SUMMER 2005

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

DEPLOYING ADVANCED COAL PLANTS

ALSO IN THIS ISSUE:

Mercury Emissions Control

Power Grid Security

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The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together... Shaping the Future of Electricity

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COVER: Commercial deployment of advanced clean coal power plants will allow the nation to make use of its tremendous coal resources while meeting ever-tightening air qualtiy regulations. (Art by Craig Diskowski/Edge Design)

JOURNAL
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Editorial

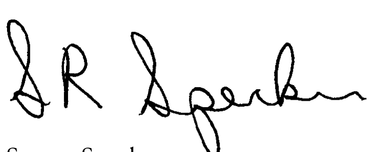
A Window Into EPRI

One of the great pleasures of my first year at EPRI is to announce the relaunch of its flagship publication, the *EPRI Journal.* I very much enjoyed reading the *Journal* while I was at GE. It was an effective window into EPRI, providing an in-depth understanding of the content and value of EPRI's programs and communicating the broader business and social contexts of the industry's most pressing issues. The *Journal* also captures something that is easy to miss in a technical portfolio as varied and rich as EPRI's: the power and value of pursuing comprehensive, integrative approaches. This highly coordinated route allows EPRI to accomplish things that others cannot. It capitalizes on the unique advantages of the collaborative model—bringing people, ideas, perspective, money, and expertise to bear on the truly difficult issues we face now and for the future. It is important that the *Journal* readers get this "big picture" of what the Institute is doing.

One of the best examples of collaborative advantage is EPRI's CoalFleet initiative, the topic of this first issue's cover story. Deployment and commercialization of advanced, clean coal generation technologies carries all of the difficulties of transformational change: a wide and disparate slate of stakeholders, hard technical challenges, cost uncertainties, regulatory unknowns, and stubborn market barriers. Yet we have here technologies that clearly speak to the needs and constraints of the coming decades. This is the kind of challenge that will only yield to the collaborative approach.

And while CoalFleet is a key initiative for electricity's future, it is only a piece of the larger, tougher question that I believe will define the power industry over the coming decades: how will we provide clean, affordable electricity in an increasingly carbon-constrained world? There is no silver bullet on this issue. We will solve the problem only by thinking beyond individual technologies, by considering a full complement of options that together can satisfy our energy needs in the new technical/environmental/societal context that we now see evolving across the globe. Carbon constraints will require the broadest, most innovative thinking we can muster. It will require the ability to look beyond a seemingly endless succession of difficult milestones and embrace a goal that must and will be achieved. As with any endeavor of this size and importance, our success depends on commitment, hard work, and strong leadership—essentials that EPRI is well-equipped and willing to provide.

I have much more to say about the challenges facing our electricity system, present and future, and I expect to do so in subsequent issues. For now, I encourage you to read and enjoy the new *EPRI Journal.* We have an exciting lineup of articles planned for the coming year that I'm sure will be both interesting and useful. And if you have ideas about how we can use the magazine to improve the service and value you derive from the Institute, please let me know—it is a window into EPRI that is designed to be open.



Steven Specker
President and Chief Executive Officer

Contributors

Coal-Based Generation at the Crossroads

(page 6) was written by science writer Taylor Moore with technical assistance from Stu Dalton and Jack Parkes.

Stu Dalton, director of EPRI's Generation Sector, came to the Institute in 1976, having previously worked for Pacific Gas & Electric and Babcock & Wilcox. From 1979 to 1994, he headed EPRI's SO_2 control and integrated emissions areas. For the last 10 years, he has managed and developed strategy for broad areas of the advanced coal and emissions control R&D portfolio. Dalton holds a BS in chemical engineering from the University of California at Berkeley.

Jack Parkes has held senior management positions at EPRI, Bechtel, Ebasco, and GE involving the design, reliability, and performance of coal-based power plants and systems. In his current EPRI position, area manager for advanced generation, he directs the CoalFleet for Tomorrow Initiative. Parkes received a BS from The Queens University of Belfast and an MS from Union College in New York, both in mechanical engineering. He also earned an MBA from the University of Santa Clara in California.

Mercury Control for Coal-Fired Power Plants

(page 16) was written by science writer Paul Haase with guidance from Leonard Levin and George Offen.

Leonard Levin is EPRI's technical leader for air toxics health and risk assessment, specializing in multimedia cycling and exposure, chemical transport, and atmospheric physics. Before coming to EPRI in 1986, he worked for six years as a senior scientist at Woodward-Clyde Consultants and earlier at Science Applications International. Levin has a BS degree in earth, atmospheric, and planetary sciences from MIT, an MS in atmospheric sciences from the University of Washington, and a PhD in meteorology from the University of Maryland.

George Offen, a technical executive for air emissions and coal combustion product management, has been with EPRI since 1985. He started the Institute's program on mercury control technology R&D in the late 1980s and expanded it into the Integrated Environmental Control program several years ago. Offen coordinates EPRI's collaborations with DOE and EPA in air emission control technology. He holds BS and PhD degrees from Stanford University in mechanical engineering and an MS from MIT in the same field.

Grid Security in the 21st Century

(page 26) was written by science writer John Douglas with technical information from Robert Schainker.

Robert Schainker is a technical executive in EPRI's Power Delivery and Markets Sector with a current focus on electricity grid infrastructure security and power quality. Before joining the Institute in 1978, he was with Systems Control, Inc., of Palo Alto for 10 years, specializing in utility SCADA and energy management systems. Schainker has a BS in mechanical engineering, an MS in electrical engineering, and a PhD in applied mathematics, all from Washington University in St. Louis.

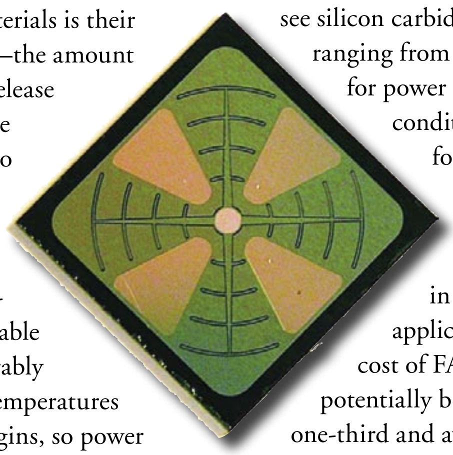
Innovation

Emerging technologies and cutting-edge engineering

Largest Silicon Carbide Switch Demonstrated

Widespread use of solid-state devices to control power flow on utility networks will require substantial reduction in cost and improvement in availability compared to the silicon-based controllers available today. Achieving such performance enhancements will involve replacing silicon in these devices with advanced semiconductors that can switch larger currents at higher voltages and operate at higher temperatures. The most promising near-term candidate is silicon carbide (SiC), and recent advances have brought SiC switches much closer to commercial applications in the power industry.

A key performance characteristic of semiconductor materials is their so-called "bandgap"—the amount of energy needed to release electrons bound in the crystalline structure so they can move freely and thus conduct electricity. Wide-bandgap semiconductors, such as SiC, are able to withstand considerably higher voltages and temperatures before conduction begins, so power controllers made from them can be smaller and more robust, and not need as much auxiliary cooling equipment. This development could make large solid-state devices, such as flexible ac transmission system (FACTS) controllers, more competitive.



The main barrier to using wide-bandgap materials in electronic switches has been crystal defects that limit their performance. Since 1996, EPRI has sponsored research aimed at improving the quality of these materials, together with finding better ways of fabricating useful devices based on them. Last year, this work paid off with a major achievement: demonstration of the largest, fastest, most powerful SiC switch ever made—a 1-cm^2 device that could switch power of 1750 volts and 250 amperes while operating at 250°C. That's twice as large as any earlier SiC switch, with about 100 times greater current-carrying capacity, and demonstrates the technology's potential for use in large-scale devices.

This accomplishment brings commercialization of power control devices based on wide-bandgap semiconductors much closer to reality, according to project manager Ben Damsky. "Within about five years, I believe we could see silicon carbide used in devices ranging from FACTS controllers for power networks to power conditioning equipment for consumer electronics," he says. "The impact will probably be the greatest in high-voltage utility applications, where the cost of FACTS devices could potentially be reduced by about one-third and availability increased significantly."

Maintaining high availability is particularly critical in power system applications, and today's large solid-state controllers have had difficulty achieving availability factors greater than 96%. The largest contributor to down time for these installations is the auxiliary cooling system, which is essential because silicon-based devices must be derated if they reach 125°C. A SiC device operating at 250–300°C could have a much simpler cooling system that would require less maintenance. Eventually, a highly reliable passive cooling system with no moving parts may become possible.

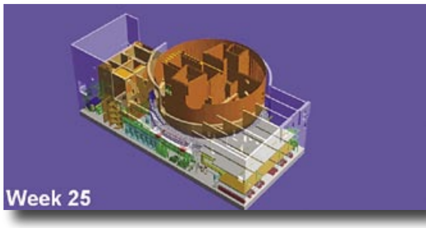
The next challenge will be to translate the accomplishments achieved so far in a laboratory setting into commercial-scale production of SiC switches. Future work is expected to focus particularly on manufacturing and characterizing SiC devices rated up to 5000 volts and 1000 amperes, while also testing their performance under a variety of operating conditions. Eventually, other wide-bandgap semiconductors may also be used in high-power controllers, further reducing their size and cost.

