilities; and the use of interstate compacts and mediation to resolve disputes on siting.

Meanwhile, a policy study of transmission issues is under way at Congress's Office of Technology Assessment. Lawmakers are particularly interested in the effect of increasing competition and access to transmission on utilities, their customers, and other power suppliers. Much of their concern revolves around possible revisions to the Public Utility Regulatory Policies Act (PURPA) of 1978, which set in motion the trend of nonutility power generation and the eventual conflicts over transmission access.

With FERC considering changes in its rules for implementing PURPA, much of the focus on transmission is converging on the commission. Chairman Martha Hesse has proposed an open-bidding approach for new generating capacity as a way to further deregulate bulk power supply. The idea, should it issue from FERC as new rules for wholesale power transactions, will have important implications for transmission policy, which FERC also plans to address separately within the next few months.

Whatever the outcome of the changing winds of law and regulation, transmission has emerged center stage as a new focal point in the nation's outlook for adequate, reliable, and affordable electricity supplies. ■

Further reading

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This article was written by Taylor Moore. Technical information was provided by Frank Young, Electrical Systems Division.

Power electronics technology could revolutionize the delivery and use of electricity, but stiff international competition has raised questions about whether the United States will be a supplier or a buyer. A new R&D center will be working to further utility and business interests in this crucial field.

NATIONAL FOCUS ON POWER ELECTRONICS

A quiet revolution in electronics, under way for some time, is now in full swing. Low-voltage, low-current semiconductor devices and circuits, having proved their potential in everything from wristwatches to desktop computers, are giving way to a new generation of high-power electronic devices. Increasingly, electric-powered industrial equipment is controlled by means of power electronics, which regulate how and how much electricity is distributed through a circuit. They are even making their way into the ultimate electric apparatus: the high-voltage utility transmission systems.

EPRI's long interest in power electronics has involved pursuit of applications across the spectrum of technology for electricity supply and end use. These range from power conversion equipment essential for technologies like fuel cells and photovoltaics, to advanced thyristors for power transmission gear, to a panoply of industrial electrotechnologies.

Meanwhile, researchers are already at work on the next generation of power electronics devices and circuits. These will integrate control and logic circuitry on a single semiconductor chip, in many cases replacing circuit boards built of discrete components. Such power-integrated devices offer revolutionary potential for electronics similar to that experienced in microelectronics when the integrated circuit replaced the transistor.

A national focus for hastening the development and use of advanced power electronics has now taken shape with the dedication of the EPRI-initiated Power Electronics Applications Center (PEAC) in Knoxville. PEAC is bringing together researchers, manufacturers, and users of power electronics equipment for collaborative efforts to advance the technology and broaden the use of semiconductor-based devices, circuits, and systems. These include electronic adjustable-speed drives for industrial motors, plus uninterruptible power supplies and power conditioners for computers and other sensitive equipment.

Getting down to business

Coincident with the dedication of PEAC last October was the first of what is planned to be an annual power electronics applications conference. PEAC officials outlined program plans, experts from leading firms in the field surveyed recent technical developments, vendors showed an array of diagnostic and power-conditioning equipment, and representatives of utilities and other firms heard firsthand about the latest in applications.

Despite the large opportunities for power electronics to significantly change the ways electricity is used, "the opportunities are greater than the reality. The reality is lagging the potential," said Fritz Kalhammer, an EPRI vice president and the director of the Energy Management and Utilization Division.

Kalhammer noted,"Very stiff Japanese competition in the power electronics area has been fostered by a decade of subsidies for development and industrial introduction in that country." An outgrowth of the opportunities, the lag between potential and reality, and foreign competition, he added, was PEAC, "an idea for which we have seen almost universally enthusiastic acclaim."

Research and development focused on the application of new technology, rather than on continual refinement of the underlying science, is just the right target for PEAC's focus, according to William Carpenter, vice president of Martin Marietta Energy Systems. Carpenter noted the changes that are occurring in the U.S. manufacturing sector, forcing technologists to join forces with users for point solutions instead of ivory tower research. "The world is not waiting on technology," warned Carpenter, noting that "our competitors don't have the institutional barriers between the research labs and the people who can take advantage of research."

In perhaps the most wide-ranging presentation at the conference, Powerex's Stanley Hunt described the competitive challenge facing American electronics firms. Hunt's own firm may be indicative of the shape of things to come. Formerly general manager of Westinghouse Electric's semiconductor division, Hunt is now vice president for commercial operations of Powerex, a joint venture formed in 1986 by Westinghouse, General Electric, and Mitsubishi.

Hunt said that U.S. firms hold a dominating 85% share of the market in electronic circuits and controls, while foreign firms have cornered over three-quarters of the device manufacturing field. Some of the reasons for the poor showing of American firms in electronic devices include relatively low energy costs that provide little incentive to develop more-efficient electronics, no major push for high-voltage direct current (HVDC) technology to drive electronics R&D, and a comparatively small modern mass-transit development effort. On the other hand, European and Japanese firms have been helped by high energy costs and government-funded development of HVDC and electric mass-transit systems that have created a ready market for such devices as gate-turnoff thyristors.

As a result of the greater incentives as well as the close associations between components and systems manufacturers, Hunt said that many of the most advanced new electronics devices are coming from off-shore, including low-current smart modules with built-in logic. Meanwhile, American manufacturers are becoming increasingly dependent on foreign manufacturers for basic components.

"The solution to the problem does not reside with just EPRI or the federal government," said Hunt. "It will take the dedicated action of all U.S. industry to make the necessary changes to reverse the present trends and make the United States once again the world-class standard for both power electronics systems and components. It appears that PEAC may be the proper catalyst to make this change possible."

Keeping up with change

The technology of power electronics is advancing so rapidly, however, that it is a major challenge for electronics engineers simply to keep abreast, according to Bimal Bose, PEAC's chief scientist and a professor of electrical engineering at the University of Tennessee, Knoxville. Formerly a senior research engineer in power electronics at General Electric, Bose said the power electronics revolution has continued unabated since the invention of the thyristor in 1957.

"During the last three decades, the field of power electronics has grown as a complex interdisciplinary technology embracing semiconductor devices, converter circuits, electrical machines, control theory, and signal electronics," said Bose. But despite the advances in technology, he added, "there seems a wide gap in the applications area. We taught Japan what power electronics is, and now their R&D is superior to ours—they're teaching us."

Whatever the national origin of current innovations, the present drive toward component integration is leading to revolutionary circuit configurations for power electronics, according to Thomas Reddoch, associate director of PEAC.

One of the factors driving new developments is the need for smaller power electronics components, according to Ray Ridley, assistant director of one of the country's largest power electronics research centers, at Virginia Polytechnic Institute and State University. "Many modern applications of electricity are placing new, more-severe demands on the power supply systems. Automotive, radar systems, and many other applications are unsuited to conventional centralized power systems. With these increased demands comes a need for reduced component size. This can be achieved primarily with higher operating frequencies."

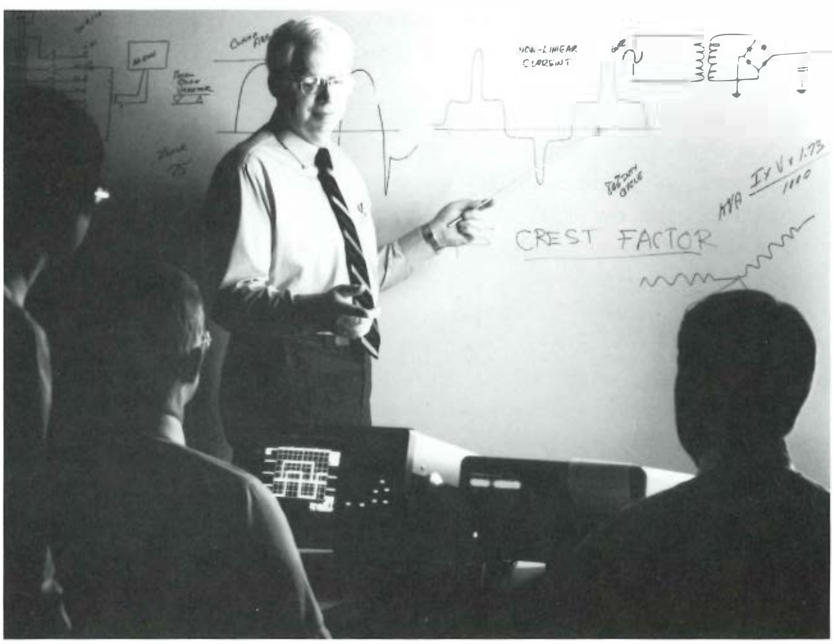
Ridley said that many computer manufacturers are turning to distributed power systems for higher voltages but at reduced current levels. To fit these power supplies onto smaller and smaller computer boards requires high-frequency switching devices, like the MOSFET (metal-oxide semiconductor field-effect transistor) and new circuit topologies that permit very high frequency (above 10 MHz) operation.

Power supplies for all sorts of computers, in fact, represent the lion's share of the current power electronics market. The market for battery-fed, electronically switched uninterruptible power supplies (UPS) continues to grow as massive corporate data and software files are increasingly recognized as highly valuable assets in need of protection from power line disturbances and outages. Michael Model, an electronics engineer from AT&T Bell Laboratories, a major producer of UPS equipment, noted that "most people are not aware that ac power is a major contributor to computer downtime, but user awareness is growing as business productivity is increasingly tied to computer uptime. Meanwhile, hardware sensitivity to power quality is mounting."

But advances in power semiconductors at the heart of UPS equipment and in digital control systems are yielding lower-

Power Quality: The Challenge of Solid-State Systems

The microelectronics revolution that has given us computers and other solid-state systems also brings a new challenge—many electronic loads are highly sensitive to the quality of electricity supplied to them. PEAC has established a power quality laboratory to help develop solutions and quantify the cost and benefits associated with power quality. The laboratory contains advanced data acquisition and analysis equipment that will lead to new approaches and recommended practices for the future. A training program will educate field service engineers, customer service representatives, and utility instructors in site surveys, power monitoring, and disturbance mitigation.



About PEAC

PEAC is operated under EPRI contract by the Tennessee Center for Research and Development, a nonprofit corporation supported by the University of Tennessee, the Tennessee Valley Authority, Martin Marietta Energy Systems (operating contractor for Oak Ridge National Laboratory), and other local businesses.

In addition to directing R&D in power electronics, PEAC is enlisting broad participation and support from the power electronics manufacturing and end-user communities. It will also conduct market and technology application assessments, as well as technology transfer and information activities.

At a ribbon-cutting and dedication ceremony in Knoxville last October, EPRI's Executive Vice President Richard Balzhiser said the electric utilities view PEAC "as an investment in their customers' future that they hope will yield important benefits in improving the competitiveness of U.S. industry. They also see it as an investment in improving the quality of their own product over the years and in better understanding the implications and power quality of many of the power semiconductor devices that we expect will play an increasingly important role in industry. We look forward to exciting times and great things from PEAC."

Later, PEAC Director Wayne Hilson called the 1986 formation of the Power Electronics Society under the auspices of the Institute of Electrical and Electronics Engineers (IEEE), followed by PEAC's dedication last year, an indication of growing professional and scientific interest in power electronics. John Kassakian, professor of electrical engineering at the Massachusetts Institute of Technology and president-elect of the new IEEE Power Electronics Society, said it was "consistent with the creation of PEAC that IEEE has found it worthwhile to recognize the unique technology challenges in power electronics."

Hilson said a key part of PEAC's effort—the involvement of researchers from all quarters—was under way with the center's first visiting scientist (from the People's Republic of China), with others expected to follow. □

John Crothers of the Tennessee governor's office and Richard Balzhiser, now president of EPRI, cut the ceremonial ribbon at PEAC's dedication last October in Knoxville, Tennessee.

cost, lower-weight, higher-density UPS system designs, according to Model. Moreover, advanced, sealed batteries and increasingly sophisticated transistorized circuitry are allowing distributed UPS protection to be installed in occupied office environments, not just in the central mainframe computer room. And the design and manufacturing of UPS equipment will become more automated, thanks to emerging new device architectures and circuit topologies.

Power quality issues

Reflecting the importance of power quality to the expanded use of advanced electronics, a major session of the conference was dedicated to the technical and regulatory dimensions.

Noting the growing importance of power quality, a problem that power electronics can both cause and solve, EPRI's Kalhammer said power electronics "may offer utilities a real vehicle for unbundling electric service," thus providing the means to supply conditioned power for sensitive loads.

Wayne Hilson, PEAC's director, described the power quality program, with its instrumented laboratory for evaluating the effects of various equipment on voltage and current waveforms, as the most developed of the center's efforts.

Hilson noted the number of both contributing and susceptible loads that can affect power quality is growing. Feedback into utility circuits from high-frequency electronic switching devices, as well as such high-power industrial equipment as arc welders, can affect the incoming waveforms and produce troublesome harmonics for other customers far afield. Susceptible loads include critical life-support medical systems and industrial processing equipment, as well as noncritical but highly sensitive loads involving data processing and communications and control systems.

A key early thrust for PEAC is to develop a state-of-the-art power quality training program for utility as well as

Applications: The Future Is Now

Though few people other than electrical and industrial engineers realize it, power electronics already affect everyday life, from the microwave oven that cooks the bacon in the morning, to the electric commuter train, to the robots on assembly lines. A conference session on the latest in applications pictured a quickening pace of the technology's diffusion into conventional and innovative uses of electricity.

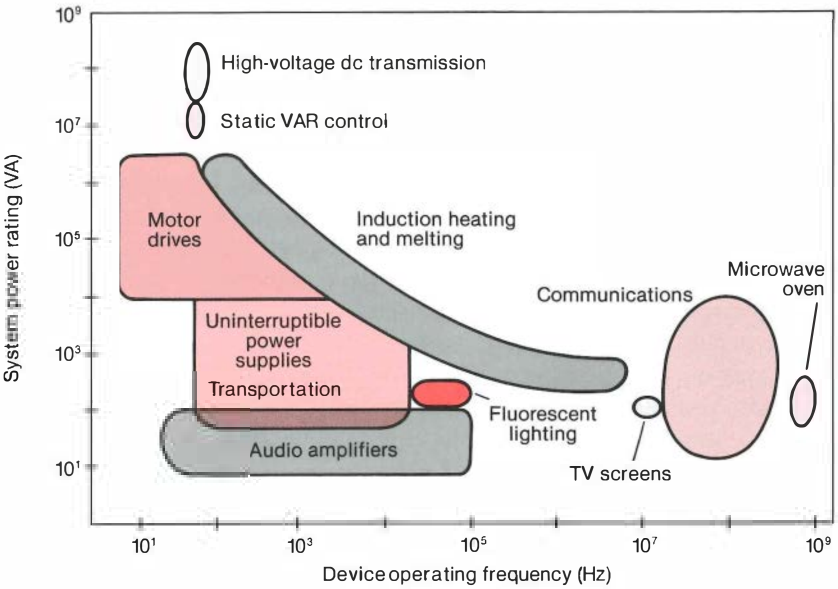
"Whether they be utilities or end users of electricity, customers are reaching out to power electronics to put that technology between their utility service and their work application to improve production efficiency, product quality, and a variety of other factors," said Ralph Ferraro, EPRI's manager for power electronics, now based full-time in Knoxville. Ferraro forecast a potential revolution in applications of power electronics as higher-power devices improve the economics of reshaping electric power to accomplish various tasks in residential, commercial, industrial, and transportation sectors.

Ramon Rosati of Superior Electric, a manufacturer of electronic industrial motion controls, outlined the market segments of a growing industry that includes factory and office automation equipment, consumer electronics components, and instrumentation and military hardware. The current $1.6 billion combined market is expected to grow at an average annual rate of nearly 14% through 1991. Motion control systems include ac-powered variable-speed drives, dc servo and brushless motors, and step motors. Integrated circuits coupled to such advanced motors are the keys to high controllability and efficiency.

Increasingly, power electronics–based equipment is being used by utilities and large industrial consumers for reactive and harmonic power compensation. Laszlo Gyugyi, manager of power electronics at the Westinghouse R&D Center, said that most present reactive power generating equipment are static devices that vary their effective impedance by controlling the current flow in an inductor and by synchronously switching capacitors in and out.

Such VAR generators, employing thyristor control with fixed or thyristor-switched capacitors, are increasingly used by utilities to improve dynamic stability on transmission and distribution lines, by industry to limit the flicker effects when large motors kick in, and for dynamic power factor correction. Meanwhile, the feasibility of active power filters that employ fast switching devices, such as bipolar and field-effect transistors to counter harmonic voltage and currents, has been

APPLICATION RATINGS AND FREQUENCIES



established, and experimental development is under way.

George Bobart, a former Westinghouse engineer and now a consultant to PEAC, surveyed the major role that power electronics is playing in industrial electrotechnologies, a broad category of processes and applications that have high and often specialized electric power requirements. Bobart said that progress in power devices, solid-state components, and control and diagnostic equipment has made a significant contribution in the development of such new technologies as lasers, electron beam generators, and ion implantation systems. Power electronics is also helping to expand the use of induction heating.

"Power electronics constitutes a thread that runs through all the major components of a process system. Power electronics provides a means of producing not only the required energy, but the control for all the process parameters as well," said Bobart.

Residential appliances and heating and cooling systems are benefiting from power electronics advances as well. Ned Mohan, a professor of electrical engineering at the University of Minnesota, surveyed the multiplicity of uses of electricity in the home and related how electronic controls are conserving electricity and reducing operating costs, while providing increased comfort and safety. Heat pumps are a prime example of how electronic controls are increasing efficiency. By incorporating capacity modulation with electronic controls, advanced heat pumps nearing commercial availability can be 30% more efficient than standard single-speed models.

Lighting is another target for power electronics. High-frequency ballasts based on electronic converters can boost by 20% the efficiency of fluorescent lights, already three or four times more efficient than the incandescent lamps.

Electronics are also the key to dimmer controls set by programming or occupancy detectors. In cooking, induction-coil stoves fed by high-frequency converters can achieve thermal efficiencies double those of conventional electric or gas ranges, while greatly reducing burn hazards. Such a stove cooks food by inducing a circulating current in the metal pan, rather than by radiant heat transfer.

The ultimate application of power electronics in residences is the Smart House, under development by the National Association of Home Builders with funding from EPRI, among others. Smart House designs feature microprocessor-controlled closed-loop power distribution to route the desired amount and type of power to appliances only when needed or programmed to do so. □

industrial engineers. Explained Hilson, "We will be making extensive efforts and study to determine the cost of power quality, both to the producers of electricity and to the consumers." Hilson said that PEAC will also assist the professional societies and standards-setting bodies by providing test data that can be used in establishing guidelines. Another element of the power quality program will involve graduate-level research on related problems.

Alex McEachern, president of Basic Measuring Instruments (BMI), a maker of power quality diagnostic equipment, noted a shift in recent years to looking for and analyzing contributing factors to insufficient power quality, rather than simply documenting disturbances. This broadening of available services has been helped by the advent of graphic displays on power quality monitors that present detailed information on contributing factors, as well as clues for solving problems. The density of information available from the monitors is increasing, and more data are being stored on computer disk in addition to the traditional strip-chart. Moreover, data can often be telemetered to an off-site computer for more-extensive analysis.

"Most instruments now analyze voltage profiles and spectrum harmonics through the 33d harmonic in addition to analyzing current waveforms," said McEachern. But as the instruments grow more sophisticated, a political dimension of the role of the power quality troubleshooter is emerging. Companies such as BMI may be hired by either the utility or the customer to come to a site and analyze power quality. How the results of the analysis are presented and how they may later be used can become a delicate issue. "It's important for utilities that the political as well as the technical aspects of power quality be taught to field engineers," he commented.

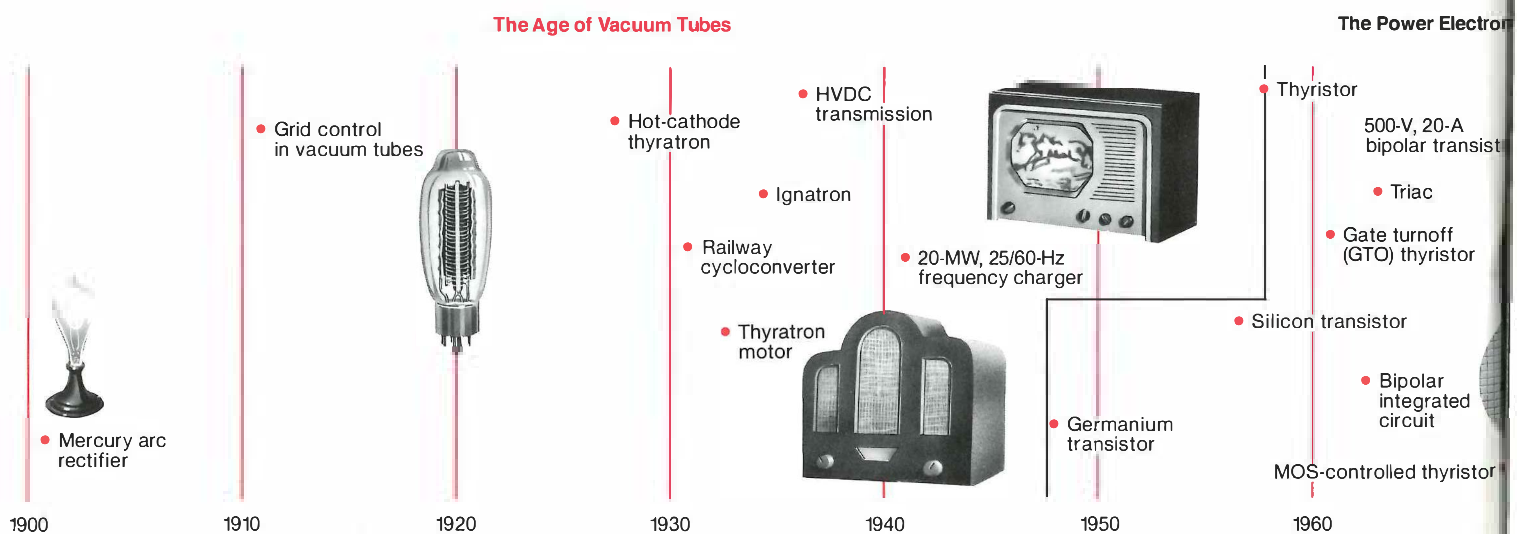
Meanwhile, courses are being developed for diagnostic engineers, McEachern reported, to formalize the lore of practice and intuition in troubleshooting. He said he hoped PEAC can play a role in developing that educational dimension.

Maurice Tetreault, principal engineer for computer-maker Digital Equipment, described the interaction between electronic data processing (EDP) equipment and its power source and how particular parameters of the one can cause misoperation of the other. Tetreault outlined the ac power anomalies most likely to cause EDP problems, including such voltage effects as sags and surges, the implications of short- and long-term power outages, the causes and consequences of high-frequency transients on EDP systems, and the role of facility distribution wiring on the performance of EDP equipment. He also discussed likely failure modes of EDP equipment—specifically, which circuits are most likely to fail because of the ac electrical environment.

The emerging regulatory dimension to power quality issues was outlined by Thomas Henneberger II, chief of the system planning and conservation bureau of the Florida Public Service Commission. He called power quality a broadening issue for regulators that is becoming more serious with increasing numbers of sus-

History of Power Electronics

Developing ways to control the flow of electricity through circuits and devices has been a goal of inventors and scientists since the early 1900s. The first electronics revolution was born in 1948 with the invention of the transistor, and a second wave of innovation occurred with development of the thyristor in 1957. In the future, the marriage of microelectronics and power electronics will make performance improvements and cost reductions possible in



ceptible loads. In Florida early power quality problems began in the 1950s with the wide use of air conditioners.

Henneberger predicted regulators will increasingly be brought into the picture as utilities take new paths in power quality assurance, including the eventual application of market-based rates for premium power quality at specified frequencies and voltages. "Poor power quality in a competitive market is the economic analog of a high-priced product," said Henneberger.

"Perhaps public service commissions should consider innovative tariffs that reflect the quality of service, as well as a special tariff for customers who impose power problems on other customers." Henneberger suggested that the utilities should go beyond maintaining acceptable outage frequency standards to develop engineering standards for minimizing power quality problems. Florida Power recently became one of the first utilities to offer a full range of power-conditioning equipment and services to customers.

Still, improved and more-consistent power quality standards are needed and are coming, according to François Martzloff of the Commerce Department's National Bureau of Standards (NBS). "Power-conditioning equipment can do a lot of things, but it is not a cure-all for power problems."

As Martzloff suggested as he surveyed a growing list of standards for wiring, equipment, and testing set by groups, including NBS, IEEE, National Electrical Code, Underwriters' Laboratory, and the National Electrical Manufacturers Association, "The ultimate test for a standard is, does it help? If not, it's back to the committee."

Martzloff noted that manufacturers of sensitive equipment often refuse to define the vulnerability, susceptibility, and transient-withstand capabilities of their products, although standards are emerging to require such specifications on equipment nameplates. "It's time to throw off the antitrust mantle, recognize world competition, and get down to opening up proprietary information and fostering friendly confrontation among vested interests," he commented.

A new beginning

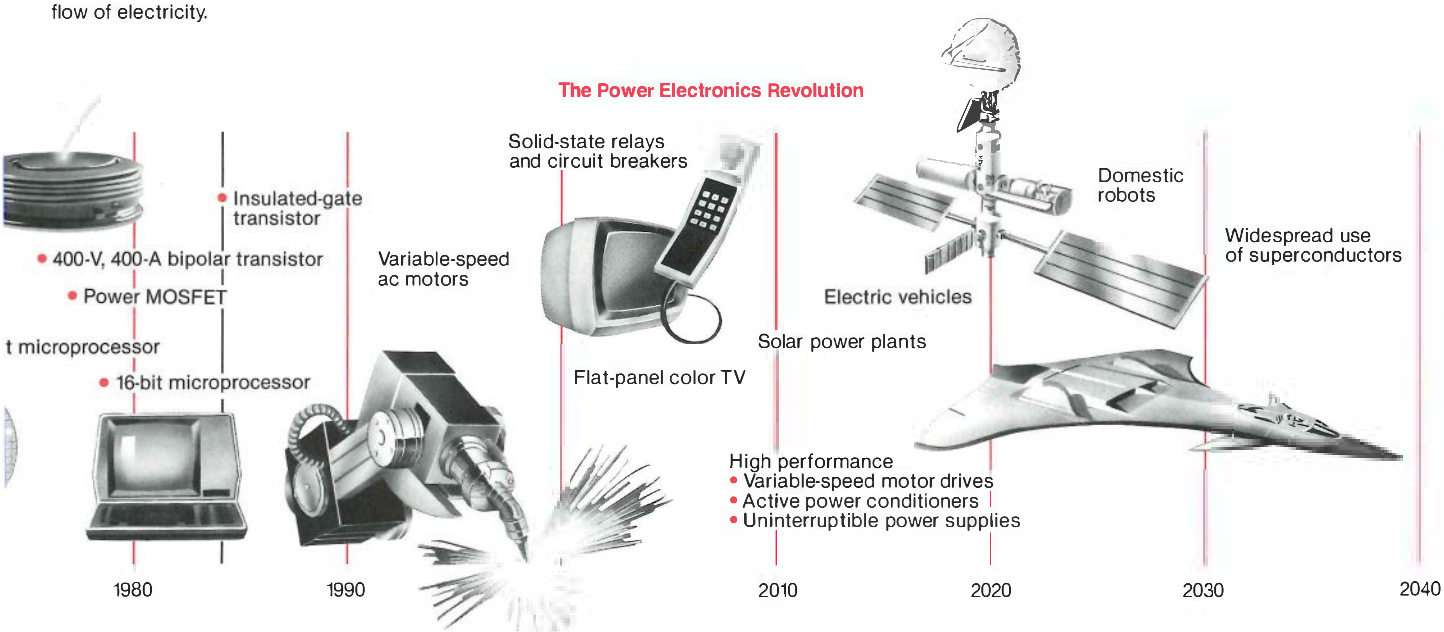
With the dedication of the nation's first cooperatively supported R&D center in power electronics, researchers envision a brighter, more-positive future for all industries whose products use, produce, or control electricity. That includes everyone from the power system dispatcher controlling bulk transmission flows down to the shop foreman and homemaker. The research challenge for PEAC is formidable, but the payoff is no less than reclaiming the high ground in the electronic age. ■

Further reading

Proceedings of the Power Electronics Applications Conference. Knoxville, Tennessee, October 6–8, 1987, forthcoming.

This article was written by Taylor Moore. Technical background information was provided by I. Leslie Harry and Ralph Ferraro, Energy Management and Utilization Division.

virtually every electricity-consuming product and industrial process, as well as entirely new products based on advanced methods for controlling the flow of electricity.



TECH TRANSFER NEWS

Battery Storage Goes Into Service at Cooperative

A 500-kW battery storage system developed with support from EPRI at the Battery Energy Storage Test (BEST) Facility in New Jersey has been obtained and put into service by Crescent Electric Membership, a rural electric cooperative in Statesville, North Carolina.

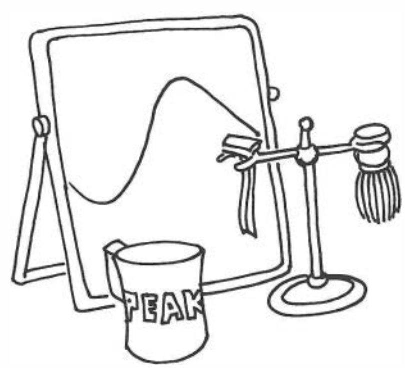
Crescent Electric has operated the battery energy storage system since July to store energy and then discharge it to customers during periods of peak demand. The system, representing an important new approach to utility load management that has proved successful in Europe and Japan, is the largest of its kind currently in operation in the United States. Southern California Edison, however, is now working with EPRI on a project to build and operate a similar, although much larger (10 MW), facility in Chino, California.

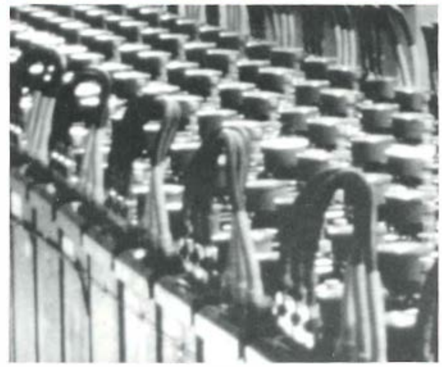
The system at Crescent Electric, consisting of a lead-acid battery, charger, and power converter, was developed at BEST to demonstrate the feasibility and cost-effectiveness of the technology. Following completion of the demonstration project, North Carolina Alternative Energy (NCAE) negotiated with EPRI and Public Service Electric & Gas, operator of the BEST Facility, to purchase the system for duty at Crescent Electric.

In June of 1987 NCAE transported the system to North Carolina on three flatbed trucks. With assistance from PSE&G, Crescent Electric personnel installed the system in a specially constructed metal building and then connected it to their distribution system. Since July the cooperative has used the system several times each month for peak shaving.

At the dedication ceremony in August 1987, North Carolina Governor Jim Martin praised the application of the system as "a pilot program that will be of interest to the entire country. There was a good deal of teamwork to achieve the culmination of the project, including the fine hand of NCAE . . . and the contribution of EPRI."

By tapping the system's stored electricity during periods of peak demand each month, Crescent Electric has been able to reduce the peak demand charges it pays to North Carolina Electric Membership by $15.64/kW. For Crescent Electric, which serves approximately 33,000 customers, this produces cost savings that are expected to average about $50,000 a year.





"The Crescent Electric application shows the effectiveness of battery storage systems for peak shaving, which is just one way that the systems can help utilities save money," says Glenn Cook, EPRI project manager for energy storage technology. "Studies show that the systems can also be cost-effective if used over longer periods of time for load leveling."

In addition to work with Edison on the Chino facility, which is scheduled for startup in early 1988, EPRI is sponsoring studies to develop and evaluate low-maintenance and advanced battery storage systems for utility use. ■ *EPRI Contact: Glenn Cook (415) 855-2797*

Managing Low-Volume Wastes

Proper and cost-effective management of low-volume wastes (LVWs) from fossil-fuel-fired power plants depends on the classification of these wastes as hazardous or nonhazardous according to the federal Resource Conservation and Recovery Act. To help utilities classify LVWs according to RCRA and choose appropriate treatment and disposal options, EPRI developed the *Manual for Management of Low-Volume Wastes From Fossil-Fuel-Fired Power Plants* (EPRI CS-5281).

Designed to help utilities implement an integrated program for LVW management, the manual summarizes current federal regulations, discusses classifications for 10 major wastes, and presents estimated costs and technical descriptions of the available treatment and disposal options. The classification of wastes includes consideration of the toxic characteristic leaching procedure proposed in RCRA.

For most LVWs, the manual describes treatment options based on two fundamental approaches: construction of dedicated treatment or disposal facilities, and codisposal with high-volume wastes, such as coal ash or scrubber sludge. The manual also identifies treatment options for boiler chemical cleaning wastes—the LVWs most likely to be classified as hazardous. EPRI is continuing to study the cleaning-waste treatment approaches, particularly for chelated sludge. ■ *EPRI Contact: Wayne Micheletti (415) 855-2469*

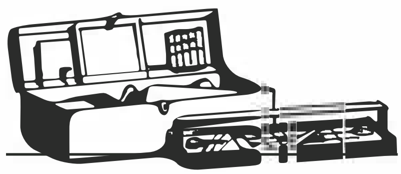
Guidance for Evaluating Generator Retaining Rings

Utilities use many different methods for detecting cracks in retaining rings in large electric generators. These methods involve different technologies and vary widely in reliability, presenting utilities with complex choices. Now, however, utilities wishing to develop in-house evaluation expertise can turn to a new reference, *Guidelines for Evaluation of Generator Retaining Rings* (EPRI EL/EM-5117-SR).

The guidelines provide an overview of stress corrosion phenomena and the currently available methods for inspecting generator retaining rings. This includes discussion of retaining-ring functions and stress; fracture mechanics and materials property data for both magnetic and nonmagnetic rings; alternative ring materials; and NDE methods, such as visual, liquid-penetrant, eddy-current, magnetic particle, and ultrasonic inspections. Guidance for using these methods includes suggestions and precautions for planning and conducting inspections. In addition, the guidelines list organizations offering inspection services and provide a reference to literature on the subject. ■ *EPRI Contact: Jan Stein (415) 855-2390*

A Manual for Better Bolting Practices

Bolted connections that leak or loosen in service are a major maintenance concern in nuclear power plants. A new report, *Good Bolting Practices: A Reference Manual for Nuclear Power Plant Maintenance Personnel;* Vol. 1: *Large Bolt Manual* (NP-5067, Vol. 1), guides mechanics through field-proved techniques to solve common bolted-joint problems, such as leaking, vibration loosening, fatigue, corrosion, cracking, and breakage.