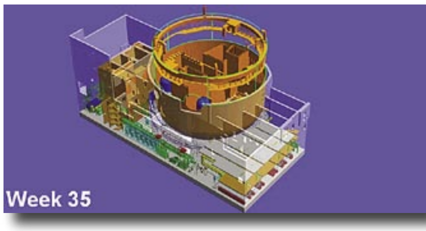
For further information, contact Ben Damsky, bdamsky@epri.com.

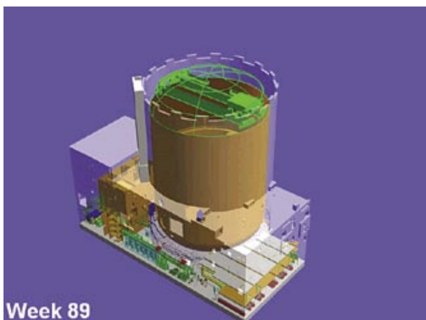
Virtual Reality Simulation to Reduce Nuclear Construction Costs

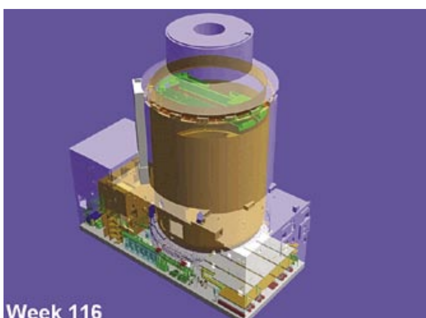
Advanced visualization technology promises to reduce the cost of building nuclear power plants and other complex industrial facilities by optimizing the construction sequence, streamlining the schedule, and identifying potential problems before they are encountered in the field. The technology represents an extension of conventional 3-D computer-aided design by adding the fourth "dimension" of time to the modeling process so that engineers can simulate the construction sequence in unprecedented detail.

Developed through collaboration between EPRI and Westinghouse, the 4-D visualization technology is being integrated into the design process of two Westinghouse advanced light water reactors. For one of the reactors, more than five months were removed from









the projected construction schedule without reducing the duration of any individual activity. Optimized sequencing of tasks also reduced the expected on-site requirements for skilled craft labor (e.g., concrete workers and pipe fitters) by several months.

The detail and specificity of the animated modeling allows examination of issues as varied as crane placement, alternative construction paths for large plant modules, and simulated "construction" of representative modules in isolation. The technology can also be used to prepare and train construction crews, verify achievable construction schedules, and enhance the confidence of potential investors in the timing of capital recovery.

"Our studies with Westinghouse indicate that EPRI's virtual reality construction technology should cut about 10% off construction times for the next generation of nuclear plants, which will help them to be more competitive," says project manager Layla Sandell. "Our next step will be to extend the technology to nuclear plant designs from additional vendors."

For further information, contact Layla Sandell, lsandell@epri.com.

MagMolecules Selectively Remove Contaminants From Liquid Waste

Processing low-level waste (LLW) effluent streams from nuclear plants remains a persistent challenge because the dissolved radioactive contaminants may be present in only minute quantities so that removing them from a large volume of liquid is difficult and expensive. Evaporation, for example, leaves a solid waste product in which the radionuclides may represent only a small fraction of the total material that must then be disposed of. Ion exchange systems can remove contaminants more selectively, but still produces an unnecessarily large volume of solid waste.

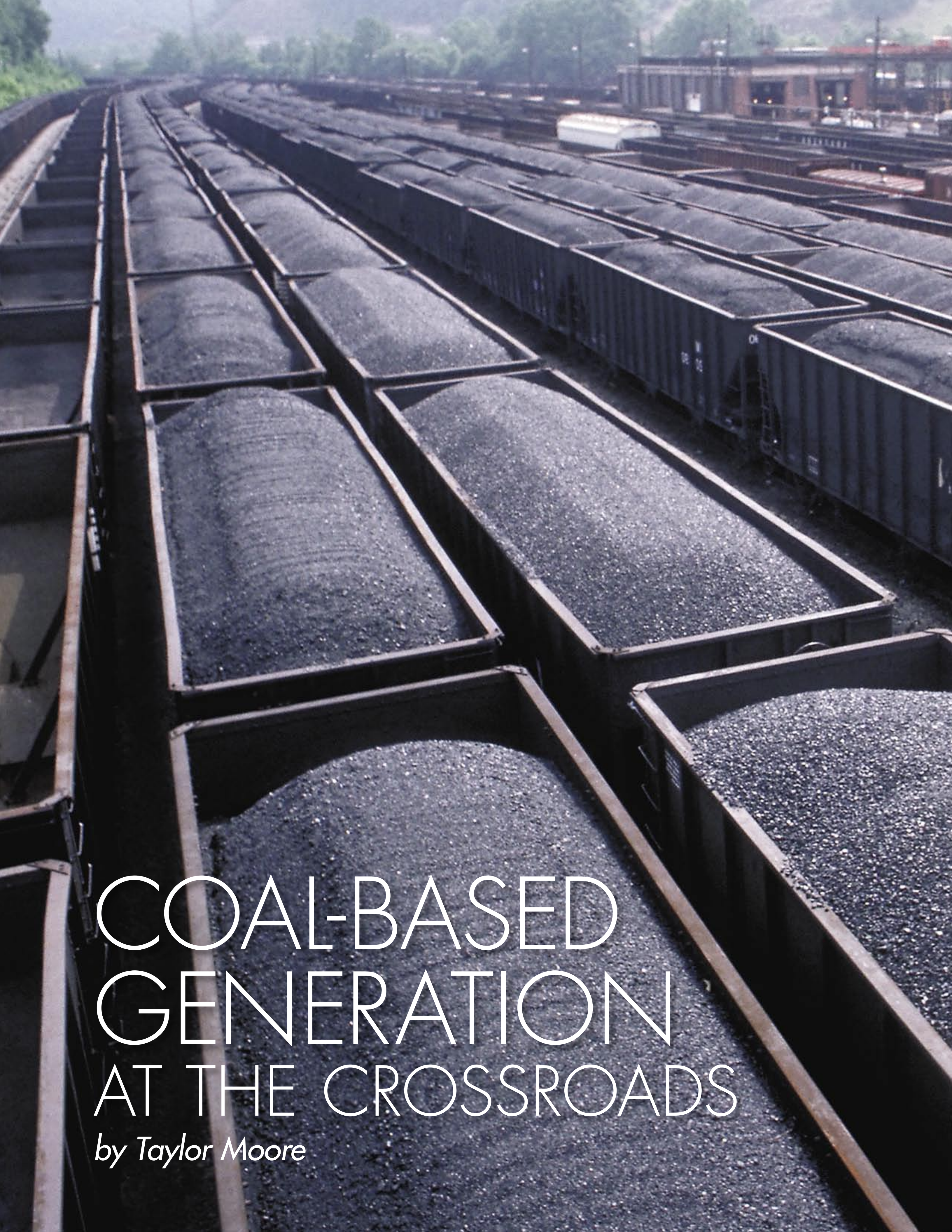
Now an innovative new approach promises to greatly reduce radioactive waste volume by using magnetic molecules that target specific radionuclides dissolved in an LLW stream. Called the MagMolecule process, for which EPRI has filed a patent application, the technology is also expected to be used in other important applications, such as removing heavy metals from industrial effluents and groundwater.

"Laboratory results indicate that MagMolecule technology has the potential for reducing waste volume by a factor of up to 5000, compared to conventional ion exchange treatment," according to project manager Sean Bushart. "The result would be significant cost savings for low-level waste management in nuclear power plants, as well as for applications in other industries."

The concept is based on the use of proteins called ferritins, which the body uses to store iron, for example, in the spleen and liver. Synthetically produced and magnetically stronger "magneto-ferritins" are used in the computer industry to manufacture data storage disks. EPRI's research has focused on modifying magneto-ferritins to bind selectively to specific contaminants—initially strontium and cesium, and now cobalt—that represent important radioactive constituents of LLW. The bound ferritin-contaminant complex is then removed from the effluent stream by a reusable magnetic filter, which is backwashed to collect the solid by-products.

Now that technical feasibility of the MagMolecule process has been established in the laboratory, the next step will be to scale up the technology for pilot application in the field. Specifically, by the end of this year, researchers hope to test the process using actual nuclear plant effluent, while also improving the associated filtration and instrumentation systems. Bushart says that commercialization of MagMolecule technology may come in as little as two years.

For further information, contact Sean Bushart, sbushart@epri.com.