The manual is small enough to fit into a mechanic's toolbox, and its alphabetical format makes it easy for maintenance personnel to quickly reference specific problems and remedies. Contents include the cost, difficulty, and applicability of remedies for common problems, as well as recommendations on choosing the best solution. The manual is not intended to be a substitute for existing specifications, codes, or standards, nor is it designed to be the sole source of information for addressing problems in those bolted joints where safety and performance are prime considerations.

More than 2000 copies of the manual have already been distributed to personnel at nuclear plants in the United States and other countries. A second volume, now being prepared, will provide similar guidance for solving power plant problems with small fasteners, such as electrical connectors and set screws. ■ *EPRI Contact: Ted Marston (415) 855-2660*

Host Utilities Wanted

□ Boiler Tube Failure Reduction Project. Utilities will demonstrate the benefits of a comprehensive, utilitywide approach to identifying the root causes of boiler tube failure and reducing the associated availability loss. *EPRI Contact: Barry Dooley (415) 855-2458*

□ Deoxygenation Process for Cycling Fossil Fuel Plants. A cycling fossil fuel power plant is needed for full-scale demonstration of an improved process for removing oxygen from the condensate flow and preventing corrosion. *EPRI Contact: John Scheibel (415) 855-2850*

□ Combustion Turbine Modifications to Improve Reliability. Sharing costs with EPRI on a 50/50 basis, participating utilities will work with A–E contractors to plan detailed modifications to combustion turbine plants to meet reliability goals. *EPRI Contact: Robert Frischmuth (415) 855-2579*

□ Application of Modular Wellhead Binary Power System. A utility is needed to host the first application of a modular binary-cycle system that can provide a low-cost option as either a geothermal generating unit or as a bottoming cycle in conventional power systems. *EPRI Contact: Evan Hughes (415) 855-2179*

□ Electric and Magnetic Field Measurement Project. Each of the 100 participating utilities will use the EPRI-developed EMDEX (electric and magnetic field digital exposure) system to measure occupational exposures to electric and magnetic fields. *EPRI Contact: Stanley Sussman (415) 855-2581*

□ Electric and Magnetic Field Epidemiologic Study. Researchers will measure exposures and survey health records to test the hypothesis that occupational exposure to electric and magnetic fields may increase the risk of leukemia and brain cancer among certain groups of utility workers. *EPRI Contact: Robert Black (415) 855-2735*

Electricity Product Development

Priority Service Methods

by Hung-po Chao, Planning and Evaluation Division

From an economic viewpoint, priority service refers to a menu of contingent forward delivery contracts offered by a utility. In the simplest case, each customer's selection of one contract from the menu determines the customer's service priority. In each contingency, the utility serves customers according to each customer's selected priorities until capacity is exhausted or all customers are served. Priority service in various forms is quite common in everyday life. Examples include reserving theater tickets before a performance date, obtaining an air fare discount by flying standby, and paying for priority in computer services. The electric utility industry has only recently turned its attention to priority service on a large scale. Priority service can be related to three important types of economic activity: product differentiation, efficient rationing, and spot and futures markets (RP2401-2, RP2801).

Product differentiation

Priority service can be viewed as a special form of product differentiation in which the market is segmented into priority classes. The service conditions are differentiated to allow customers with different preferences to select different levels of service. All customers are presented with a menu of service options. Those customers willing to pay higher prices would select a higher priority in receiving the service, and at the same time, those who select a lower priority would pay lower prices.

Priority service differs from ordinary product differentiation, however, in that the qualities obtained are endogenous—that is, they depend on the number of other customers who select the same or higher priorities. The importance of this scheme is underscored by a research finding that among all incentive mechanisms, priority service is the most efficient one in the context of a single firm with limited capacity.

Whenever customer interruption costs or service values differ, the differentiation offered by a menu of priority service options promotes a more economically efficient allocation of supplies. A first step in planning priority service offerings is to use market research to understand the distribution of interruption costs and service values, taking into account different kinds of power outages and their effects, such as partial outages, duration of interruption, and warning time.

Further, advances in metering and control technologies make possible a greater variety of options. For example, in addition to selecting from a number of priority classes, customers can elect one priority for receiving continued service and another for resumption of service after an interruption. A customer who incurs significant shutdown and restart costs when service is interrupted might place a higher priority on continued service than on resumption of service after an interruption. This may be particularly important to an aluminum producer, for instance, where molten metal must be removed from the cells to avoid solidification when power is interrupted.

Efficient rationing

Priority service can be seen as a rationing scheme for curtailing excess demand in the event of insufficient supply. The theory of efficient rationing suggests that allocation should be made to those who value the service most highly. Priority service imple-

ABSTRACT *Priority service is a concept for developing new, differentiated electricity service options that would enhance the value of electricity in increasingly competitive energy markets. Made possible by advances in communications and control technologies, this concept would allow customers to select a particular level of electric service according to their reliability needs, with the cost of service keyed to the level selected. The establishment of a sound theory of priority service is an important step in the development of analytic methods utilities can use to plan new service offerings.*

ments precisely this method of allocation by using a price menu that enables customers to make selections on the basis of their valuations.

It is well known that electric power interruptions may be caused by failures in generation, transmission, or distribution components. In particular, distribution failures explain, by far, the largest fraction of power outages and are the least controllable. Auxiliary insurance may be used to help achieve an efficient rationing of electricity. The price structure would consist of a basic service charge and an insurance premium. In the event of an interruption, regardless of its source, the customer would be compensated by a specified amount that depends on the insurance premium.

Compared with a rationing scheme in which loads are curtailed randomly in case of a power shortage, priority service is unequivocally superior. One implementation of priority service demonstrated theoretically that every customer benefits, and the utility does not lose net revenue because the efficiency gains realized can be distributed to increase every customer's net benefits without affecting the customer's incentives to select efficiently.

Spot and futures markets

Priority service can be interpreted as a form of market organization that supplements, and in some cases supplants, spot markets. Spot prices are revised continually, whereas priority service contracts cover an extended period. In principle, the price charged for each priority class is the expectation of what the spot prices would be for the same quality of service purchased in the spot markets under a number of different contingencies. Corresponding to each priority class is an imputed reservation price that is the maximum spot price at which the customer would make spot purchases.

In addition to its theoretical justification as an efficient form of market organization, the priority service contract has practical implications in terms of service order. Delivery under forward contracts is inherently contingent on sufficiently low spot prices. Such contracts typically promise delivery at a future time in specified contingencies. Because spot prices vary widely, the seller who draws supplies from the spot market is expected to be willing to fulfill a forward contract only if the spot price is below some critical level. Therefore, aspects of priority service typically are embedded in any futures contracts and other contingent forward contracts. More-complex contracts can be written most simply and efficiently by relying on priority assignments or equivalent clauses specifying reservation prices.

Priority service can be a less costly form of market organization if customers' valuations are stable over time and transaction costs are significant. In the extreme case that customers continually revise their priority selections, spot markets and priority service are equivalent. The comparative infre-

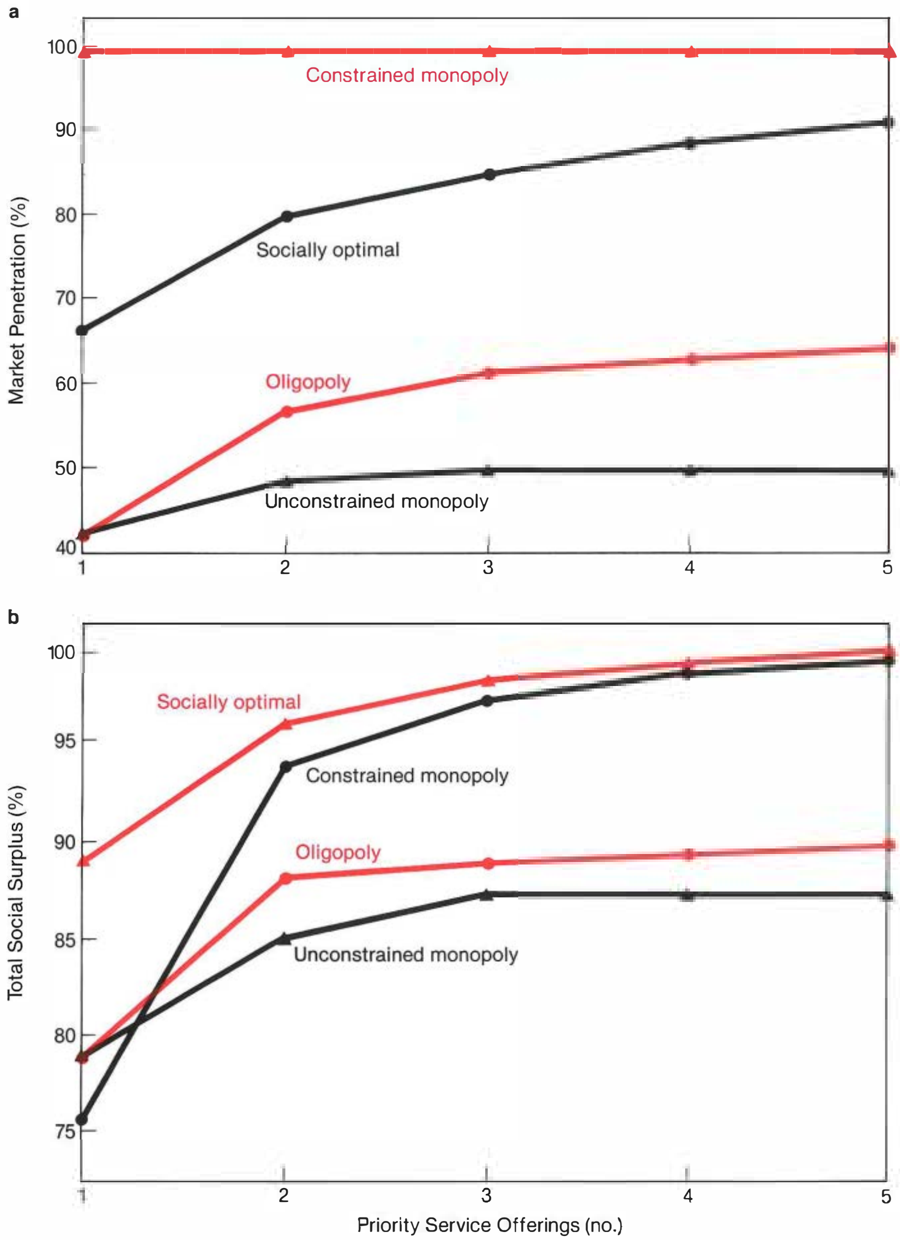


Figure 1 (a) compares scenarios in which the ideal offerings maximize the consumers' and producers' surplus; (b) indicates how alternative markets enhance priority service gains.

quency of priority service contracting saves on transaction costs. But, to the extent that customers' service valuations change over the contract period, the allocative efficiency of priority service is reduced. The optimal duration of the contracts thus involves a trade-off between the greater transaction costs and the greater efficiency gains from more-frequent contracting; in turn, the efficiency gains depend on the serial correlation of customers' valuations.

Market penetration

Market structure and competition have important implications for priority service. Analyses show that competition among incumbent firms does not provide sufficient incentive to offer efficient product diversity. Product differentiation would be motivated largely by the potential entry of new independent suppliers into a competitive market. However, dispersion among many firms may limit productive power pooling. Priority service could capture some of the efficiency gains that would be obtained in competitive markets without the costs and risks of major restructuring.

To illustrate how priority service enhances market penetration and the value of electricity service, Figure 1a compares four market penetration cases through computer simulation. The socially optimal case represents an ideal situation in which the priority service offerings are designed to maximize a widely used social welfare measure—the sum of consumers' and producers' surplus. The case with unconstrained monopoly represents another extreme, in which a monopoly is allowed to seek maximum profits. The oligopoly case assumes that a finite number of suppliers are providing competing service offerings, and each supplier specializes in one service offering. The case with constrained monopoly assumes that a monopoly is required to set prices in such a way that all customers with valuation higher than the marginal cost are induced to subscribe to the service.

Figure 1b shows how under alternative market structures, most of the efficiency gains of priority service can be obtained with only a few priority classes. These simulation results confirm the theory that the realized gains approach the theoretical limit rapidly, where the gap is inversely proportional to the square of the number of classes offered.

Planning workstation

A workstation is a self-contained and dedicated computer system typically designed for use by engineers, scientists, or financial analysts to perform a variety of tasks, such as product design and investment planning. It can accomplish dozens of tasks at once and can be linked with other workstations in a network. Workstation applications have been characterized by rapid response and exceptional user interfaces.

The planning and implementation of priority service requires an integrated analysis that cuts across the functional boundaries of current utility organizations. Besides the theoretical development, a specific goal of this research is to produce a series of interrelated computer models that provide the analytic capability needed for developing priority service offerings. These computer models may be packaged in the form of a personal computer workstation with well-integrated capabilities.

Power Conditioning

Power Electronics for Renewables

by Frank Goodman, Advanced Power Systems Division

Power electronics is undergoing a radical change because of advances in power semiconductor switching device technology and as a result of the availability of low-cost microelectronics for the control logic of power conversion circuits. In general, the reliability, size, weight, and cost of power electronics equipment are being improved. Research over the next decade in high-purity silicon materials, power semiconductor switching device technology, and power conversion circuit topology will lead to more and more applications for power electronics equipment. Those applications will permeate all aspects of electricity production, delivery, and use, ranging from the multimegawatt in utility networks to the fractional kilowatt in home appliances. For additional information about trends in this technology, see the *EPRI Journal*, December 1986, pp. 4–15, and AP/EL/EM-5470.

Photovoltaics, wind power, and other renewable resource technologies hold the potential for various applications of power electronics equipment and therefore may be expected to benefit from advances in the broader field of power electronics. Before those benefits can be realized, however, well-planned and application-specific research has to be conducted.

Power electronics and photovoltaics

Over the past 10 years photovoltaic technology has steadily moved toward the cost and performance goals set for utility-scale commercialization. Photovoltaics is showing significant promise of becoming a competitive source of bulk power in the mid 1990s, which is also when the next major increase in new generation requirements is expected to occur. Hence, if progress continues as expected, photovoltaics has an important role to play in the future generation expansion in those regions with adequate sunlight. Concomitantly, steps must be taken to

ABSTRACT *Photovoltaics, wind power, and other renewable resource generation technologies are prime prospects for future applications of power electronics equipment. EPRI-funded assessments identify several applications that will help advance the renewable generation technologies toward eventual utility-scale commercialization. In particular, advances in power electronics are expected to significantly improve power conditioners for photovoltaic systems, wind power stations, and thermal generation systems. However, realization of these benefits depends on immediate application-specific R&D programs.*

ensure that a reliable and competitive power-conditioning technology is available to support this large-scale commercialization of photovoltaics.

The power conditioner, an indispensable component of photovoltaic power stations, converts the generated dc power to ac and provides key control functions. Because all generated power must pass through the conditioner, overall station reliability can be no better than that of the conditioner. Indeed, much of the downtime of experimental photovoltaic systems has been caused by power conditioner failures.

The status of power conditioners for photovoltaics is essentially the same as it was in the mid 1970s, with most of the available conditioners custom-built by small manufacturers. Larger power electronics vendors (such as members of the uninterruptible power supply industry) have lacked market incentives to enter the competition and develop standard products for photovoltaic power conditioning. It is possible, however, that the power-conditioning requirements of photovoltaics and other technologies will be similar enough to make the aggregate market for a standard line of adaptable power conditioners sufficiently large to encourage the involvement of the larger vendors.

EPRI and Sandia National Laboratories are conducting a joint assessment to determine the state of the art of power conditioning, the technology development options, and effective approaches for mobilizing resources to ensure that a suitable power conditioning technology is available for large-scale commercialization of photovoltaics. Additional objectives include: (1) examining engineering and field experience, (2) identifying similarities between photovoltaic power conditioners and those designed for other applications, and (3) identifying other power electronics applications in photovoltaics, such as tracking servomechanisms and dc switchgear, which may require research and development. Thus far, the assessment has indicated the following.

- Power conditioning technology that is suitably reliable, efficient, and cost-effective for large-scale commercialization of photovoltaics in utility markets does not exist.
- A modular power-conditioning capability is desirable; a desirable module for utility-scale photovoltaics would be in the 50–2000-kW range (nominal).
- The lead time for developing and debugging a new power conditioner is from two to four years, assuming the components are available at the start. Hence, work would have to begin now if a new generation of power conditioners is to be ready in the early 1990s.
- The lead time is even longer if a new component type (for example, the metal oxide semiconductor–controlled thyristor) is to be used because the development of the component and of the power conditioner requires time.
- Experience indicates that there is considerable room for improvement in the reliability and serviceability of photovoltaic power conditioners; small gains in efficiency are also possible. Cost remains a major challenge. To drive costs down significantly will require not only advances in technology but also a sufficient market to bring about economy of production. In addition, vendor field support capabilities can be significantly improved.

Power electronics and wind power

Wind power has significant promise as a future utility generation option. Numerous studies indicate that wind power technology can be significantly enhanced and made more attractive to the utility industry by a proper application of power electronics. There are two principal possibilities for power electronics in wind power applications: static VAR compensators and variable-speed wind turbines. Also, because a wind power station consists of many small generating units and a large power collection network, power electronics equipment will most likely be used to meet some station control and protection requirements.

The widespread use of induction generators in wind turbines causes high reactive power flows, which result in inefficient use of electrical equipment within a wind power station and in the adjacent utility system. Further, operating problems can result from adverse reactive power flows. Similar problems have existed for some time with inductive load concentrations. Adverse reactive power flows have often been partially compensated by using fixed or mechanically switched capacitors. In some cases, static VAR compensators have been employed. The early static VAR compensators were mainly custom-built units targeted at high megavolt-ampere levels. These static VAR compensators were generally some combination of thyristor-controlled capacitors and reactors.

The growing use of induction machinery and related reactive power problems create a need for a family of advanced static VAR compensators. In the wind power application, the compensation problem is particularly challenging because the reactive power is subject to continuous random fluctuations in response to the vagaries of the wind. The advanced static VAR compensators should use emerging power electronics to establish a compensation technology that is adaptable to a variety of applications in which continuously adjustable compensation is needed. Also, they should be modular or scalable to allow a flexible range of rating levels (AP-5210).

Current wind turbines operate at a constant rotor speed to comply with the constant electrical frequency established by the utility system. By using suitable power electronics circuitry, it is possible to decouple the wind turbine's rotor speed from the utility system's operating frequency and thereby allow the wind turbine to operate at variable rotor speed. A variable-speed wind turbine would provide prospective gains in torsional dynamics and energy capture relative to its constant-speed counterpart. The improved torsional dynamics, in turn, would reduce structural loads and thereby possibly reduce weight, increase component service life, or both. The power electronics circuitry might also aid in power factor control. The research challenge is to develop a suitable power electronics package that provides an optimal blend of the above benefits and to integrate that package into a wind turbine system, while maintaining an overall system cost-to-benefit ratio less than unity (AP-4261, -4590, -4794, and -5219).

The role of power electronics in wind power and the appropriate research activities are being further examined in a current feasibility assessment jointly funded by EPRI and U.S. Windpower.

Other opportunities

Another principal prospect for power electronics applications in the renewable resource technologies is in adjustable-speed drives (ASDs) for control of the electric motors used in thermal systems. The motor applications would include the pumps, fans, and conveyors used in geothermal, solar-thermal, and biomass utilization systems. A good example is the large ASDs used in pumps at geothermal power stations.

In general, the number of ASDs required for these purposes is not large enough to warrant major commitments to advancing ASD technology. However, there are similarities between these ASDs and those used in other applications. The range of ASD uses is indeed very broad, and the overall market is sufficient to justify significant research and development to advance ASD technology and thereby capitalize on progress in power electronics. Hence, the multitude of applications (including renewables) for ASDs provides the basis for ASD research and development.

Another prospect for power electronics in the renewable resource technologies is robotics. Like ASDs, robotics has an expanding range of applications, one that reaches far beyond those in the renewable resource systems. Again, the advances in robotics and the capabilities to use them will be driven by the entire range of potential applications, not by those of the renewables alone. However, there may be sufficient need for robotic devices in certain instances, for example, solar tracking servomechanisms, to justify application-specific research.

One way of classifying the many different applications of power electronics equipment is by categorizing them in terms of function: (1) power inversion and rectification; (2) drive circuitry for rotating machinery; (3) power quality enhancement; (4) protection and control; (5) robotics; (6) appliances.

Most power electronics concepts can be so grouped. For example, harmonic suppressors and static VAR compensators are in the third category, power quality enhancement. However, some power electronics equipment may have more than one function and thus fall into a primary category and one or more secondary categories. For example, a photovoltaic power

Table 1
APPLICATION SYNERGIES

Power Electronic Functional Category	Examples of Power Electronic Equipment	Areas of Application
Power inversion and rectification	Power conditioners, power supplies	Batteries, fuel cells, high-voltage dc transmission, photovoltaics, industrial electrotechnologies
Drive circuitry for rotating machinery	Adjustable-speed drives, electronic brakes, motor starters, variable-speed generators	Industrial electrotechnologies, transportation, wind power, small hydro, pumps and fans in thermal generation technologies
Power quality enhancement	Power line conditioners, static VAR compensators, harmonic suppressors, uninterruptible power supplies	Transmission, distribution, utility customer loads, wind power
Protection and control	Sensors, switching equipment	All electrotechnologies
Robotics	Position servos, automatic loaders, automatic assembly equipment, automated field service equipment	Industrial electrotechnologies, generation, transmission, distribution
Appliances	Lamp dimmers, microwave ovens	Industrial, commercial, and residential electrotechnologies

conditioner's primary function is inversion (category 1), and its secondary function is protection and control (category 4). A key issue in photovoltaic system design is what protection and control should be integral to the power conditioner versus what should be done with separate equipment.

Using these categories, the similarities that exist between power electronics applications in renewable resource and other technologies can be summarized as indicated in Table 1. The information given in the table is not all-inclusive, and certainly other schemes of categorization are conceivable. Nonetheless, the table illustrates areas of common application. In planning research and development activities, it is important to consider this commonality in order to maximize the use of resources. For example, the market size in any given area of application for an advanced ASD or static VAR compensator may not be sufficient to warrant a research effort, but the collective market of several areas may be. In considering these similar areas, it is important to make certain that the operating parameters of the different applications are truly accommodative.

Environmental Control

FGD Economics

by Paul Radcliffe, Coal Combustion Systems Division

ABSTRACT *The possibility of new emission control legislation for coal-fired plants has heightened utility interest in the cost of flue gas desulfurization systems for both new and retrofit applications. Generic guidelines that EPRI published in 1984 for estimating such costs have recently been supplemented with RETROFGD, an interactive computer program that allows utilities to make site-specific FGD cost estimates with increased accuracy. Work is under way on updating the FGD economic data base, the guidelines, and the companion computer program. This update will expand the data base to include the emerging dry-sorbent injection technologies.*

With acid rain legislation already in effect in some states and pending at the federal level, interest in estimating costs for flue gas desulfurization (FGD) systems is growing. The cost issue is often raised in debates on how extensive mandated SO_2 controls should be. An FGD system can account for up to 30% of the capital cost of a new power plant. Government policymakers, as well as utilities, need accurate, consistent, and up-to-date information on the capital, operating, and maintenance costs of commercially viable FGD alternatives. EPRI's Desulfurization Processes Program is committed to periodically updating FGD system costs. A computer model for quickly estimating FGD costs was recently released, and work is in progress on updating the existing FGD cost data base.

Existing data base

In 1982 EPRI began a four-year research effort to develop cost estimates for 26 FGD processes (Table 1, page 48). Results were published in a five-volume report, *Economic Evaluation of FGD Systems* (CS-3342). These cost estimates were developed for a hypothetical new plant installed at a midwestern site. As this project progressed, EPRI recognized the need for guidelines applying these generic estimates to specific new or retrofit installations, using utility-selected economic/design criteria and site requirements. *Retrofit FGD Cost Estimating Guidelines* (CS-3696, published in 1984) has served as the basis for a number of utility and government agency estimates for both new and retrofit FGD applications.

Cost estimates for each of the 26 processes are expressed in December 1982 dollars in terms of capital required ($/kW) and total levelized busbar cost (mills/kWh). The base hypothetical plant estimates are based on installing FGD systems at two new 500-MW generating units. The systems are designed to comply with federal New Source Performance Standards: 90% SO_2 reduction for high-sulfur coals, and 70% reduction for low-sulfur coals. Waste disposal is accounted for in the estimates.

Table 1
FGD PROCESSES EVALUATED

Low-Sulfur Coal Nonregenerable Processes*	High-Sulfur Coal Nonregenerable Processes*	High-Sulfur Coal Regenerable Processes*
Conventional limestone	Conventional limestone	Wellman-Lord
Lime spray dryer	Bechtel CT-121 (Chiyoda 121)	Magnesium oxide
Nahcolite injection (also trona injection as a subcase)	DOWA	Sulf-X
	Limestone with forced oxidation	Flakt-Boliden
	Saarberg Holter with lime	Aqueous carbonate
	Limestone dual alkali	Conosox
	Lime dual alkali	Pfizer
	Wet lime	Mitsui-Desox
	Bischoff	NOXSO
	Lime spray dryer	SOXAL
	Saarberg Holter with limestone	
	Limestone with adipic acid	
	Limestone with adipic acid and forced oxidation	
	Forced oxidation limestone with wallboard by-product	

*Nonregenerable processes produce a by-product that must be disposed of. Regenerable processes regenerate the sorbent used to remove SO_2 and produce sulfur, liquid SO_2, or sulfuric acid as a by-product.

Selective equipment redundancy is included to ensure acceptable reliability. Spares are assumed for FGD components whose loss would require immediate system shutdown. Such components as tanks, silos, agitators, fans, and heat exchangers do not have spares.

Researchers took into consideration the stage of development of each process: commercially available, available in the size range of 20–100 MW, pilot scale, and bench scale. Contingency factors applied to each process reflected the stage of development. Sensitivity analyses were done for each process for coal sulfur content, reagent consumption and cost, by-product value, power cost, fuel cost, maintenance requirement, altitude, and disposal cost.

RETROFGD

EPRI developed a computerized version of the *Retrofit FGD Cost Estimating Guidelines* so that utilities could apply the guidelines without complicated manual calculations and lengthy worksheets. RETROFGD is an interactive personal computer program that uses internally stored design information to readily estimate capital, operating and maintenance (O&M), and total levelized costs for both new and retrofit applications. The program was validated in a demonstration test at eight utilities

RETROFGD allows users to obtain estimates in a fraction of the time required by the guidelines manual. The model computes costs by using site-specific data entered by the user and default values for the selected FGD process. Examples of site-specific user inputs are given in Table 2. On the basis of this information, the program estimates FGD system costs by using the steps shown schematically in Figure 1.

Users can adjust the base case estimates to account for variations in process parameters, such as unit rating, gas flow rate, coal sulfur content, required SO_2 removal efficiency, and flue gas reheat. Site location factors consider the cost effects of seismic zone, climate, soil conditions, labor rates, and material prices.

Retrofit installations can be accommodated by incorporating adjustment factors for changes to existing plant equipment. Such adjustments typically include stack modifications (or replacement), boiler structural reinforcement, demolition and/or relocation of equipment to provide space for FGD components, underground obstructions, ductwork distances, and waste transportation requirements.

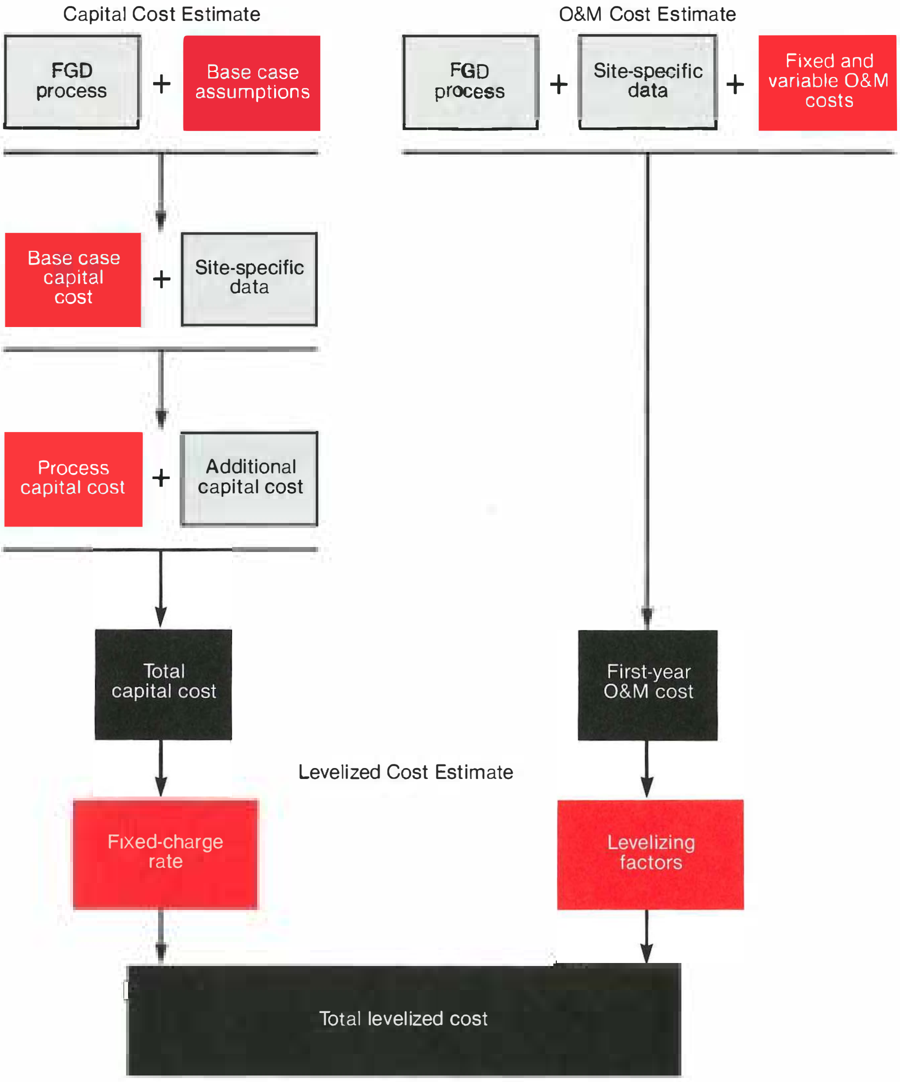
The model allows the user to define up to five FGD systems at a given site with common systems or components shared in any desired manner. The user can evaluate the cost effects of design trade-offs by varying appropriate input parameters between model runs. User input for each run is stored on a disk, then retrieved for use in subsequent runs.

RETROFGD can present results in three levels of detail, selected by the user. The summary output gives total capital cost ($/kW), the overall first-year O&M costs ($/kW-yr), and total levelized cost (in both mills/kWh and $/ton SO_2 removed). At the user's option, the program can print a com-

Table 2
EXAMPLE INPUTS:
FGD COST–ESTIMATING MODEL

Factor	Input
Process parameter	Type of FGD process Plant rating Flue gas flow rate SO_2 removal requirement Coal sulfur content Flue gas reheat requirement Waste disposal requirement
Location	Seismic zone Regional labor rates Soil conditions Climate category
Retrofit	Ductwork distances Underground obstructions Demolition and relocation costs Site accessibility/congestion Boiler reinforcement requirement Stack modification Particulate control modification
Financial data	Minimum acceptable rate of return Levelized fixed-charge rate Escalation rate
Operation	Capacity Remaining plant life Auxiliary power requirement Operator and maintenance costs Utilities' consumption and costs

Figure 1 Schematic of the process used by RETROFGD to compute total capital cost, first-year O&M cost, and total levelized cost. User input is shown in gray, model computations in color, and cost estimates in black.



plete listing of a run's input data with each output.

RETROFGD gives utilities a customized tool for quickly and inexpensively comparing the costs of alternative FGD systems. The RETROFGD program is intended to help utilities screen alternative systems and complement, but not replace, detailed engineering studies. The program's principal purpose is to compare FGD system cost estimates by uniformly applying the defined economic methodology to all candidate processes. Model results have a predicted absolute accuracy of ±30% for a given process and a relative accuracy of ±15% for comparing different processes.

Sensitivity analyses can be performed for variations in utility economic and design criteria, as well as site-specific requirements. Users can identify the relative importance of different cost elements, such as capital equipment, energy, and manpower. The program is designed for use on IBM or IBM-compatible personal computers. EPRI expects the model to be particularly useful for evaluating the economics of emerging FGD technologies.

Updating the data base

Work is in progress on a new round of FGD system economic evaluations. Competitive proposals are currently being evaluated. The successful contractor will revise and update the design and economic premises for FGD process evaluations and develop detailed cost estimates for a selected number of processes to be established when the contract is awarded. The selection will include previously evaluated processes that have been significantly improved, as well as promising new processes. EPRI intends to include emerging dry-sorbent injection technologies in this update, including the following.

- Boiler convection-pass, dry-sorbent injection
- Duct sorbent injection (with upstream flue gas humidification)
- Duct spray drying (simultaneous humidification)
- Hybrid pollution abatement system, which consists of ESP/humidification/dry-sorbent injection/baghouse
- Lurgi circulating-fluid-bed FGD system
- Tampella Lifac SO_2 removal process

As this research proceeds, additional state-of-the-art FGD technologies may develop. If EPRI's preliminary review shows that a process may become commercially feasible, it will be added to the evaluation list. All cost estimates will be updated to reflect the latest economic criteria in the December 1986 publication of EPRI's *Technical Assessment Guide.*

The contract will also provide for updates of the *Retrofit FGD Cost Estimating Guidelines* and the RETROFGD computer program to include data from the current evaluations.

Issues to be addressed

EPRI recognizes the concern (shared by utilities, regulators, legislators, and equipment suppliers) with inaccurate and biased FGD cost estimates. Estimates should be derived from consistent premises and must compare alternative processes on an equal footing. The FGD supplier base has undergone substantial restructuring over the past few years, which has altered pricing strategies. In addition, alloy prices have vacillated widely (numerous alloys have dropped in price). Proper choice of an FGD system can save a utility millions of dollars in initial capital outlay alone. The range of capital costs for commercially available FGD technologies may be as much as $70/kW for nonregenerable systems and $200/kW for regenerable systems. In addition to detailed design estimates, utilities often need quick estimates for screening alternatives for planning purposes, as well as for responding to proposed acid rain legislation.

A number of important issues related to how FGD cost estimates are developed must be addressed in the current update effort. EPRI intends to reevaluate economic and design assumptions used in the previous economic analyses and applied in both the retrofit guidelines and RETROFGD. If appropriate, certain assumptions will be revised. The following are some of the issues that need resolution.