COAL-BASED GENERATION AT THE CROSSROADS

by Taylor Moore

The Story in Brief

Offering clean electricity generation from an abundant fuel, advanced coal technologies seem tailor-made for a power industry facing ever-tighter environmental regulations. But committing to new approaches—and the inevitably higher cost of first-of-a-kind units—is always a difficult business proposition. To help break through the final barriers to market acceptance, EPRI is leading an industry-driven initiative to speed the deployment of new clean coal plants and support the development of next-generation designs.

Long the workhorse of electric generating systems around the world, coal-based power plants are increasingly seen as one of the most economic choices for meeting future growth in demand for power. But while today's units operate *far* more cleanly than when air-quality rules were ramped up in the 1970s, coal-burning plants are still constantly chasing tighter regulatory limits on emissions through the refinement of add-on cleanup technologies. Now a new generation of advanced, clean coal power plants that integrate emissions reduction into their basic designs stands at the threshold of commercial deployment. These plants not only address the sulfur and nitrogen oxides at the center of today's air quality regulations more efficiently, but also carry advantages in removing carbon dioxide (CO_2), which may be regulated in the future because of its role as a greenhouse gas associated with global climate change.

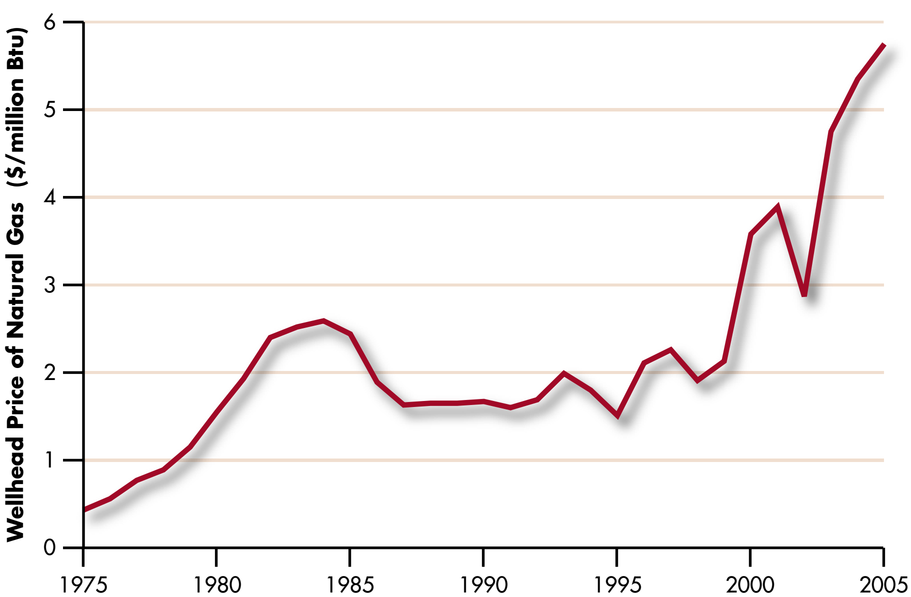
Such clean coal technologies have been evolving for more than two decades; the last major hurdle to reaching technological maturity and, in turn, economic competitiveness with conventional coal plants is the demonstration of their commercial viability and reliable operation at full-scale by utilities and power generators. Expanded operating experience with advanced coal generating systems is essential for convincing prospective investors that the costs and risks are well understood and manageable. And getting more such plants built and operating is critical for the necessary engineering development that will take the technology from first-of-a-kind plants to fully optimized, "learned out" units with costs as low as designers can eventually drive them.

To accelerate commercial deployment of advanced clean coal power systems, the electric utility industry is leading a broad-based collaborative program encompassing the development, demonstration, and deployment of technologies including integrated gasification combined-cycle (IGCC), ultra-supercritical pulverized coal (USC PC), and supercritical circulating fluidized-bed combustion (SC FBC).

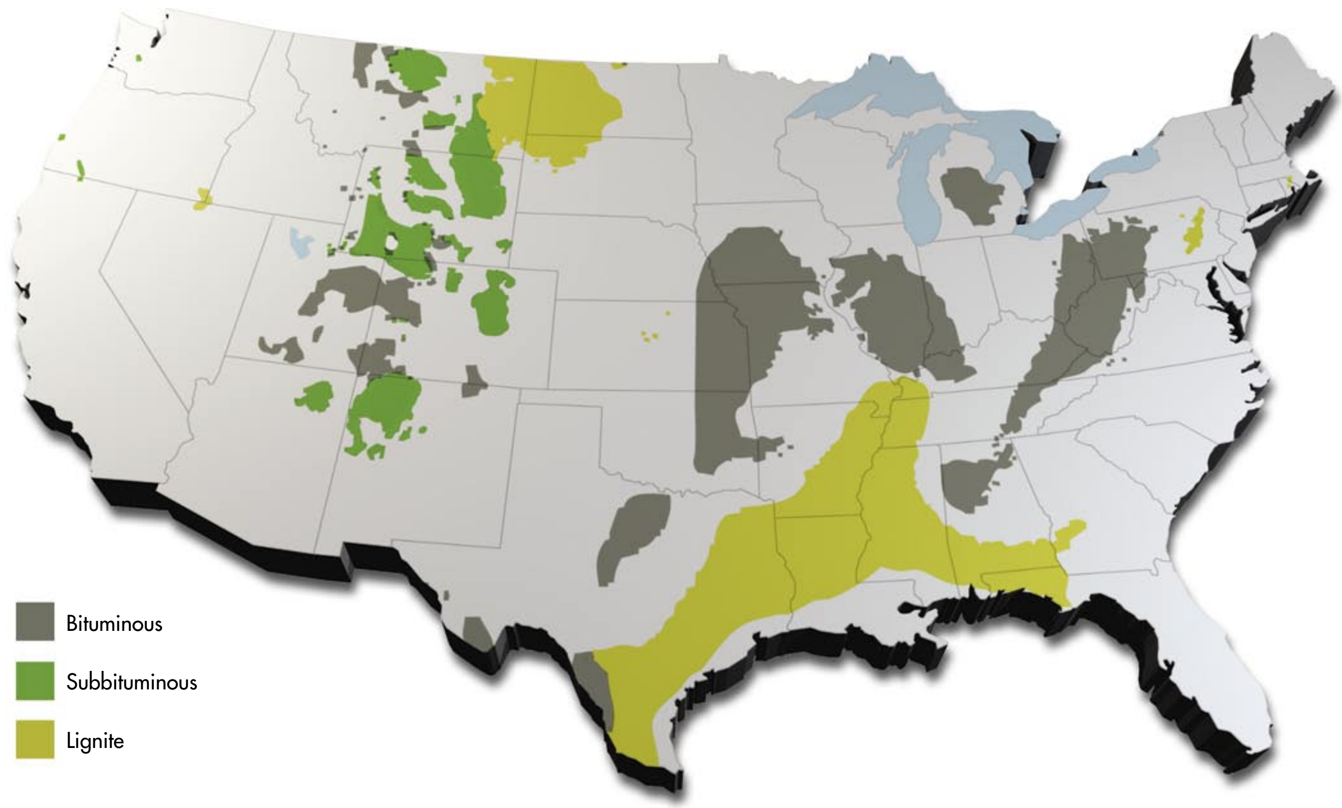
Known as CoalFleet for Tomorrow, or simply "CoalFleet," the initiative aims to tackle the technical, economic, and institutional challenges to making clean coal power systems a prudent investment option for both the short run and the long run. By collaborating across all sectors of the power industry, CoalFleet is focused on breaking through the impasse of the longstanding conundrum of advanced clean coal technologies: despite wide agreement on their ultimate need and value—and on the magnitude of investment and long lead time required to reach commercial maturity—there is still inadequate commitment of resources to bring these advanced systems to fruition. EPRI organized the CoalFleet initiative with broad input from and on behalf of the industry as a vehicle for mutual cooperation in speeding the deployment of advanced clean coal plants and in introducing next-generation designs.

Hank Courtright, EPRI's vice president for generation, explains: "CoalFleet's goal is to preserve this abundant source of fuel as a vital component in the electricity generation mix. Work must begin now to ensure that the advanced coal technologies can establish a solid track record—before large numbers of coal plant replacements become necessary. We see the need to get plants built and operating soon in order to gain experience with and reduce the cost of advanced coal plant technology."

In the near term, CoalFleet is focused on incorporating user-defined requirements and lessons learned from existing advanced plants into new designs that will be developed for commercial orders anticipated over the next decade. To accomplish this, the initiative has assembled teams of engineers and other technical experts to advise and provide input to early deployers of new advanced coal technologies and their technology suppliers. In turn, the early deployers have agreed to make general design basis and nonproprietary engineering information available to all CoalFleet participants with the aim of helping spur reductions in capital costs and risks for subsequent orders as well as improvements in plant availability and performance.



The low capital cost, quick construction, and relatively straightforward permitting of gas-fired power plants made them by far the top choice for new generation capacity over the past decade. However, a near tripling of the wellhead price of natural gas in recent years has changed the cost equation substantially, making advanced coal generation options more attractive for strategic additions.



Economic and engineering studies have shown that costs and performance for advanced coal technologies vary significantly with the type of coal they use. Because there are substantial regional differences in coal type, several advanced technologies—IGCC, USC PC, and SC CFBC—must be developed to fully utilize the nation's tremendous coal reserves. (Source: USGS)

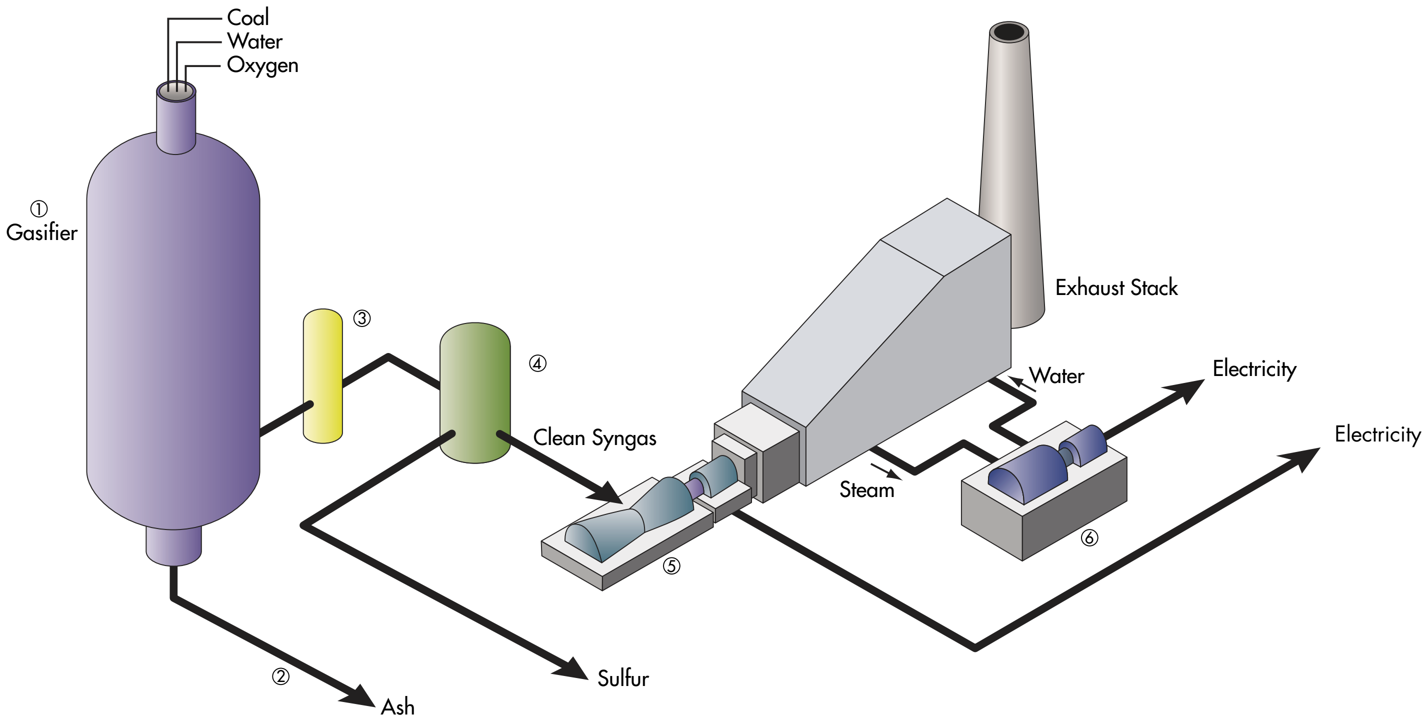
CoalFleet for Tomorrow is already gaining a high degree of visibility among the utility and power generation technology industry. Over 40 organizations have committed so far to support the initiative, including energy companies representing more than half of all presently installed U.S. coal-fired generating capacity, major coal-based European generators, leading power equipment manufacturers, technology suppliers, and the U.S. Department of Energy (DOE).

Policymakers are taking notice as well. Earlier this year, the U.S. Congress took under consideration various possible financial incentives that may help close the current gap in the levelized cost of electricity (COE) between conventional coal plants, which produce much of the nation's lowest-cost electricity, and the 15–20% higher COE expected for the next several advanced coal plants that may be built. EPRI provided valuable data and insight as input for congressional deliberations.

Changing Times Turn the Tables

Despite the abundance and consistently low cost of coal as a generating fuel, few coal-fired power plants have been built around the world for well over a decade, except in Asia. Instead, the lower capital costs, quicker construction, and more straightforward permitting for natural gas–fired plants led utilities and generating companies that needed additional capacity to favor these units, at least while natural gas prices remained relatively low. In the past seven years, over 200 GW of gas-fired generating capacity have been built in the United States, compared with about 15 GW of coal-fired capacity. A similar preference was followed in Europe.

Today, far different economic conditions apply: oil and natural gas prices have both set new record highs in recent years. As a result, many gas-fired combined-cycle plants are being called on to generate at only a fraction of their planned capacity factor. The average capacity factor for such plants in 2003 was 32% and continued to decline into 2004, making many of the units poor performers as financial assets. Gas prices are forecast to remain high as a result of supply and demand imbalances and transportation bottlenecks. Increases in imports of oil and liquefied natural gas, while potentially reducing the volatility of natural gas prices, are also heightening concerns over energy security and international trade balance. Together, these factors are making the economics of coal power appear more attractive to both power generators and government agencies.



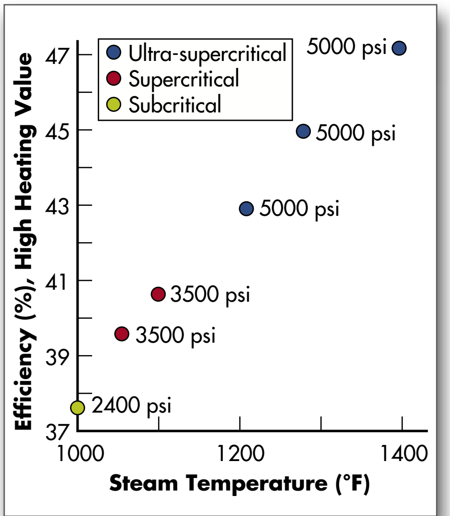
In IGCC plants, coal is not burned directly, but rather is processed with oxygen and water in a high-pressure gasifier (1) to form a synthesis gas. Ash forms a slag (2) that is removed from the gasifier for disposal or commercial use. The syngas is cooled (3) and stripped of sulfur compounds (4), which are converted to elemental sulfur that can also be sold commercially. The clean syngas is then combusted in a gas turbine/generator (5), which generates most of the electricity the plant produces. The waste heat is recovered and used to produce steam that drives a smaller turbine/generator (6) in a combined-cycle configuration to produce additional electricity.

Meanwhile, environmental advocates and regulators are maintaining pressure on coal plant operators to further reduce emissions. As a result, new coal plants will need to have substantially lower emissions, despite the industry's impressive achievements in reducing emissions from the current fleet of plants. Future requirements for controls on CO_2 emissions from new plants under consideration today could significantly influence decisions on technology selection and design.

Conventional coal plant technologies offer lower capital costs and lower projected costs of electricity than today's handful of advanced generating systems; however, looming environmental restrictions that could lead to requirements to retrofit emissions control equipment or to purchase emission allowances creates uncertainty over which coal technologies will actually be the most economical over various design lifetimes. The answer is also influenced by location and the economics of fuel supplies. Given the diversity of regional electricity markets and the variability in the properties of economical coals among regions, a portfolio of advanced coal power systems—including IGCC, USC PC, and SC CFBC—is needed to comprehensively meet the needs of the market.

IGCC systems combine the high efficiency and low emissions of gas turbines with the ability to run on syngas, which is coal-derived, or other low-cost solid or heavy liquid fuels. But as Stu Dalton, EPRI director for generation, told the Senate Energy and Natural Resources Committee's Coal Conference last April, "Electricity from initial IGCC plants without CO_2 capture and storage will cost 15–20% more than electricity from conventional coal power units with SO_2 and NO_x emission controls. Additional experience with full-scale IGCC plants will likely reduce or eliminate this cost differential. Incentives will be needed to deploy these initial IGCC plants in order to overcome higher capital costs and technology risks," Dalton told the conference.

IGCC's relative competitiveness with conventional, pulverized-coal plants firing bituminous coal improves if CO_2 removal is required, but such a requirement significantly reduces the power output and increases the cost of both plant types. Studies by EPRI, DOE, and others have found that the incremental cost penalty for removing CO_2 from high-pressure IGCC syngas is about 25% on a levelized COE basis, whereas the cost penalty for removing it from the flue gas of a conventional coal plant is about 70%. Additional costs for transporting and storing captured CO_2 are not included in the calculation, but would be comparable for both plant types.



Improvements in materials are allowing pulverized coal plants to operate at higher temperatures and pressures, which increases plant efficiency and reduces the release of CO_2 and other emissions. Ultra-supercritical plants are already in use in Europe and Japan, with steam temperatures of 1120°F and pressures of 4200 psi. Units with steam temperatures up to 1400°F and pressures up to 5000 psi are expected to be demonstrated in the United States within 10–15 years.