- Use of larger, but fewer, absorber vessels
- Use of alloys and greater differentiation of alloys for components in each process
- Use of alloy claddings
- Reduction in the number of redundant auxiliary components
- Downsizing of the base plant rating
- Modification of the economic analysis to more accurately represent the shorter life spans for retrofit installations
- Inclusion of availability assessments
- Incorporation of recent European and Japanese advances in SO_2 control methods
- Correlation of differential maintenance costs with alternative construction materials
- Adjustment of base case reheat temperature downward to reflect current design practice

Land and Water Quality

Environmental Effects of Organics

by Ishwar Murarka and Jacques Guertin, Environment Division

ABSTRACT *In recent years regulatory attention has turned from inorganic environmental contaminants to organic compounds and their implied health and ecologic effects. Newly proposed regulations directly affect the electric utilities. Utility operations, ranging from advanced fuel combustion techniques to the preservation of wood poles, can introduce organic compounds into the environment. EPRI's EBOS project will provide data to help utilities develop cost-effective plans for controlling organic wastes by identifying the sources and extent of utility-derived organic substances and developing a model to accurately predict the migration of organic waste.*

Until about five years ago, most of the public and regulatory concerns about environmental contaminants centered on inorganic chemicals. However, regulations proposed over the last two years make mandatory the assessment of released organic substances as well. The results of these assessments will then dictate pollution control requirements and prescribe cleanup and remedial action, including limitations on the land disposal of some wastes or even an outright ban on their disposal.

In addition to the regulatory concern there is a responsibility to protect the environment because some of the utility-derived organics could affect human health and the ecology. The utility industry's interest in the environmental effects of organic substances stems from the many utility operations that use organic compounds. For example, wastes from precombustion cleaning of fossil fuel contain organic chemicals that must be disposed of or put to other uses. Advanced technologies, such as fluidized-bed combustion and flue gas cleaning, generate solid residues that contain organics. Runoff from coal piles, herbicides used in rights-of-way maintenance, accumulation of stored fuels and solvents, treated wood poles, and even the sites of former gasworks at which consumer gas was produced many years ago—all are potential sources of utility-generated organic substances.

Because so little is known about how

these compounds are released, transformed, and transported in the environment and what the health-related consequences of their release may be, EPRI has undertaken comprehensive research in its environmental behavior of organic substances (EBOS) project (RP2879). EBOS will address the issue of the environmental effects of utility-derived organic chemicals by developing new data aimed at improving the understanding of their migration in groundwater, surface water, and soil.

A 1986 survey of research needs indicated that the first three to four years of EBOS research should emphasize field and laboratory investigations. Accordingly, EBOS comprises three phases. Phase 1 (1987–1989) will evaluate sample collection and chemical analysis methods and available data for quantifying the environmental release, transport, and biogeochemical transformation of organic substances in the subsurface environment. This phase includes making initial field measurements to describe the distribution and rates of movement for selected organics at sites of old gasworks and at leaking storage tanks containing fuels, oils, or solvents.

Phase 2 (1989–1993) will consist of laboratory and field experiments on leaching, geochemical and microbial transformation reactions, and the transport characteristics of organics as multiphase materials. If needed, phase 3 of EBOS will develop and validate new models for predicting the environmental disposition of organic compounds of interest to the electric utility industry.

In a related project, a preliminary technical evaluation contract was awarded in early 1986 to the University of Michigan, its purpose being to evaluate multiphase flow and transport computer models for describing the movement of organic compounds in the subsurface environment (RP2377-5). Researchers at the university searched the literature for efforts to develop mathematical models that simulate the movement of selected organics as miscible and immiscible fluids. The results of the review show that multiphase flow and transport models for organic compounds are in their infancy (Table 1). A major problem is to accurately represent the geochemical and microbiologic processes that control the release and transformation in the wastes and subsequently in the geologic media. The available computer codes are also very costly to use.

Table 1
MULTIPHASE FLOW AND TRANSPORT MODELS

Model Type	Authors
Immiscible multiphase flow and transport	Abriola and Pinder (1985)
	Faust (1985)
	Hochmuth and Sunada (1985)
	Osborne and Sypes (1986)
	Kuppusamy et al. (1987)
Immiscible vapor-phase transport	Allan (1986)
	Baehr and Corapcioglу (1987)

The computer codes reviewed fall into two categories. The first deals with immiscible multiphase movement of organic compounds in the subsurface. The second group represents vapor-phase movement for volatile organics, and these codes are based on transport mathematics.

A forthcoming report of this research will provide a critical and comprehensive review of existing models and will compare the approaches to model design that are proposed for addressing the complex issues of the EBOS project. The report will also describe those aspects of the study that require immediate research attention. Follow-on research into appropriate models will be conducted under a subsequent EBOS contract (RP2879-5).

EPRI awarded the first EBOS contract to Cambridge Analytical Associates (with Atlantic Environmental Services as a subcontractor) in July 1987 to begin an evaluation and case studies of selected organic compounds (RP2879-1). The research team will select two field sites (a gasworks waste site and a leaking fuel storage tank site) from a statistically adequate grouping of candi-

COMPOUNDS FOR EBOS STUDY

Polycyclic Aromatic Hydrocarbons

Acenaphthene
Acenaphthylene
Anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene
Benzo[*g*,*h*,*i*]pyrelene
Benzo[*k*]fluoranthene
Chrysene
Fluoranthene
Fluorene
Indeno[1,2,3-*cd*]pyrene
Naphthalene
Phenanthrene
Pyrene
1,2,5,6-dibenzanthracene
2-methylnaphthalene

Monocyclic Aromatics

Benzene
Cresol
Ethyl benzene
Nitrobenzene
Nitrophenol
Phenol
Toluene
Xylene
Xylenol
4-methylphenol

Heterocyclics

Carbazoles
Dioxins
Furans
Pyrans
Pyridines
Pyrroles
Quinolines

Halogenated Compounds

Chlorophenol (e.g., pentachlorophenol)
Chlorobenzene
Halomethane (e.g., chloroform, dichloromethane)
Tetrachloroethylene
Trichloroethane
Trichloroethylene

Other Compound Classes

Carbon disulfide
Creosote
Cyanide (including nitriles)
Diesel fuel
Gasoline
Hydrazines (including azo compounds)
Phthalates

date sites to permit the characterization and evaluation of field sampling and chemical analytic methods for the organic compounds listed (page 51). Researchers will statistically analyze the field data to obtain a preliminary description of leachate generation, biogeochemical transformation, and transport processes at these sites.

Early in this study, available measurements of environmental distribution and waste characteristics for the gasworks site will be evaluated so that inferences can be drawn about the environmental processes controlling the release and mobilization of organic compounds. In the initial field sampling researchers will collect and preserve soils, interstitial fluids, and interstitial gas samples for chemical analysis. Microbiologic activity associated with the spatial distribution of waste chemicals will also be determined. Where necessary, upwind and downwind air samples near the site surfaces will be collected to detect any emissions of the volatile organics. The sampling and chemical analysis are geared toward defining vertical as well as areal concentration profiles for the selected organic compounds. In addition, subsurface environmental characteristics, such as pH, Eh hydraulic conductivity, porosity, soil mineralogy, density, and water flow velocity, will be measured.

All these data will be analyzed to describe empirically (and fundamentally, to the extent possible) leaching characteristics, retention strengths, degradation and transformation forms, and migration rates for the selected organics. This research will provide a few early answers by identifying site-specific mechanisms and developing hypotheses for predicting the release, attenuation, degradation, and transport of organic compounds. This research is scheduled for completion at the end of 1989.

A second EBOS contract was also awarded in July 1987. It provides for an evaluation (by Tetra Tech) of pertinent work, both current and planned, on the characteristics that influence the transport, transformation, and disposition of the organics listed. This work will determine what is known about the fundamental properties of those constituents of wastes that find their way into the land and water environment. It is scheduled for completion at the end of September 1988.

The phase 1 EBOS studies will address key issues about organics with which the electric utility industry must deal. The near-term results of this research should be useful to utilities responding to groundwater contamination by organic components. Subsequent EBOS research should make possible the prediction of long-term migration patterns of organics and should therefore help utilities develop cost-effective plans for controlling or correcting contamination at sites where drinking water supplies must be protected.

Electric Transportation

Commercialization of Electric Vans

by Gary Purcell, Energy Management and Utilization Division

Electric vehicles (EVs) offer a number of potential advantages: they are quiet and clean, and in widespread use would promote a desirable shift from oil to the more abundant domestic energy sources used to generate electricity. EVs could be a major new source of off-peak sales for the utilities that would provide better load management without large capital investment. They would also provide an opportunity for the utilities to increase revenues through local EV sales and service and battery leases. EVs are already performing well in service fleets and could have the range and speed to compete as passenger vehicles in the near future.

Concentrating first on technology for electric fleet vans, EPRI is sponsoring R&D on batteries, power trains, and test vehicles that could greatly improve EV performance in the next five years.

The Griffon: Today's EV

In 1984 the Electric Vehicle Development Corp. (EVDC), EPRI's EV-marketing counterpart, began a series of demonstrations with partial funding from EPRI (RP1569-10). The purpose of the program was to demonstrate how far EV technology had advanced and to identify the outstanding R&D issues that had to be addressed before EVs could compete with vehicles powered by internal combustion engines in commercial transportation markets. The General Motors Griffon, the first contemporary production-line EV, was chosen as the introductory vehicle because of its proven performance in service fleets in England. In addition, the Griffon was the first EV for which full manufacturer warranties and service were offered.

Since 1985, 31 Griffons (manufactured by General Motors' Bedford Commercial Vehicles Division, Luton, England) have been introduced into the service fleets of 11 utilities in the United States and Canada. As of June 1987 they had been driven almost 300,000 miles (482,700 km) in a variety of uses, including customer service, employee transport, parts delivery, and public relations. Although economic conditions in the United Kingdom caused Griffon production to be suspended in 1986, the Griffon continues to chalk up miles in the service fleets of utilities participating in the demonstration program. This field test has provided valuable information about design features and component improvements that

ABSTRACT *Electric vehicles (EVs) are promising alternatives to gasoline-powered cars and light trucks in certain use-specific applications. They also constitute the utilities' largest potential new market for electricity. The reliability and practicality of the Griffon, a special-purpose electric van now being demonstrated at several U.S. and Canadian utilities, have been established. Lead-acid batteries give the Griffon a range of about 60 miles (97 km) and a top speed of about 50 mph (80 km/h). Current testing indicates that the electric G-Van, based on the General Motors Vandura, will match the Griffon's performance, while accommodating a 25% larger payload. Also currently being developed, the Chrysler TEVan will employ a nickel-iron battery, giving the TEVan better acceleration, higher maximum speed, and much longer range. Moving into the 1990s, high-performance batteries and a switch to ac power trains will allow EVs to compete in a much broader market.*

will make future EVs commercially competitive in North America.

Griffons at Detroit Edison and Hydro-Quebec have been used to test the effectiveness of a new battery heating system, following initial evaluation of the system at the EPRI- and TVA-funded Electric Vehicle Test Facility (EVTF) in Chattanooga, Tennessee. Similarly, a Griffon owned by TVA has been used as a test bed for an experimental air conditioning unit. The Griffon is also being used to pretest the new Lucas Chloride EV Systems (LCEVS) electronic controller and improved lead-acid battery slated for the upcoming electric G-Van.

Besides serving as a test bed for EV improvements, the Griffon has helped dispel the public image of EVs as unreliable "experimental" vehicles. At auto shows, at ride-and-drive events, and at international EV symposiums, demonstrations of the Griffon's 53-mph (85-km/h) top speed and 60-mile (97-km) range per charge have helped bring the public up to date on the state of EV development.

In a related effort, Detroit Edison sponsored a Griffon loan program in 1986. Eleven of that utility's commercial customers, including a florist, a state university, and an auto parts store, were given Griffons to use for a one-month trial. Ten of the 11 found that the Griffon met their fleet needs. Fleet owners were impressed with the van's average energy consumption of 1.08 kWh/mile; at 5¢/kWh (a typical off-peak rate), the Griffon's "fuel" cost was 5.4¢ per mile; fuel costs for a conventional van of similar size and load capacity would be 8–10¢ a mile.

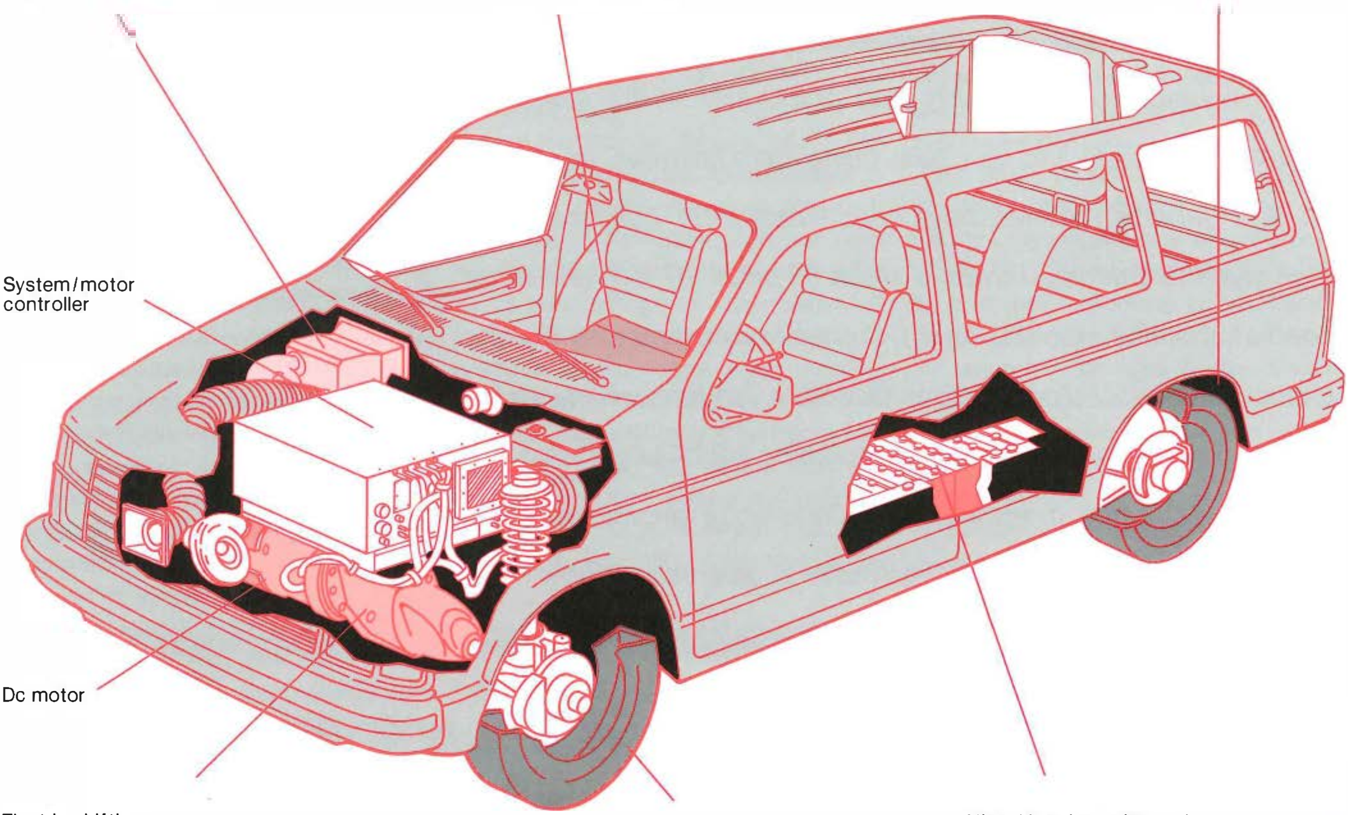
In addition to its value as a fleet van, a test bed, and an EV-promotion vehicle, the Griffon was provided with the first comprehensive EV support system. That system now includes service representatives, parts warranties, vehicle and component manuals, and a spare-parts distribution network. Building from this foundation, EPRI, EVDC, and other EV supporters are working to ensure that next-generation EVs are backed by a solid network of support from the automotive and electric utility industries.

G-Van and TEVan: Next-generation EVs

Following the suspension of Griffon production in England, EPRI and EVDC accelerated work on the next phase of the demonstration program—domestic production of an improved van. U.S. production would make electric vans more cost-competitive with conventional vans by eliminating import duties and the cost of retrofitting vehicles to conform with federal safety standards. Proximity of the manufacturer to the market would also make it easier to meet market design requirements and would simplify the organization of the service structure. Currently, EPRI is funding van-development projects designed to lead to domestic production of two commercial EVs in the next three years: the G-Van and the TEVan.

The G-Van project is being conducted for EPRI by General Motors, LCEVS, and Cars & Concepts (a specialty vehicle manufacturer in Brighton, Michigan). The first G-Van will be produced at Cars & Concepts with funding from EPRI (RP2664-3). It will have the body of a General Motors Vandura and operate on LCEVS HED-88 lead-acid batteries (an improved version of the LCEVS EV-5T lead-acid battery used in the Griffon), an upgraded controller and motor, and a single-speed transmission. This new battery and set of components will allow the G-Van to maintain the Griffon's range per charge—60 miles (97 km) or more—even given its 25% greater cargo space and payload capacity. The G-Van will be offered in both cargo and passenger configurations. Power

Figure 1 Next-generation TEVan. The body is that used in the Dodge Caravan and Plymouth Voyager minivans. Configured as a cargo van, the TEVan has a 120-ft³ cargo area and a 1500-lb payload capacity; configured as a passenger wagon, it can hold seven passengers. The nickel-iron batteries and compact electronics provide better acceleration, higher maximum speed, and longer range. Prototype tests are scheduled in 1988, and full production is planned for late 1989.



steering and power brakes will be standard, and air conditioning will be available as an option.

The G-Van was tested at EVTF in late 1987. Plans call for field-testing 10–15 prototype vans at selected utilities in the first half of 1988, with full production beginning in September 1988. The vans will be available through the General Motors national dealership network, which will also provide parts and service. Ordering will be arranged by EVDC.