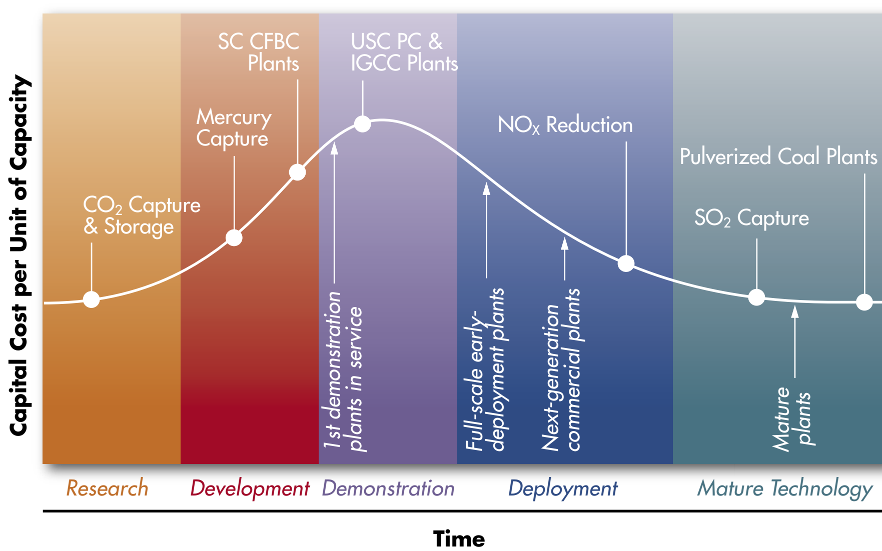
The economics of IGCC technologies demonstrated so far in the United States are less favorable for lower-rank coals such as subbituminous or lignite that predominate the resource in certain regions, as the technologies currently work best using the higher-rank bituminous coal typical of many commercially mined coal deposits east of the Mississippi River. Design changes or success with the advanced, dry-feed compact gasification systems now under development by DOE and industry partners may eventually make IGCC more economical for low-rank fuels.

For regions where low-rank fuels predominate, USC PC and SC CFBC may be the most cost-effective advanced coal options. For large-scale coal plants burning very low-grade fuels, new supercritical CFBC designs are a high-performance, cost-effective option. Meanwhile, worldwide advances in boiler and turbine materials that have greater strength at high temperatures and less susceptibility to thermal creep and fatigue have enabled the emergence of reliable pulverized-coal plants operating with main steam conditions in the ultra-supercritical range. Such plants are already in operation in Japan and parts of Europe, where high fuel prices place a premium on efficiency.

"Limits on CO_2 emissions in the United States would have a comparable price-driver effect on the cost of electricity from conventional coal-fired plants," explains Dalton. "DOE, EPRI, and other organizations are working to develop long-lived, reliable components for ultra-supercritical PC units with main steam temperatures up to 1400°F (760°C) and pressures up to 5000 psi (340 bar). Plants operating at such steam conditions are expected to achieve generating efficiencies topping 45% on a higher heating value basis and to reduce CO_2 and other emissions by 15–22% compared with current conventional plants."

Strategy for Deploying Advanced Coal Technologies

To provide technical input and advice to a slate of task working groups and early-deployment project owners under the CoalFleet for Tomorrow Initiative, EPRI formed the CoalFleet World-Class Expert Working Group, composed of key EPRI personnel, independent industry experts in advanced coal technologies, and utility representatives with advanced coal plant operating experience. The expert working group is developing a comprehensive strategy for surmounting the so-called "mountain of death" (high cost of market-entry units) that new technologies in general and advanced coal technologies in particular must overcome before reaching technological maturity and the lowest achievable cost. According to Jack Parkes, EPRI's area manager for CoalFleet, "The strategy is closely examining ways to remove barriers that have hindered the implementation of advanced coal systems, including high capital and construction costs, inadequate reliability, long project schedules, lack of standardization, and difficult environmental permitting procedures. Optimizing, modularizing, and standardizing plant designs for a range of technologies, coal types, regional issues, and types of owner/deployer organization are the keys to reducing the time,



The difficult—and costly—process of bringing a new technology into the marketplace has been called the "mountain of death." Advanced coal technologies are nearing the crest of the curve, but the high cost of first-of-a-kind plants can often stall a new technology in the demonstration stage. The primary focus of the CoalFleet initiative is to get the first group of full-scale advanced coal plants deployed as early as possible.

Incentives for Advanced Coal Plant Deployment

The current estimated cost of electricity from initial IGCC plants is about 15-20% more than that from a conventional pulverized-coal plant when higher capital and fixed costs are accounted for and an allowance is included for the risk of potential shortfalls in the IGCC plant's availability. In light of this, CoalFleet members expect that financial incentives will be needed to spur initial plant deployment and provide the design and operational experience necessary to reduce cost and demonstrate reliable performance.

EPRI and CoalFleet participants have analyzed financial incentives that potentially could reduce the incremental cost gap of IGCC plants for early deployers. In particular, the CoalFleet Incentives Task Working Group examined eight types of federal financial incentives: loan guarantees, direct federal loans, federal cost-sharing grants, investment tax credits, production tax credits, tax-exempt financing, accelerated depreciation, and the new concept of federal availability insurance. Their analysis considered three types of power producers—regulated investor-owned utilities (IOUs), independent power producers (IPPs) with contracts for their plants' generating output, and public power producers (cooperatives, municipal utilities, and federal and state entities)—and accounted for differences among them in borrowing costs and tax obligations. The findings were tabulated in terms of the effect of an incentive on an IGCC plant's levelized cost of electricity (COE).

No single type of fully evaluated incentive bridged the COE gap between IGCC and PC plants for all company types. Moreover, variation in the value of different incentives to various types of power producers was substantial. For example, public power producers receive no direct benefit from tax-based incentives, and loan guarantees provide much greater benefit to IPPs than they do to other producer types. "As a result, CoalFleet members have concluded that combinations of incentives, or tailored packages of incentives, will be necessary to significantly lower the cost barrier to IGCC deployment and to give relatively equal incentive to all power producers," says EPRI's Jack Parkes. "Particularly interesting with respect to the equitability aspect is the newly developed concept of availability insurance." In this type of incentive, the federal government would provide insurance for covered plants that are unable to meet a specified target for availability. Although analyses showed that availability insurance alone would not close the cost gap and make IGCC competitive with conventional pulverized coal, such an incentive may be valuable and effective in combination with other incentives.

Tom Wilson, EPRI senior technical manager for climate change, who conducted the analyses along with Charles Clark, an analyst working with EPRI for the CoalFleet for Tomorrow Initiative, explored how various combinations of incentives might work. In an article for *Public Utilities Fortnightly,* the two noted, for example, that doubling the base-case investment tax credit from 10% to 20% and combining it with accelerated depreciation would come close to closing the cost gap for IOUs and IPPs. Alternatively, doubling the production tax credit to equal that currently available for wind energy facilities could actually make IGCC's COE less than that of conventional PC for taxable entities. A third package of incentives—tripling the federal government's cost-sharing to 30% without repayment and adding availability insurance—would provide public power producers and cooperatives with sufficient cost-reduction to make IGCC attractive compared with conventional PC. The gap would still not be closed for IOUs and IPPs, "but the difference is small enough that other considerations might well determine their choice," Wilson and Clark note.

"In the end, however, it must be remembered that any incentives such as those just discussed are intended only to get IGCC 'over the hump' of initial commercial deployment," the analysts point out. "After that, commercial attractiveness of this prototypical clean coal technology will depend on a variety of other factors. Foremost among these will be resolution of the technical risks involved, specifically by showing that IGCC plants can achieve sufficiently high availability to compete with conventional coal plants. Initial capital costs should also decline with design and operational experience and as the infrastructure for building, maintaining, and utilizing IGCC facilities develops. Additional factors that may influence the long-term attractiveness of IGCC technology include the potential need to capture and sequester CO_2 to mitigate global warming or to produce hydrogen for future fleets of fuel-cell vehicles. Because of this potential, the ultimate value of IGCC may be its importance as a hedging strategy—a way to keep using the nation's most abundant energy resource while providing options to deal with long-term environmental hazards."

EPRI is coordinating CoalFleet's deployment incentives analyses with DOE to ensure that the impact of incentives on federal budgets is properly calculated. CoalFleet plans to update its incentives analyses on the basis of peer review comments, evaluate additional types of incentives, and extend the analysis to address a broader range of technology options.

costs, and risks of building advanced coal plants."

To start the process, EPRI and the CoalFleet world-class experts have assembled an Advanced Coal Technologies Knowledge Base, the core of which presently comprises more than 50 design cases from eight recent state-of-the-art studies conducted by EPRI, DOE, utility companies, consultants, and technology supplier teams. Each case study details vital characteristics in up to 450 defined fields. CoalFleet will continue to add data as they become available from new feasibility studies by members and from design decisions made by companies undertaking early plant deployment projects. The knowledge base will also include papers from key conferences and lessons learned from IGCC demonstration units at Cinergy Corp.'s Wabash River Generating Station and Tampa Electric Co.'s Polk Power Station.

"EPRI, the CoalFleet independent experts, and a CoalFleet participants' task working group are drawing on the knowledge base to assemble a clear and complete User Design Basis Specification (UDBS) for IGCC plant designers," says Parkes. CoalFleet's initial version of the UDBS will include three 600-MW bituminous coal–fired IGCC plants, one for each of the three commercial entrained-flow gasifiers (i.e., GE Energy, ConocoPhillips, and Shell). For utilizing low-sulfur Powder River Basin (subbituminous) coal, the UDBS will include an 800-MW IGCC plant from Shell and a 600-MW transport-gasifier plant from Kellogg, Brown & Root.

For each plant, the UDBS will estimate availability with and without a spare gasifier and will specify three cooling options—wet tower, dry cooling, and parallel wet-dry. Also included are heat rate targets, back-up fuel considerations, time-to-build targets, emission limits for start-up and off-design operation, and expected supplier performance guarantees. Subsequent CoalFleet UDBS documents will cover USC PC and SC CFBC plants.

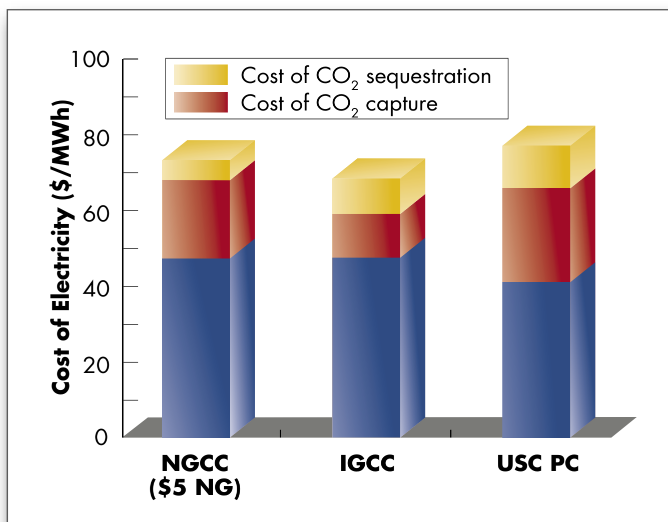
Supporting Early-Deployment Projects

The operating concept for CoalFleet is "learning by doing," with EPRI and the independent experts participating directly in the site-specific engineering feasibility studies being conducted by the owners of three to five CoalFleet companies that have pledged to build IGCC or other advanced coal plants. The early-deployment project owners will benefit from the knowledge, design, and operations and maintenance experience in CoalFleet, while the broader CoalFleet membership will benefit from the rapid, real-life feedback from the early-deployment projects. This symbiotic relationship will continue as early-deployer companies select a supplier and commit to the development of a process design package and front-end engineering design, followed by detailed design and construction.

As the early-deployment projects progress, CoalFleet will form teams for each project that will translate project-specific, nonproprietary information into a CoalFleet Pre-Design Specification and a Generic Design Specification. The Pre-Design Specification is essentially a generic version of the project's feasibility study, and the Generic Design Specification corresponds to approximately the first 50% of front-end engineering design. Nonproprietary costs and project financial proformas for different organizational types will also be derived, allowing CoalFleet participants to see the anticipated benefits of standard, or reference, designs for IGCC and other advanced coal plants.

As with the UDBS documents, CoalFleet's goal is to create standard plant design guidelines for each major IGCC gasifier technology and its applicable fuels and for USC PC and SC CFBC technologies. These CoalFleet specifications, based on the real-world experience of early-deployment projects, should reduce the time and cost for plant engineering considerably and result in plants with improved performance and availability.

While IGCC is inherently very clean, obtaining environmental permits for an IGCC plant is a critical-path item in the project development process, and applications often must be submitted before front-end engineering is under way. The limited experience of regulators with IGCC permitting and a dearth of reference information from previous permits compound the challenge. As a result, obtaining permits for a new IGCC plant can be highly complex and pose a significant risk for delays in plant construction. CoalFleet's IGCC Permitting Task Working Group



In comparisons of the 30-year levelized cost of electricity from new plants of similar capacity (500–600 MW), IGCC and USC PC compete effectively with conventional natural gas–fired combined-cycle (NGCC) plants when the price of natural gas reaches $5/million Btu—a level already exceeded today. And when the cost of capturing and sequestering CO_2 becomes a factor, as many believe it will in the future, IGCC appears to have a clear economic advantage.

Two demonstration projects supported by DOE and the industry have paved the way for the deployment of IGCC technology. Cinergy was host to a 262-MW IGCC repowering demonstration at its Wabash River Generating Station near Terra Haute, Indiana, in 1995. Tampa Electric's 250-MW Polk County IGCC demo is a green-field unit that began operation in 1996.

is attempting to significantly reduce the time to permit an IGCC plant through identification of the critical technical, regulatory, and procedural issues that must be addressed up-front and through the plant design and equipment selection process. The group's findings will guide the development of design recommendations for enhancing and streamlining the permitting process.

Columbus-based American Electric Power Co. announced in 2004 that it plans to build a large-scale, commercial 600-MW IGCC plant. The company contracted with GE Energy and Bechtel Corp. for a scoping study of the parameters of an IGCC facility at one of three sites in Ohio, Kentucky, and West Virginia.

"Continuing significant environmental investments in our current fleet and building a commercial-scale IGCC plant are the right steps going forward to ensure that we can continue to burn coal economically while reducing our emissions," says Michael G. Morris, AEP's chairman, president, and chief executive officer. "AEP is taking significant steps to keep coal in the picture as a low-cost, low-emissions energy source. We must be able to rely on our vast coal resources to generate electricity if America and the world are to continue to have growing economies."

Adds Robert Powers, AEP's executive vice president for generation, "The CoalFleet initiative is important to the industry's ability to help resolve many of the new environmental issues and challenges we face in a cost-effective manner. We're at a crossroads. After the demonstrations of IGCC in the 1990s, we're now working to answer how the technology will perform at large scale and whether it can compete as new baseload capacity. Achieving the low capital cost and low cost of electricity demanded by today's customers will be an exciting challenge. CoalFleet reflects the recognition by EPRI's membership that it's time to make something happen and to move ahead with advanced coal power systems."

Meanwhile, Cincinnati-based Cinergy Corp., under an agreement with GE Energy and Bechtel, is studying the feasibility of building a commercial 500- to 600-MW IGCC generating station at one of several possible sites, including the 50-year-old coal-fired station of its subsidiary Public Service of Indiana at Edwardsport, Indiana. PSI earlier was host and cosponsor with DOE of a $417 million IGCC repowering demonstration at PSI's Wabash River Generating Station near Terre Haute. The project's new 262-MW IGCC plant successfully demonstrated 40% efficiency and plant availability as high as 79% from 1995 to 1999. Akron-based FirstEnergy Corporation has also announced interest in the development and commercial deployment of IGCC technology within the next several years. And a team led by Southern Company was selected for a DOE Clean Coal Power Initiative (CCPI) Round 2 award to build a 285-MW transport-gasifier IGCC plant in Orlando, Florida.

"We face the need for additional generation in Indiana, and as the demand for electricity increases in the future, we will need to build more power plants," says James E. Rogers, Cinergy's president, chief executive officer, and chairman. "Coal is our most practical, economical option. But the key to building more coal plants will be to develop zero-emission, clean coal technologies. Our central challenge is to find ways to use an abundant energy resource—of which our country has a more than 250-year supply in reserve—in an economic and environmentally clean way," adds Rogers. "Coal gasification has proven to be efficient, and there is no cleaner coal generating technology. It is critical for our country to commercialize IGCC, from the standpoint of greater energy independence and from that of the international balance of payments. We need to get to work now deploying and optimizing the current generation of commercial IGCC so that even more economical generations of the technology will be available over the next 10 to 15 years."