To broaden the EV market, EPRI is also supporting development of the Chrysler TEVan (RP2664-4). The TEVan will feature the popular Chrysler T-115 minivan body used in the Dodge Caravan and Plymouth Voyager (Figure 1). Powered by a nickel-iron battery providing approximately 50% more energy storage capacity than the Griffon's EV-5T lead-acid battery, the TEVan will have a range per charge of over 110 miles (177 km). The van's size and range, along with its top speed of 65 mph (105 km/h), will make it competitive as a passenger fleet vehicle. (Performance specifications of the Griffon, G-Van, and TEVan are shown in Table 1.)

To save on propulsion system weight and decrease vehicle cost, the TEVan will be equipped with a compact electronics package in which the controller, charger, and dc-dc converter are combined into a single unit. This unit will also have a microprocessor-run management system to monitor battery temperature, hydrogen concentration, watering, and charging. This should limit the need for battery maintenance to twice a year. The TEVan will be equipped with front-wheel drive, power brakes, electric power steering, and an electronically shifted two-speed transmission.

Table 1
PERFORMANCE AND LOAD SPECIFICATIONS

	Griffon	G-Van*	TEVan*
Acceleration 0–30 mph	11	11	7
Top speed (mph)	53	53	65
Range (miles)	60	60	110
Cargo space (ft³)	208	256	120
Payload (lb)	1900	2400	1200

*Projected

In August 1987, with funding from EPRI, DOE, and Southern California Edison, Chrysler began work on two proof-of-concept TEVans at its subsidiary, the Acustar Co. in Huntsville, Alabama. The vans will be tested at EVTF in 1988, and production will probably begin in late 1989 or early 1990. As with the G-Van, the first TEVans will be offered to electric utilities for field testing.

EV vans of the 1990s

The electric van of the 1990s will feature two key improvements in technology: a high-performance battery and an ac power train. These improvements will give EVs the range and speed they need to compete in a broad range of vehicle markets.

Two types of high-performance batteries, lithium-sulfide and sodium-sulfur, are being considered for use in the advanced van; both are capable of extending the van's energy and power capabilities. Development of the lithium-sulfide battery (*EPRI Journal*, January/February 1987, p. 50) is being conducted with EPRI funding at Gould Inc. (RP2415-1) with support from Argonne National Laboratory (RP2216-2); the battery should be ready for in-vehicle testing by late 1988. The advantages of the lithium-sulfide battery for EV propulsion lie in its better range per charge (2–3 times better), better acceleration, and higher top speed than current lead-acid batteries can provide.

The ac power train slated for the 1990s van will use an ac induction motor projected to be some 50% lighter and 75% cheaper than a dc motor of comparable power. Transistors in small, lightweight power inverters will change the battery's dc power into ac power for the motor. The ac power train will provide one of two advantages: 10% lower initial vehicle cost at a constant range per charge, or a 10% greater range per charge at a constant vehicle life-cycle cost.

EPRI is funding ac power-train research at the Jet Propulsion Laboratory (RP2861-1) and is monitoring DOE-sponsored propulsion projects under way at Ford Motor and the Eaton Corp. By 1991 EPRI plans to fund the testing of the most promising high-performance battery and ac power-train options in a van.

Another future EV option being pursued by EPRI is the extended-range electric vehicle (XREV). The XREV would be powered by an electric motor and a small, supplementary gasoline engine–driven generator. Designed to be used only for occasional long trips, the generator would delay the discharge of the propulsion battery by means of an "intelligent" controller, thus augmenting the energy capacity of the battery and extending the vehicle's range per charge. For routine trips, the vehicle would be powered by the propulsion battery alone; as in other EVs, it would be recharged overnight.

With the added capacity of the generator, an XREV could achieve a range of 200–400 miles (322–644 km), making it particularly suitable for urban and suburban driving or other uses requiring only infrequent long-distance travel.

Commercial electric vehicles offer a number of potential advantages for the public as well as for the utilities. From experience gained with the Griffon to today's emphasis on the domestically produced electric G-Van and Chrysler TEVan and on to research and development for the advanced van and extended-range EVs of the 1990s, EPRI continues to support and develop this promising new market for utility-generated electricity.

Generating Equipment

Motor and Generator Reliability

by J C. White, Electrical Systems Division

The most common rotor defects in squirrel-cage induction motors are open-circuited rotor bars and cracked end rings. A recent EPRI study of power plant motor failure indicated that 5% of all failed motors did so for that reason (EL-2678). If such defects could be detected at an early stage, it would be possible to repair the motor at a lower cost than if the motor were to fail in service.

As reported in May 1985, EPRI funded research to develop a detector that reliably indicates the presence of rotor cage defects (RP2331). A prototype device has been assembled by the contractor (General Electric) and is currently undergoing field trial at a dozen member utilities.

The prototype—which consists of a stand-alone PDP 11/73 computer, graphics terminal, printer, and equipment rack with electronic circuitry—monitors motor external leakage flux and line current signals (Figure 1, page 56). The leakage flux signal derives from a multiturn coil that is placed on the outside of the motor at the outboard end. The current signal can be obtained from the existing current transformers or from a clip-on CT. Motor disassembly is not required. The broken bar detector can be installed and activated while the motor is under load and at constant speed.

The detector diagnoses the defects while the motor is running. The automated data acquisition and processing takes about 20 minutes for one load point. Subsequently, the results (in the form of current and flux spectra) can be viewed at the computer terminal or printed out.

The final report (to be available this spring) includes the independent assessment by the host utilities and the commercialization plan.

ABSTRACT *Plant operators can take advantage of modern detection equipment to prevent costly outages. Detectors that can be installed while a motor is under load, for example, can discover open rotor bars. The motor can then be repaired at lower cost than if it had failed. This report describes a number of such diagnostic and preventive maintenance actions that power plant engineering and operations personnel can use to improve plant reliability, availability, and efficiency.*

Surge protection

Ontario Hydro is currently studying the surge environment of large generators, including the effect of generator circuit breakers (RP2594). This research was prompted by changes in technology, such as the increased use of generator breakers, zinc oxide surge arresters, and higher transmission voltages, as well as the failures of large generators. The study includes a survey of generator protection practices and utility experiences, as well as analysis of the generator surge environment and the tested withstand strength of several machines. Although this project is still in progress, several results are worth noting.

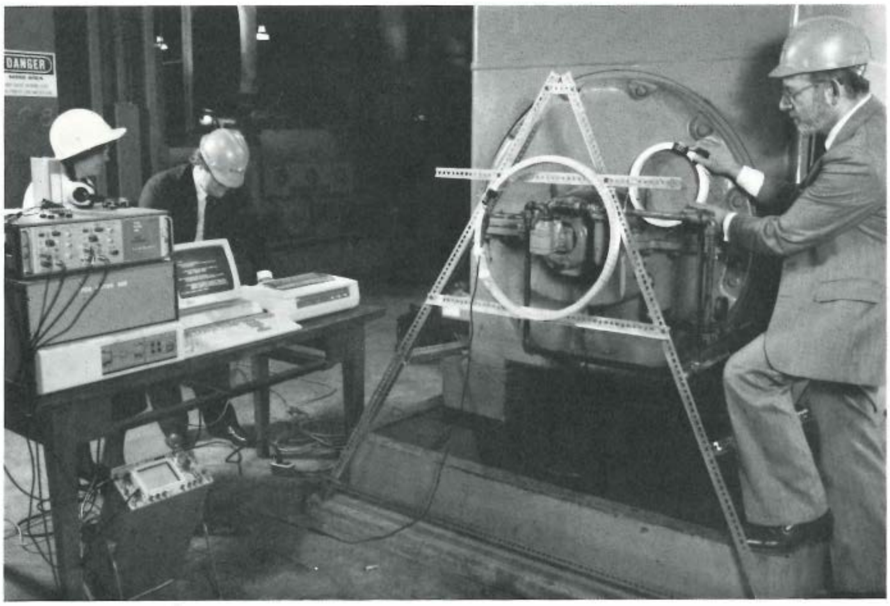


Figure 1 Prototype open rotor bar detector applied to a motor driving a boiler feedpump. The external leakage flux coil, mounted on the A-frame, and the split-core current transformer (not visible) provide signals that are analyzed by the detector. The signature characteristic of a broken rotor bar can be viewed on the computer screen or on a printout.

- Survey results indicate that failure of generator insulation is relatively rare.
- Generator circuit breakers have made a fairly large penetration into the U.S. utility industry; 84 units have been supplied since 1977. Where no zinc oxide surge arresters are used, the failure of one phase of the generator circuit breaker to open and a bus fault can lead to voltages in excess of five per unit. Steep-fronted surges that result when a generator circuit breaker closes and energizes the generator out of phase with the system can exceed five per unit.
- The impulse-to-60-Hz withstand ratio of two generators tested to date exceeded 180%. The commonly used value for coordination is 125%. If the tested ratio on the two machines proves representative, it may result in unduly low protection levels and increased risk of surge arrester failures during temporary overvoltages.

A technical paper describing the results to date was presented at the IEEE Winter Power Meeting in February 1987 (IEEE Paper 87 WM 216-5). Dielectric tests on a third machine are under way. Computer models of usual and unnatural generator surge conditions are being developed. The project is scheduled to be completed by the end of 1987.

Plant construction and maintenance

An important milestone has been reached in a project that will provide considerable benefit to the utilities in a very practical sense. A 15-volume power plant electrical reference series has just been published. The objective of this series is to fill a vacuum.

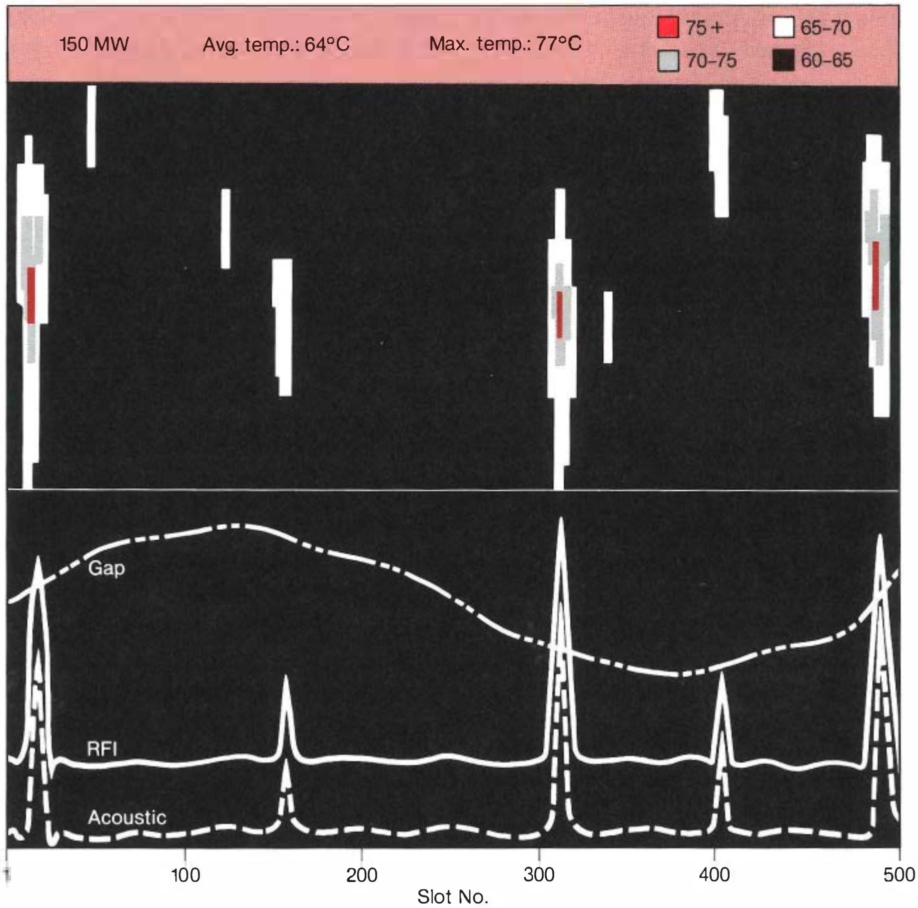
Some years ago, Westinghouse, General Electric, and other manufacturers produced extensive reference material covering their products and utility applications. This information appeared not only in instruction books and pamphlets but also in more-general reference materials of considerable size. These sources were extremely important to utilities in the design, construction, application, operation, and maintenance of power plants. About 15 years ago, however, the manufacturers stopped publishing this kind of information.

The original sources are out of print, and a great deal of new information has been generated in the intervening years. Unfortunately, this new information, in particular, is scattered to such an extent that engineers or operations personnel in utilities have access to only a small fraction of it. The objective of an EPRI project was to gather together as much of this information as possible from all the sources (RP2334). The information about the state of the art is up to date and adds results from EPRI research that can be directly applied by utilities.

Stone & Webster Engineering wrote the series under the guidance and criticism of a team of utility experts who studied each volume in considerable detail. The first volume (number 9 in the series) on direct-current systems was published in mid 1987 and has been well received by utility people who have reviewed it.

The price of the entire 15-volume set is $15,000. Member utilities can order the set without charge because it is covered by their EPRI dues. Certain college professors and government employees can receive a complimentary set, as determined by EPRI's normal publishing policy. All others, including nonmember utilities, will pay the full price per set. Individual volumes may be ordered for $1000 each.

Figure 2 Data from the generator scanner on the hydroelectric generator at Boundary Dam: stator hot spots (top) and evidence of corona discharge (RFI), loose wedges (acoustic), and the air gap dimension (bottom).



Induction motors

More than 60% of all electric power generated in this country is consumed in motor drives. In fact, 9% of all electric power generated in the country is consumed in the power plant, primarily in motor drives. A significant improvement in motor efficiency will result in a substantial improvement in operating costs for utilities and their customers. A recently completed project, directed at satisfying the need for improved efficiency of all sizes and types of induction motors, has met its goals (RP1944). The contractor was the University of Colorado at Boulder, and the final report has been published in three volumes, *Optimization of Induction Motor Efficiency* (EL-4152).

The first phase was a study of three-phase motor design, and the results were published in 1985—Volume 1: Three-Phase Induction Motors (CCM). The next phase was a thorough exploration of a technique proposed by C. L. Wanlass for improving three-phase induction motor efficiency and was published in 1986—Volume 3: Experimental Comparison of Three-Phase Standard Motors With Wanlass Motors.

The final volume of this report was published in 1987—Volume 2: Single-Phase Induction Motors—and is discussed below.

To reduce the costs of induction motor design and fabrication, motor manufacturers have had to compromise efficiency. To respond to market demand for higher-efficiency motors, manufacturers have added copper and magnetic materials, thus increasing frame size. However, the true key to improving efficiency lies in optimizing the motor design with the highest possible efficiency as the primary objective, rather than the lowest cost. This is particularly important in the small, fractional-horsepower motors, largely single-phase, which historically have had the lowest efficiencies.

The analytic approach used in EL-4152, Vol. 2, by the contractor resulted in the development of a nonlinear model for a single-phase motor. The model was then incorporated into a new optimization software package capable of handling the model's complexity and nonlinearity. Using the software, studies were made of the effects of production cost, electrical steel properties, power factor, and other motor design parameters on maximum efficiency. The following results were verified through extensive tests.

□ Improving efficiency of a standard single-phase induction motor is possible without increasing cost.

□ Optimizing design alone improves efficiency by about 4.5%.

□ Optimizing the run capacitor can increase efficiency 5% without any increase in cost other than the additional cost of the larger capacitor.

□ Optimizing the winding design can increase efficiency 1.5%.

□ Converting to low-loss electrical steel results in a 0.5% improvement in efficiency, with some added cost.

The methods developed in this project, devised primarily for motor designers, will greatly help in the design, construction, and testing of single-phase motors with the highest possible efficiency.

Rotor scanner

Another milestone was reached in May 1987 when a newly developed hydroelectric generator rotor scanner was demonstrated in the field for Seattle City Light (RP2591-5). The contractor, Spectra Technology of Bellevue, Washington, obtained CRT displays and plots in its office, 400 miles from the host machine, City Light's hydrogenerator at Boundary Dam near Canada. "We had already decided that excessive heat in a number of stator coils in a generator at Boundary would lead to failure, probably during spring run-off this year," said Bob Youngs, chief electrical engineer at Seattle City Light, "but this instrument gave us the surveillance that enabled us to continue full-time operations at reduced rating, thereby forestalling an expensive shutdown (worth $1.5 million) during the generator's period of maximum revenue this past spring." Shutdown for maintenance has been postponed indefinitely and, even then, may simply amount to cutting out a few coils that are overheating and returning the unit to service.

The scanner is a simple, effective device for monitoring the stator from the vantage point of the rotor. Sensors mounted on the rotor sweep over the entire stator once each revolution. These electronic sensors provide data on temperature distribution, partial discharge activity, and acoustic noise at each coil, and locate any stress in the stator precisely—for example, by the slot (Figure 2). Infrared detectors mounted in the sensor bridge monitor temperature distribution. The signals from all sensors are processed electronically, converted to light signals, and transferred to optical receptors mounted on the stator. There they are fed to a minicomputer for final processing and display.

The Bonneville Power Administration has agreed to cofund and host a second field installation. The machine chosen for tests has known problems, and the data collected will be used to determine the extent of repairs needed.

The basic concept of the monitor could apply equally well to turbine generators; the principal barrier to overcome is finding a suitable place on the rotor to mount the sensors.

Nuclear Power Plants

Nuclear Construction Issues Group

by Warren Bilanin, Nuclear Power Division

In early 1984 nuclear industry representatives met at an ASME-sponsored forum on nuclear plant construction issues. The consensus of the forum participants was that utilities constructing nuclear generating stations were experiencing common hardware quality problems for which likely solutions existed and should be pursued. At subsequent meetings of utility representatives, participants agreed that although a number of construction issues could be addressed, developing weld acceptance criteria and inspection guidance for structural welds should be the first task undertaken.