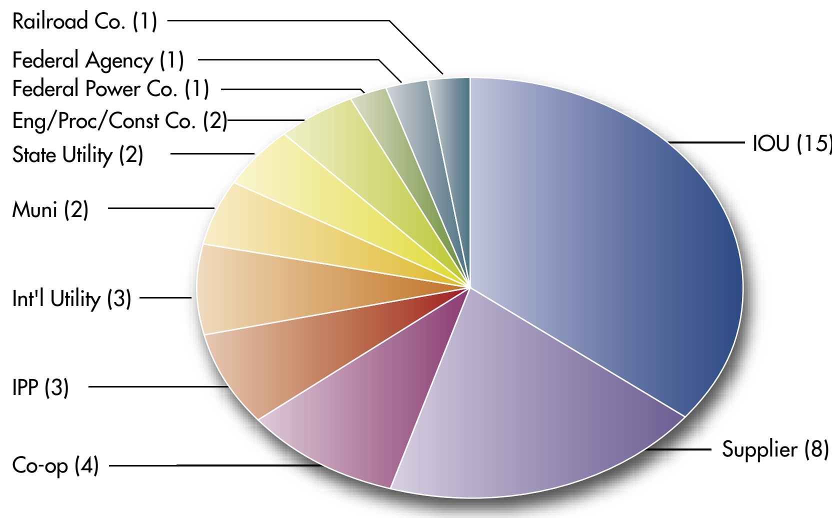
Linking R&D and Deployment to Reduce Costs

CoalFleet participants believe that collaborative research, development, and demonstration among power industry stakeholders can both hasten the deployment of current state-of-the-art advanced coal plants and spur the development of technical and operational improvements. Such advances promise to boost availability or lower heat rate and emissions in the near term and ultimately lead to the commercial introduction of next-generation plant designs that are approximately 20–25% lower in capital cost.

The initiative's strategy simultaneously addresses the RD&D needs for three major timeframes:

- Near-term refinements or evolutionary technologies for IGCC, USC PC, and SC CFBC plants coming on-line around 2010–2012—the early-deployment projects.
- Mid-term R&D requiring demonstrations that will conclude after the earliest commercial projects are built; this work will produce technologies that can be readily incorporated in plants coming on-line around 2012–2015.
- Longer-term R&D on advanced concepts for IGCC, USC PC, and SC CFBC plants—including integration of CO_2 capture systems—for plants coming on-line after 2015–2020.

DOE is currently supporting fundamental materials research, coal plant–related RD&D, and new coal technology plant demonstrations through the CCPI. FutureGen, a large IGCC demonstration project initiative of the DOE, will involve approximately $1 billion when fully funded. These efforts represent a substantial contribution to the development of advanced coal systems. EPRI is actively participating in many of these programs to help ensure the suitability and transferability of results to users. Technology from DOE's RD&D programs, along with CoalFleet results and industry RD&D, must be incorporated and proven in both early-deployment and next-generation units. Coordination with relevant programs in other countries will also help CoalFleet accelerate advanced coal plant deployment, especially for USC PC units.



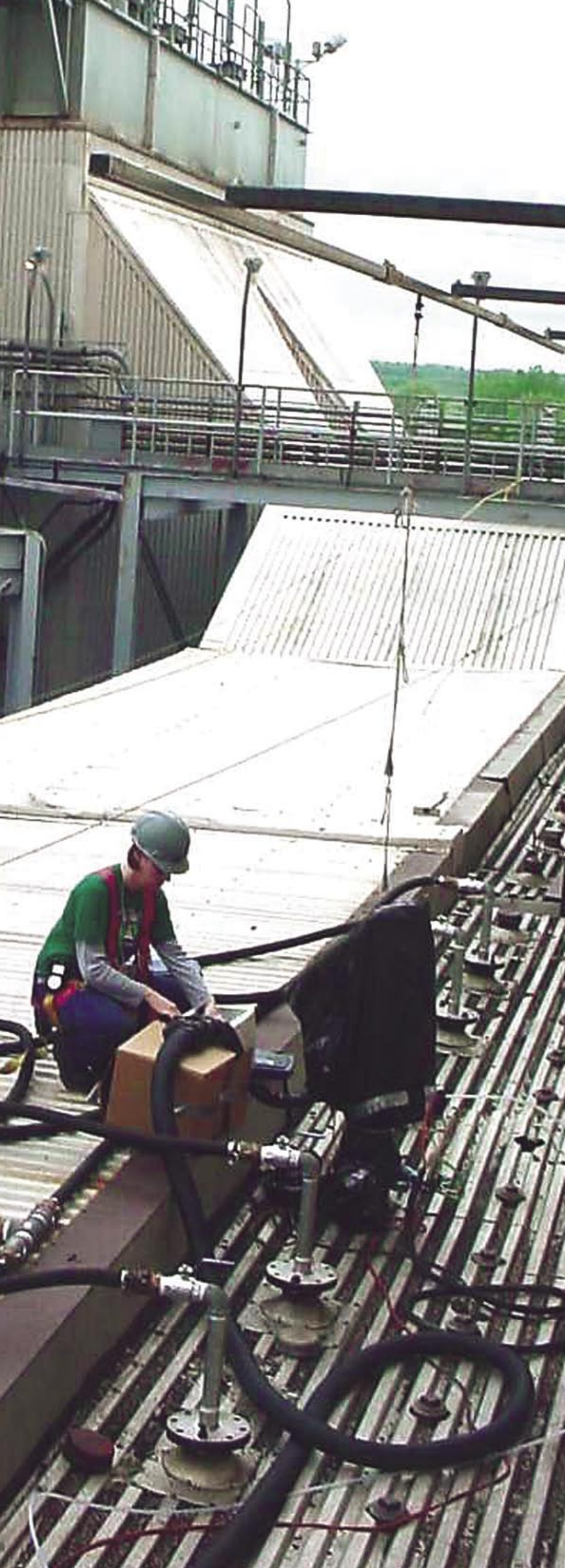
The CoalFleet for Tomorrow Initiative is supported by an extremely broad range of stakeholders. At the time of publication, 42 participants were on-board, representing more than 50% of the coal-fired generation in the United States.

In 2005, CoalFleet is creating an industry-focused RD&D plan with projects that augment and accelerate current RD&D activities; the initial emphasis is on technology that could be ready for inclusion in early-deployment plants. Some needs are well understood, and plans are already being developed for collaborative RD&D projects that address longer gasifier feed nozzle and refractory life and reliability improvements for syngas-fed combustion turbines. Other projects will explore heat rate improvement and lower-cost CO_2 separation and capture processes. Human performance capability enhancement projects will also be developed, including efforts involving training simulators, instrumentation and control systems, and operation and maintenance guidelines. Private and public partners will be identified to help launch high-priority projects over the next year.

Pushing Forward to a New Generation

CoalFleet has attracted a great deal of industry support, and for good reason. "CoalFleet for Tomorrow is an extremely important initiative for our energy and environmental future, considering that our nation generates half of its electricity from coal, which is really the only generating fuel we have in ample, long-term supply," notes Barry Pulskamp, Cinergy's vice president for power operations. "The CoalFleet initiative is bringing all the players in advanced coal systems technology into the fray to reduce the cost of these systems for producing electricity. We've seen tremendous improvement in the reliability of IGCC technology and the resolution of many technical issues over the past decade. Now the industry must take advanced clean coal technologies to the next generation and further drive costs down through plant standardization. Chevrolet has improved its V-8 engine enormously over 50 years, and the company has produced around 100 million units. I would hope that our industry could achieve the same degree of improvement in advanced coal systems in terms of cost efficiency and emissions. I'm excited about our prospects for the future."

Background information for this article was pro-vided by Stu Dalton (sdalton@epri.com), Jack Parkes (jparkes@epri.com), Neville Holt (nholt@epri.com), and Tom Wilson (twilson@epri.com).



MERCURY CONTROL

FOR COAL-FIRED POWER PLANTS

by Paul Haase

The Story in Brief

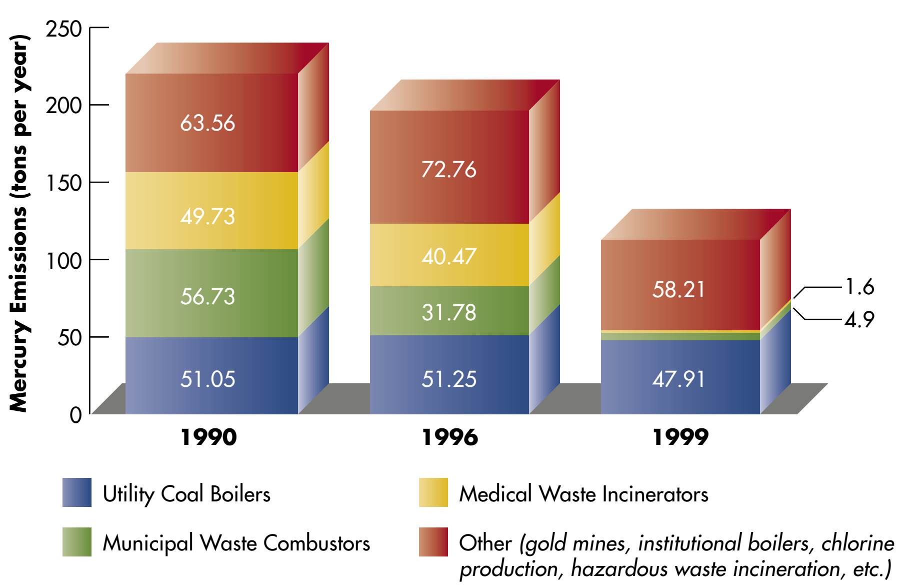
After some 15 years of study, the U.S. Environmental Protection Agency issued final rules on March 15, 2005, for regulating mercury emissions from coal-fired power plants. The new regulations require a reduction of mercury emissions by 70%, phased in over the coming 12 years. No commercial technologies yet exist for fully controlling mercury emissions from coal plants, but several approaches show good potential in full-scale tests and some are nearing market readiness. EPRI, working closely with DOE and the power industry, has conducted extensive mercury control research and developed some of the most promising technologies.