The utilities formed the Nuclear Construction Issues Group (NCIG) and developed visual weld acceptance criteria (VWAC). The criteria eventually included a VWAC manual, sampling plan, training program, and an ASME code case for similar types of welds. The Nuclear Regulatory Commission (NRC) issued a review letter favorable to VWAC on June 26, 1985. Since then, utilities have implemented VWAC at a number of nuclear plants. In addition, ASME Code Case N-430, allowing the use of VWAC for code piping supports, has been approved and published. Contributing to the timely development and success of VWAC was the voluntary participation by a number of technical representatives from major architect/engineer (A/E) organizations and a direct, positive interaction with NRC regulatory staff throughout the criteria development.

With the completion of VWAC, NCIG members decided to pursue a number of additional activities to effectively resolve other issues associated with engineering, construction, modification, and repair of nuclear power plants. In December 1985 members requested that EPRI serve as program manager for NCIG, and the Institute accepted this responsibility. NCIG has now been established as a jointly funded EPRI Owners Group Program.

NCIG has the following objectives.

□ Develop a common approach to the resolution of issues acceptable to the nuclear industry and NRC, as appropriate, in construction, modification, and repair of nuclear power plants

ABSTRACT *The Nuclear Construction Issues Group, under EPRI sponsorship, is composed of a number of utilities that work to resolve technical issues associated with engineering, construction, modification, and repair of nuclear power plants. The group is designed to be a vehicle for obtaining practical, engineering-based solutions to problems in these areas. With the success of its first project, development of visual weld acceptance criteria, NSIG has expanded its activities to seven new tasks, including procurement and use of commercial-grade items, modification and design control, and issues related to use of computers in nuclear plants.*

▫ Provide a forum for sharing information on nuclear issues with industry organizations and societies and obtaining their support in the resolution of NCIG issues

▫ Provide support for NCIG-developed documents to maintain consistency with industry changes until these documents are incorporated, as appropriate, into established consensus standards

▫ Support the needs of NCIG members and pursue those technical tasks that are generally applicable to the nuclear industry

Twenty-two domestic utilities support NCIG activities. Utilities that accept and fund one or more NCIG tasks are members. Although they may not fund NCIG tasks, other utilities provide active technical support and participate in NCIG activities. In addition, eight A/E organizations currently support NCIG on a regular voluntary basis. EPRI–NSIG tasks are coordinated with INPO, NUMARC, and other industry organizations, as appropriate.

NCIG operates as a jointly funded EPRI Owners Group Program. The NCIG organization rapidly develops effective engineering solutions to plant modifications and construction problems that affect a number of utilities. NCIG, chaired by a selected utility representative, meets every two or three months. Interested utilities propose candidate tasks. Once approved by EPRI/NCIG, each task is controlled by a task group, which is chaired by a utility representative. In general, an EPRI contractor is responsible for completion of all or part of an NCIG task. Personnel from NCIG utilities, interested A/E organizations, and EPRI all help review and complete a task. Meetings are held on individual subjects as necessary. The task group chairman reports the status of a given task at NCIG meetings. Task completion usually includes review and concurrence with a task product by NRC and/or adoption by the appropriate codes and standards group. This broad participation helps ensure the usefulness and quality of the products and strengthens NCIG recognition as being representative of the nuclear utility industry. EPRI provides technical, administrative, and contractual management and jointly funds NCIG activities. Information and reports on all ongoing and completed tasks are available to all EPRI member utilities.

NCIG task groups are working on seven tasks at present: technical data requirements for plant maintenance and operations, guidelines for piping system reconciliation, nuclear power plant welding issues, commercial-grade items, modification and design control, nuclear plant specifications, and computer issues. All NCIG tasks are coordinated with other industry organizations, as appropriate, to ensure consistency and avoid duplication.

The purpose of the first task—technical data requirements for plant maintenance and operations—is to provide engineering-based guidelines for retention of essential plant data and to identify acceptable actions when essential data are not readily available. Over the last decade, conservative interpretations of existing codes and regulations required that large numbers of records be retained at plants. Lack of uniform industry guidance resulted in all data being retained in many cases. Maintaining all records is expensive, and because of the quantity of stored information, rapid retrieval of specific data can be difficult and time-consuming. NCIG will request that NRC and the appropriate ASME organization accept these guidelines. NCIG has formally transmitted a report to NRC and responded to NRC comments. NCIG expects NRC to accept these guidelines in the first quarter of 1988.

The purpose of the guidelines for the piping system reconciliation task is to publish a document for reconciling as-built piping systems with final piping system design on the basis of the acceptance criteria (tolerances on the as-built piping system geometry) specified in Welding Research Council (WRC) Bulletin 316, *Technical Position on Piping System Installation Tolerances.* The NCIG guidelines document will implement the WRC bulletin tolerances, provide a practical set of instructions for reconciling piping system designs with as-installed configurations, and provide for uniform application of the WRC bulletin tolerances by plant owners. NCIG will request NRC acceptance of these guidelines. A report was formally transmitted to NRC, and NCIG is resolving NRC's comments with the commission staff.

NRC acceptance of this task product is expected in early 1988.

The nuclear power plant welding issues task group addresses various issues concerning interpretation and use of welding codes. The group's purpose is to improve the quality and efficiency of nuclear power plant welding. Welding issues addressed include proposed code revision requests, code requirements for control of filler materials, weld acceptance criteria for sheet metal, interpretation of American Welding Society fabrication/erection versus verification inspection requirements, and guidelines for engineering evaluation and disposition of structural welding discrepancies identified by visual examination. Additional issues will be identified and addressed on an ad hoc basis.

All aspects of the procurement and use of commercial-grade items (CGIs) in safety-related applications are not completely or clearly defined by existing regulations or standards. The purpose of this task group is to provide a document for the nuclear industry that will address the procurement and use of CGIs in safety-related applications. The task group has the following objectives.

- Research and compile existing codes, standards, regulations, and guidelines relevant to the procurement and use of CGIs
- Investigate and compile existing utility practices and procedures related to the procurement and use of CGIs
- Develop a generic CGI process and publish it with examples in different CGI categories
- Coordinate industry review of the published document
- Coordinate incorporation of the generic process, as appropriate, into the industry codes and standards

This task was initiated in January 1987 and completed in December 1987.

Emphasis is continuing on the modification and design control (MDC) of safety-related systems, components, and structures. NRC inspection reports continue to identify generic MDC problems, which raise concern that the MDC process may need improvement or clarification. The purpose of this task group is to publish guidelines for eliminating or minimizing recurring generic problems in the MDC processes currently being used by individual utilities. The task group has the following objectives.

- Use existing information from NRC reports, LERs (licensee event reports), and utility-initiated review and improvement programs that have identified problems in the MDC process
- Identify problems generic to the MDC process, such as those that occur at a large number of plants and tend to be consistent over time
- Analyze identified problems for root causes
- Provide utilities with analysis results and recommendations for evaluating current MDC processes.

This task was initiated in January 1987 and completed in December 1987. NCIG will continue to coordinate efforts of this task group with other related work being carried out by INPO and the Nuclear Safety Analysis Center.

Nuclear plant specifications are used in almost all phases of procurement and installation. Because of the need to reduce plant capital and operating costs, attention should be given to simplifying the specifications without sacrificing essential elements of safety. The purpose of this task is to develop guidelines for preparers and reviewers of future nuclear plant specifications by establishing good specification practices. This task was initiated in early 1987 and completed in December 1987.

The use of computers and computer services in nuclear power plant applications continues to increase as in other highly technical areas. However, unique to the nuclear industry are the quality and regulatory requirements applied to safety-related activities. The purpose of this task is to address computer issues relating to design of, and regulatory requirements for, computer hardware and software used in safety-related applications. The task group will resolve issues by establishing industry methods and approaches necessary to ensure compliance with quality commitments, promote uniform solutions to computer problems, and focus attention on ways to improve the cost-effectiveness of computer applications without reducing quality. The task group has the following objectives.

- Prepare position papers to establish standards for compliance and interpretation of computer issues in the industry
- Develop revision requests for codes and standards, including any required presentation before the subject codes or standards organization
- Reach agreement with the industry on the acceptability of solutions to computer problems
- Provide improved communications within the industry for promoting uniformity

This task was initiated in early 1987 with the selection of specific computer issues to address; it is scheduled for completion by the end of 1988.

The results of the various EPRI/NCIG efforts to date have established the effectiveness of the organization at identifying and accomplishing needed industry activities. Utility leadership and A/E participation are essential. This participation ensures the usefulness and quality of the NCIG task products and strengthens NCIG recognition as being representative of the nuclear utility industry. The resolution of generic engineering and construction problems on the basis of accumulated industry experience and sound engineering principles represents a prudent use of industry resources.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Advanced Power Systems		
Storage Model Commercialization (RP1084-31)	$76,155 10 months	Energy Management Associates/*R. Schainker*
Cerro Prieto Field Test of Upstream Reboiler (RP1197-6)	$96,230 63 months	Instituto de Investigaciónes Eléctricas/*E. Hughes*
Use of Slag for Production of Synthetic Lightweight Aggregate (RP1654-38)	$35,404 1 year	Praxis Engineers, Inc./ *S. Alpert*
Development of Fuel Cell Demonstration Project Plan (RP1677-17)	$25,000 2 months	Flynn & Associates/ *E. Gillis*
Turning-Gear Operation/Blade Walking Problems in Gas Turbines (RP1802-9)	$69,313 4 months	Southwest Research Institute/*R. Frischmuth*
Coal Agglomeration Subscriber Agreement (RP2655-93)	$80,000 63 months	Northeast Utilities Service Co./*L. Atherton*
Phased Construction for Dow GCC Plants (RP2690-11)	$167,767 10 months	Fluor Technologies, Inc./ *M. Gluckman*
Evaluation: Phased Texaco-Based Kraftwerk Union Combined-Cycle Power Plant (RP2699-10)	$249,875 8 months	Fluor Technologies, Inc./ *M. Gluckman*
Intermediate Temperature Solid-Oxide Electrolytic Characterization (RP2706-4)	$30,000 11 months	Solid-State Fuel Cells, Inc./*G. Cook*
Geotechnical Reconnaissance: Carpenter Dam (RP2917-1)	$10,000 56 months	Arkansas Power & Light Co./*D. Morris*
Coal Combustion Systems		
Investigation: International Experience With Coal Pulverizer Fires and Explosions (RP1266-46)	$27,500 8 months	Brigham Young University/ *D. Broske*
Scoping Study: Dry SO_2/Particulate Control (RP1402-36)	$26,997 3 months	ADA Technologies, Inc./ *R. Altman*
AFBC Fabric Filter Monitoring (RP2303-21)	$50,000 18 months	Southern Research Institute/*T. Boyd*
Technology Transfer: Fossil Fuel Plant Controls (RP2710-5)	$34,315 17 months	Science Applications International Corp./ *S. Divakaruni*
Demonstration: EPRI Heat-Rate Improvement Guidelines, North Omaha Unit 5 (RP2818-5)	$85,000 20 months	Omaha Public Power District/*B. Leyse*
TVA 10-MW Spray Dryer–Electrostatic Precipitator Pilot Plant Facility (RP2826-1)	$60,000 34 months	Tennessee Valley Authority/*R. Rhudy*
Economic Modeling: SO_2 and NO_x Control by Combination of Multiproduct Coal Cleaning and Fluidized-Bed Combustion (RP2924-2)	$90,000 1 year	Decision Focus, Inc./ *D. O'Connor*
Fluidized-Bed Combustor System Characterization, Differential Pressure Probes (RP8006-7)	$25,000 1 year	CSIRO, Division of Mineral Engineering/*J. Stringer*
Electrical Systems		
Integration of HVDC Links in Large Ac Systems—Program Modifications and Maintenance (RP1964-4)	$30,000 20 months	Manitoba HVDC Research Centre/*N. Bahr*
EMTP Code Development (RP2149-10)	$135,000 1 year	Power Computing Co./ *M. Lauby*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Portable Conductor Thermal Monitoring (RP2546-3)	$55,925 5 months	Pacific Gas and Electric Co./*V. Longo*
Advanced Trench Compaction Device (RP2769-1)	$140,000 25 months	Foster-Miller, Inc./ *T. Kendrew*
Energy Management and Utilization		
Development and Demonstration of an Extended-Range Vehicle (RP1136-92)	$42,000 18 months	Los Angeles Dept. of Water & Power/*G. Purcell*
Program Plan: Identification of Emerging Metals Production and Fabrication Technologies (RP2729-2)	$25,000 8 months	Daedalus Associates/ *R. Jeffress*
ETS Applications Guide and Product Directory (RP2731-5)	$25,000 7 months	George Reeves Associates, Inc./*V. Rabl*
EAF Model Assessment (RP2863-2)	$46,655 5 months	Xenergy, Inc./*S. Braithwait*
Design Criteria: Direct-Contact Ground Coils (RP2892-4)	$72,500 11 months	Martin Marietta Energy Systems, Inc./*P. Joyner*
Microwave Vacuum Drying of Food Products (RP2893-7)	$83,668 4 months	California State University Fresno Foundation/ *A. Karp*
Nuclear Power		
Adaptation of the Paris Technology for Measuring Wall Thinning in Ferritic Steel Components (RP1570-22)	$97,801 3 months	Sigma Research, Inc./ *S. Liu*
Thermal Performance Adviser (RP2407-3)	$60,000 1 year	General Physics Corp./ *N. Hirota*
European In-Plant Radwaste Minimization Techniques (RP2414-17)	$47,812 4 months	Utility Power Corp./ *P. Robinson*
Low-Level Waste Adviser (RP2414-19)	$62,370 6 months	Odetics, Inc./*F. Gelhaus*
Improved Test Methods for Plant Protective Coatings (RP2495-4)	$93,890 9 months	Westinghouse Electric Corp./*N. Hirota*
Foam Rubber Model Experiments of Soil-Structure Interaction (RP2556-47)	$26,000 10 months	University of Nevada, Reno/*J. Stepp*
Palladium-Doped Type 304 Stainless Steel (RP2614-20)	$50,991 3 months	Babcock & Wilcox Alliance Research Center/ *H. Ocken*
Expert System for Nuclear Plant Component Life Assessment (RP2614-21)	$39,990 1 month	Structural Integrity Associates, Inc./*D. Cain*
Tubesheet Expansions for Improved PWSCC Resistance (RPS406-4)	$70,000 10 months	Westinghouse Electric Corporation/*A. McIlree*
Optimized Test Specimen for Tubesheet Expansions (RPS406-9)	$50,000 10 months	Westinghouse Electric Corporation/*A. McIlree*
Analysis of Applied Stresses in Roll Transition Zones (RPS406-10)	$22,216 6 months	S. Levy Inc./*A. McIlree*
Effect of Boric Acid on Intergranular Corrosion in Tube Support Plate Crevices (RPS407-14)	$558,000 23 months	Centre d'Etudes Nucléaires de Cadarache/ *C. Shoemaker*
Planning and Evaluation		
Evaluating Causal Factors Related to Why Issues Emerge (RP2345-55)	$28,043 4 months	J. F. Coates, Inc./*S. Feher*

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

Comparison of Acoustic and Conventional Flow Measurement Techniques at the Raccoon Mountain Pumped-Storage Plant

AP-4713 Final Report (RP2038-4); $25
Contractor: Tennessee Valley Authority
EPRI Project Manager: C. Sullivan

Simulator-Analyzer for Binary-Cycle Geothermal Power Plants

AP-5134 Final Report (RP2195-7); $40
Contractor: Esscor
EPRI Project Managers: J. Bigger, V. Roberts

Hesperia Photovoltaic Power Plant: 1985 Performance Assessment

AP-5229 Final Report (RP1607-6); $25
Contractor: New Mexico Solar Energy Institute
EPRI Project Manager: J. Schaefer

Proceedings: Geotechnology Workshop on Compressed-Air Energy Storage in Porous Media Sites

AP-5301 Proceedings (RP2488-10); $55
Contractor: ANR Storage Co.
EPRI Project Manager: B. Mehta

Statistical Analysis of Geothermal Wells in the United States

AP-5310 Final Report (RP2195-8); $25
Contractor: GeothermEx, Inc.
EPRI Project Manager: E. Hughes

Radon as an In Situ Tracer in Geothermal Reservoirs

AP-5315 Final Report (RP1992-1); $32.50
Contractor: Stanford University
EPRI Project Manager: E. Hughes

Demonstration of a High-Efficiency Steam Reformer for Fuel Cell Power Plant Applications

AP-5319 Interim Report (RP2192-1); $32.50
Contractors: Haldor Topsoe, Inc.; Westinghouse Electric Corp.
EPRI Project Manager: D. Rastler

Benefits of Battery Storage as Spinning Reserve: Quantitative Analysis

AP-5327 Final Report (RP1084-25); $25
Contractor: Zaininger Engineering Co., Inc.
EPRI Project Manager: B. Louks

Advanced Air Separation for Coal Gasification–Combined-Cycle Power Plants

AP-5340 Final Report (RP2699-1); $25
Contractor: Union Carbide Corp.
EPRI Project Manager: B. Louks

Acoustic Flow Measurement Evaluation Project

AP-5341 Final Report (RP2038-2); $32.50
Contractor: British Columbia Hydro & Power Authority
EPRI Project Manager: C. Sullivan

Rheology of Coal-Water Slurries at Elevated Temperatures for Gasification

AP-5394 Final Report (RP2470-1); $25
Contractor: University of North Dakota
EPRI Project Manager: G. Quentin

COAL COMBUSTION SYSTEMS

Integrated Environmental Control

CS-4439 Final Report (RP1609-1); $32.50
Contractor: Stearns Catalytic Corp.
EPRI Project Manager: E. Cichanowicz

Fireside Corrosion of Superheater Alloys for Advanced-Cycle Steam Plants

CS-5195 Final Report (RP1403-11); $32.50
Contractor: Foster Wheeler Development
EPRI Project Manager: R. Jaffee

SPEEDM Solid-Particle Erosion Economic Decision Methodology

CS-5239-CCML Computer Code Manual
Contractor: General Electric Co.
EPRI Project Manager: T. McCloskey

Proceedings: Fossil Fuel Plant Inspections Conference

CS-5320 Proceedings (RP1863-7); $85
Contractor: Karta Technology Inc.
EPRI Project Manager: J. Scheibel

Evaluation of the Toxicity Characteristic Leaching Procedure (TCLP) on Utility Wastes

CS-5355 Final Report (RP2708-2); $32.50
Contractor: Western Research Institute
EPRI Project Manager: D. Golden

1987 Symposium on Stationary Combustion Nitrogen Oxide Control

CS-5361 Proceedings (RP2154-12); Vol. 1, $62.50; Vol. 2, $62.50
Contractor: Radian Corp.
EPRI Project Manager: D. Eskinazi

Water Management in Ash-Handling Systems

CS-5369 Final Report (TPS 80-740); $40
Contractor: Water General Corp.
EPRI Project Manager: W. Chow

Laboratory Protocol to Demonstrate Equivalency for Plant Wastewater Cotreatment

CS-5371 Final Report (RP1260-13); $32.50
Contractor: Water General Corp.
EPRI Project Manager: W. Chow

Wastewater Reuse as Cooling-Tower Makeup

CS-5373 Final Report (RP1260-19); $32.50
Contractor: Water General Corp.
EPRI Project Manager: W. Chow

ENERGY MANAGEMENT AND UTILIZATION

Lithium/Iron Sulfide Batteries

EM-5183 Interim Report (RP2415-1); $32.50
Contractors: Gould Inc.; Argonne National Laboratory
EPRI Project Managers: D. Douglas, R. Weaver

Electrotechnologies: Potential for Improving Manufacturing Productivity

EM-5259 Final Report (RP2381-2); $47.50
Contractor: Mathtech, Inc.
EPRI Project Managers: J. Wharton, C. Gellings, R. Squitieri

Roles of Electricity: A Brief History of the Beginnings of Electroprocessing From the 1880s to the 1930s

EM-5297-SR Special Report; $25
EPRI Project Manager: O. Zimmerman

Roles of Electricity: A Brief History of Electricity and the Geographic Distribution of Manufacturing

EM-5298-SR Special Report; $25
EPRI Project Manager: O. Zimmerman

Heating, Ventilating, and Air Conditioning of Commercial Buildings: Research Workshop

EM-5300 Final Report (RP2792-4); $25
Contractor: Analysis and Control of Energy Systems, Inc.
EPRI Project Manager: M. Blatt

Heat Pump Repair Costs in Alabama

EM-5328 Final Report (RP2417-1); $25
Contractor: Alabama Power Co.
EPRI Project Manager: C. Hiller

Models of Commercial Sector Equipment and Fuel Decisions for the COMMEND Code: Framework Design and Data Development Plan

EM-5356 Final Report (RP1216-11); $25
Contractors: Regional Economic Research; Cambridge Systematics, Inc.
EPRI Project Manager: S. Braithwait

ENVIRONMENT

Inorganic and Organic Constituents in Fossil Fuel Combustion Residues

EA-5176 Interim Report (RP2485-8); Vol. 1, $47.50; Vol. 2, $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: I. Murarka

CHEMTRACE: A Database of Product Hazard Profiles

EA-5212-CCML Computer Code Manual (RP2222-1)
Contractor: Dynamac Corp.
EPRI Project Manager: W. Weyzen

Chemical Characterization of Fossil Fuel Combustion Wastes

EA-5321 Final Report (RP2485-8); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: I. Murarka

Solid-Waste Environmental Studies (SWES): Description, Status, and Available Results

EA-5322-SR Special Report; $25
EPRI Project Manager: I. Murarka

Estimating the Impact of Ozone on Crops

EA-5335 Final Report (RP1829-5); $32.50
Contractor: International Science & Technology, Inc.
EPRI Project Manager: R. Wyzga

Risk Assessment of Toxic Pollutants From Fossil Fuel Power Plants

EA-5358 Final Report (RP1826-5); $55
Contractor: The Rand Corp.
EPRI Project Manager: A. Thrall

Risk Assessment of Toxic Emissions: Alternative Models and Practices

EA-5359 Final Report (RP1826-5); $40
Contractor: The Rand Corp.
EPRI Project Manager: A. Thrall

ELECTRICAL SYSTEMS

Partial Combustion of Electrical Insulation Fluids

EL-5262 Final Report (RP2028-11); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: G. Addis

Series Connection of Gate-Turnoff Thyristors

EL-5331 Final Report (RP2745-1); $32.50
Contractor: General Electric Co.
EPRI Project Manager: H. Mehta

Feasibility of Gate-Turnoff Thyristors in a High-Voltage Direct-Current Transmission System

EL-5331 Final Report (RP2745-1); $32.50
Contractor: General Electric Co.
EPRI Project Manager: H. Mehta

Feasibility of Gate-Turnoff Thyristors in a High-Voltage Direct-Current Transmission System

EL-5332 Final Report (RP2443-5); $25
Contractor: General Electric Co.
EPRI Project Manager: H. Mehta

Evaluation of an Acoustic Resonance Temperature Sensor for Transformers

EL-5353 Final Report (RP994-1); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: S. Nilsson, S. Lindgren

NUCLEAR POWER

PWR Power Shape Monitoring System

NP-4413M Final Report (RP1582-2); Vol. 1, $32.50; Vol. 2, $40; NP-4413SP Final Report; Vols. 1–3, $100,000
Contractor: Systems Control, Inc.
EPRI Project Manager: J. Kim

Tests of Steam Generator Transient Response to Scenarios Involving Steam Generator Tube Ruptures and Stuck-Open Safety Relief Valves

NP-4787 Final Report (RP1845-8); Vols. 1 and 2, $70
Contractors: Westinghouse Electric Corp.; Central Electricity Generating Board
EPRI Project Manager: S. Kalra

Concrete Containment Tests, Phase 2: Structural Elements With Liner Plates

NP-4867M Interim Report (RP2172-2); $32.50
NP-4867SP Interim Report; $15,000
Contractor: Construction Technology Laboratories, Inc.
EPRI Project Manager: M. Behravesh

Nondestructive Evaluation Program: Progress in 1986

NP-4902-SR Special Report; $62.50
EPRI Project Manager: M. Behravesh

A Compendium on Mobile Robots Used in Hazardous Environments

NP-5060 Final Report (RP2232-5); $40
NP-5060P Final Report; $100
Contractor: HB Meieran Associates
EPRI Project Manager: F. Gelhaus

Good Bolting Practices: A Reference Manual for Nuclear Power Plant Maintenance Personnel

NP-5067 Final Report (RP2520); Vol. 1, $32.50
Contractor: Raymond Engineering Inc.
EPRI Project Manager: T. Marston

In-Plant Testing of Radwaste Ion-Exchange Materials

NP-5099 Final Report (RP1557-10); $500
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: P. Robinson

Intergranular Attack or Corrosion in a Once-Through Model Steam Generator

NP-5120 Final Report (RPS302-6); $40
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: C. Shoemaker

Mechanisms of Intergranular Attack and Stress Corrosion Cracking of Alloy 600 by High-Temperature Caustic Solutions Containing Impurities

NP-5129 Final Report (RPS302-1); $32.50
Contractor: Brookhaven National Laboratories
EPRI Project Managers: D. Cubicciotti, J. Paine

Inspection of Centrifugally Cast Stainless Steel Components in PWRs

NP-5131 Final Report (RP2405-16); $32.50
Contractor: Aptech Engineering Services, Inc.
EPRI Project Manager: S. Liu

Phase Relations and Fluid Compositions in Steam Generator Crevices

NP-5138 Final Report (RPS302-5); $32.50
Contractor: Lawrence Berkeley Laboratory
EPRI Project Manager: J. Paine

Preliminary Conceptual Design Study for a Small LWR

NP-5150M Final Report (RP2660-8); $25
NP-5150SP Final Report; Vol. 1, $30,000; Vol. 2, $15,000
Contractor: General Electric Co.
EPRI Project Manager: W. Sugnet

Evaluation of Reactor Vessel Beltline Integrity Following Unanticipated Operating Events

NP-5151 Final Report (RP1757-41); $25
Contractor: Novetech Corp.
EPRI Project Manager: T. Griesbach

Sulfate Hideout in Heated Crevices

NP-5156 Final Report (RPS311-3); $25
Contractor: Central Electricity Generating Board
EPRI Project Manager: C. Shoemaker

Proceedings: 1985 Workshop on Primary-Side Stress Corrosion Cracking of PWR Steam Generator Tubing

NP-5158 Proceedings (RPS303-5); $70
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: A. McIlree

Guidelines for Specifying Integrated Computer-Aided Engineering Applications for Electric Power Plants

NP-5159M Final Report (RP2514-3); $40
NP-5159S Final Report; Vols. 1–9, $500
Contractors: Duke Power Co.; Westinghouse Electric Corp.; Cygna Corp.
EPRI Project Manager: J. Carey

Stress Corrosion Cracking of A471 Turbine Disk Steels

NP-5182 Final Report (RP1398-12); $32.50
Contractor: SRI International
EPRI Project Manager: F. Gelhaus

Snubber Reduction Program

NP-5184M Final Report (RP1757-39); $25
NP-5184SP Final Report; $7500
Contractor: Teledyne Engineering Services
EPRI Project Manager: S. Tagart, Jr.

Microstructural Effects on Microdeformation and Primary-Side Stress Corrosion Cracking of Alloy 600 Tubing

NP-5192 Final Report (RP2163-4); $25
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: A. McIlree

Measurement of pH and Corrosion Potentials of Tube Alloys in Solutions Found in Steam Generators

NP-5193 Final Report (RP2160-13); $32.50
Contractor: SRI International
EPRI Project Manager: C. Shoemaker

Chemical Enhancement of Crevice Flushing
NP-5199 Final Report (RPS302-18); Vol. 1, $32.50; Vol. 2, $55
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: L. Williams

Contamination and Decontamination Experience With Protective Coatings at TMI-2
NP-5206 Final Report (RP2558-2); $25
Contractor: Pentek, Inc.
EPRI Project Manager: R. Lambert

Pitting in Steam Generator Tubing: Causes and Corrective Actions
NP-5207 Final Report (RPS308-6); $40
Contractor: Battelle, Columbus Division
EPRI Project Manager: J. Paine

Validation of Critical BWR Signals
NP-5211M Final Report (RP2448-1); $32.50
NP-5211SP Final Report; Vols. 1 and 2, $21,000
Contractor: Charles Stark Draper Laboratory, Inc.
EPRI Project Managers: M. Divakaruni, K. Sun

Generic Seismic Ruggedness of Power Plant Equipment
NP-5223 Final Report (RP1707-15); $19,000
Contractor: Anco Engineers, Inc.
EPRI Project Manager: G. Sliter

Seismic Verification of Nuclear Plant Equipment Anchorage
NP-5228 Final Report (RP1707-6); Vol. 1, $10,000; Vol. 2, $4,000
Contractor: URS Corp./John A. Blume & Associates, Engineers
EPRI Project Manager: G. Sliter

PWR Radiation Fields: 1983–1985
NP-5234 Interim Report (RP825-2); $47.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: R. Shaw

Approaches to the Verification and Validation of Expert Systems for Nuclear Power Plants
NP-5236 Final Report (RP2582-6); $25
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Naser

Risk-Based Evaluation of Technical Specification Problems at the LaSalle County Nuclear Station
NP-5238 Final Report (RP2142-2); $40
Contractor: Delian Corp.
EPRI Project Manager: J. Gaertner

Ultrasonic Characterization of Centrifugally Cast Stainless Steel
NP-5246 Topical Report (RP1570-2); $40
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: M. Behravesh

Investigation of Causes and Corrective Actions for Pitting in Steam Generator Tubes: Prototypic Tests
NP-5248 Final Report (RPS308-4); $40
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: J. Paine

Qualification of Remedial Methods to Prevent Primary-Side Stress Corrosion Cracking of Steam Generator Tubing
NP-5249 Final Report (RPS303-27); Vol. 1, $40; Vol. 2, $47.50; Vol. 3, $77.50
Contractor: Belgatom
EPRI Project Manager: A. McIlree

Emergency Operating Procedures Tracking System
NP-5250M Interim Report (RP2347-17); $32.50
NP-5250SP Interim Report; $10,000
Contractor: Nuclear Software Services Inc.
EPRI Project Manager: D. Cain

Effectiveness of Thermal Ignition Devices in Rich Hydrogen-Air-Steam Mixtures
NP-5254 Final Report (RP1932-14); $25
Contractor: Atomic Energy of Canada, Ltd.
EPRI Project Manager: J. Hosler

Production of Intergranular Attack of Alloy 600, Alloy 690, and Alloy 800 Tubing in Tubesheet Crevices
NP-5263 Topical Report (RPS302-3); $40
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: J. Paine

Hideout of Sodium Salts in Tubesheet Crevices
NP-5265 Final Report (RPS311-4); $32.50
Contractor: Commissariat à l'Energie Atomique
EPRI Project Manager: C. Shoemaker

Micromorphology and Microchemistry of Corrosion Products in Tubesheet Crevices
NP-5400 Final Report (RPS302-23); $25
Contractor: Calgon Corp.
EPRI Project Manager: C. Shoemaker

Electrochemical Corrosion of Alloy 600 in Secondary Water
NP-5406 Final Report (RPS302-17); $25
Contractor: University of Nevada at Reno
EPRI Project Managers: M. Angwin, J. Paine

PLANNING AND EVALUATION

OVER/UNDER Capacity Planning Model, Version 3: User's Guide
P-5233-CCM Computer Code Manual (RP1107-5); $47.50
Contractor: Decision Focus, Inc.
EPRI Project Manager: H. Chao

Projections of Cost of Development of U.S. Natural Gas Potential
P-5284 Final Report (RP1367-2); $55
Contractor: Institute for Energy Resource Studies
EPRI Project Manager: J. Platt

Selected Papers on Priority Service Methods
P-5350 Interim Report (RP2801-1); $40
Contractor: Pricing Strategy Associates
EPRI Project Manager: H. Chao

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

MARCH

2–4
4th Symposium: Integrated Environmental Control for Fossil Fuel Power Plants
Washington, D.C.
Contact: Ed Cichanowicz (415) 855-2374

9–10
Power Quality for End-Use Applications
San Antonio, Texas
Contact: Marek Samotyj (415) 855-2980

15–17
Forum: Strategic Planning in a Competitive Environment
Atlanta, Georgia
Contact: Sherman Feher (415) 855-2838

16–18
PWR Primary Chemistry and Radiation Field Control
Berkeley, California
Contact: Chris Wood (415) 855-2379

22–25
7th Symposium: Transfer and Utilization of Particulate Control Technology
Nashville, Tennessee
Contact: Ralph Altman (615) 899-0072

29–31
Workshop: Reactor Coolant Pump/Recirculation Pump Monitoring
Toronto, Canada
Contact: Joe Weiss (415) 855-2751

MAY

3–5
1988 Seminar: FBC Technologies for Utility Applications
Palo Alto, California
Contact: Stratos Tavoulareas (415) 855-2424

10–12
1988 Conference: Heat Rate Improvement
Richmond, Virginia
Contact: Robert Leyse (415) 855-2995

23–26
International Conference: Validation of Flow and Transport Models for the Unsaturated Zone
Ruidoso, New Mexico
Contact: Ishwar Murarka (415) 855-2150

Authors and Articles


Yeager


Young


Ferraro

Coal Technologies for a New Age (page 4) was written by Michael Shepard, a senior feature writer of the *Journal,* with background information contributed by **Kurt Yeager,** an EPRI vice president and director of the Coal Combustion Systems Division. Yeager, a division director since 1979, has been with EPRI since 1974. Before that he was director of energy planning for the EPA Office of Research and, still earlier, associate head of environmental systems research at Mitre Corp. He is a chemistry graduate of Kenyon College and earned an MS in physics at the University of California at Berkeley. ■

Floyd Culler: A Penchant for People (page 18) pays tribute to EPRI's second president, who retired in January. This profile was written by Ralph Whitaker, *Journal* feature editor, from conversation with Culler and many of his former associates. ■

Exploring the Limits of Power Transfer (page 22) was written by Taylor Moore, *Journal* senior feature writer, drawing on the expertise of **Frank Young** of EPRI's Electrical Systems Division. Associate director of the division since April 1987, Young had been EPRI's manager of strategic planning since 1981. He came to the Institute in 1975 after 20 years with Westinghouse Electric, where he became manager of UHV transmission research. Young graduated in electrical engineering from Stanford University and earned an MS in the same field at the University of Pittsburgh. ■

A National Focus on Power Electronics (page 32) was also written by the *Journal*'s Taylor Moore, who attended an EPRI conference on power electronics applications and conferred with **Ralph Ferraro** of the Energy Management and Utilization Division. Ferraro, now EPRI's technical manager for power electronics at a newly established applications center in Tennessee, managed research in industrial electricity utilization from 1984 to 1987. He joined EPRI in 1977 after four years with Bechtel Power, where he was design supervisor for power plant control and instrumentation systems. Still earlier, he worked in the design and production of power conversion and control equipment. Ferraro has a BS in electrical engineering from the New Jersey Institute of Technology. ■

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