As late as the 1950s, mercury permeated American life. Parents annually administered mercurous chloride, or calomel, to children as a laxative and dewormer. Mercury-bearing calamine lotion soothed itches; mercurochrome sterilized wounds; mercuro-organic wonder-compounds preserved seeds and wood. Mercury even helped smooth the ride of luxury cars—one Studebaker model employed some 40 pounds of it. Although the risk of mercury vapor as a human neurotoxin was not unknown—the U.S. Public Health Service banned mercury from felt-making in 1941—few concerned themselves with mercury waste when children sought out spilled blobs of mercury to play with. Factories discharged mercury directly into rivers and lakes, hospitals and laboratories discarded broken mercury thermometers with the trash, incinerators and power plants sent mercury skyward.

Quick Change for Quicksilver

By the 1960s, recognition of mercury as a toxin and environmental danger turned the public attitude toward mercury upside-down. The U.S. Environmental Protection Agency (EPA) named mercury as a potentially hazardous air pollutant in 1971, and the Safe Drinking Water Act in 1974 established limits on mercury in public water systems. The 1976 Resource Conservation and Recovery Act identified mercury as a hazardous material and mandated safe management and disposal (including for emissions from combustion). Regulators have since refined and expanded pollution laws to eliminate mercury in batteries and paint, reduce emissions from municipal incinerators and industry, and control most other sources. Today, domestic use of mercury has dropped to well below one-fifth of its 1964 peak, according to EPA estimates. The worst human health problem, discharging mercury-containing waste into water where it can contaminate food fish, has been virtually eliminated in the United States.

Mercury emissions to the air were the last to be regulated, with initial rules focusing on two of the most obvious sources—medical waste incineration and the burning of municipal waste. As a result, U.S. mercury air emissions have fallen by half since 1990, to about 115 tons per year, and continue to decline. This progress has focused attention on a third substantial source of mercury air emissions: the nation's 600 or so large coal-fired power plants. Mercury from these plants accounts for 45–50 tons of domestic mercury air pollution annually. And while the releases have remained steady at this level for the past 15 years, as other mercury emissions have fallen, coal plants have come to represent a greater and greater fraction—now about 40%—of total domestic emissions. In a global accounting, mercury emissions from U.S. coal plants represent less than 1% of natural and human-caused sources.

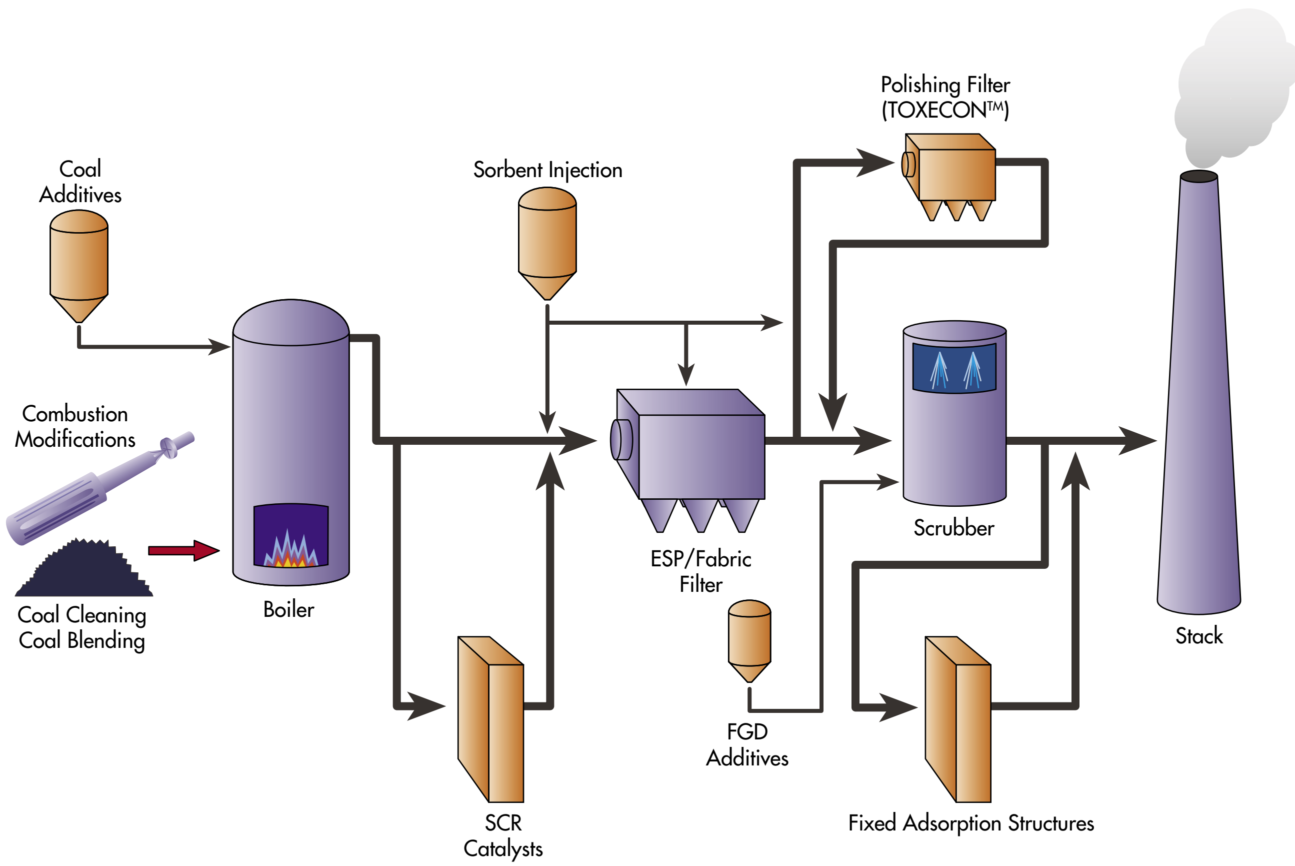


U.S. mercury air emissions have been substantially reduced over the last 15 years, in part through regulation of medical waste incineration and municipal waste combustion. EPA's Clean Air Mercury Rule, issued earlier this year, will put limits on emissions from the nation's 600 or so large coal-fired power plants.

The Clean Air Mercury Rule

EPA began studying coal plants as the last significant source of mercury emissions in 1997 and, after some controversy (see sidebar, p. 24), formally issued its Clean Air Mercury Rule, or CAMR, to regulate coal plant emissions on March 15, 2005. This two-phased rule creates performance standards and establishes permanent, declining caps on mercury emissions from coal plants. The Clean Air Mercury Rule marks the first time EPA has regulated mercury emissions from coal-fired power plants and makes the United States the first country in the world to regulate these emissions.

The mercury rule is intended to work in tandem with EPA's new Clean Air Interstate Rule, or CAIR, which tightens existing regulations on two other coal plant emissions: sulfur dioxide (SO_2), which contributes to acid rain and fine particulates, and nitrogen oxides (NO_x), a precursor of ozone (sometimes referred to as smog) and also of fine particulates. The aim is that by 2018, these two rules will reduce coal plant emissions of mercury by about 70%, to 15 tons per year nationwide. Reductions will be achieved through a market-based "cap-and-trade" program similar to that of EPA's highly successful Acid Rain Program, which in the 1990s delivered its environ-



A number of approaches are being investigated for controlling mercury emissions from coal-fired power plants. Potentially beneficial modifications of the fuel or combustion process include coal cleaning, coal blending, and control of the mixing of air and coal during combustion. Options to increase the removal of mercury by scrubbers, which are already on the system to control SO_2 emissions, include adding an SCR (which also reduces NO_x emissions) or catalysts and additives designed specifically to convert the mercury to a scrubbable form. Finally, several mercury-specific approaches are being developed—injection of activated carbon or other sorbent material into the flue gas, sorbent-based polishing filters, and fixed adsorption structures.

mental improvements faster and much more inexpensively than anticipated.

Under the cap-and-trade program for mercury, EPA will assign individual states (and two Native American tribes with coal-fired power plants on their lands) an emissions budget for mercury. Each state will determine how to regulate its coal plants to meet this emissions budget. During the phase-in period, plants that meet emissions limits ahead of time can bank these credits for use later or can sell them to those that will not be able to meet their limits on time. After the 2010 Phase 1 compliance date and the 2018 Phase 2 compliance date, companies whose plants in aggregate control mercury emissions below their allocated limit will be able to sell the "over-control" amount to companies whose plants cannot achieve their allocated limits cost effectively.

The Capture Challenge

Now that EPA has ruled, coal plant owners and operators will need the means to better capture mercury emissions. Some improvements can be achieved by modifying existing SO_2 or NO_x control devices, but new approaches will be required to meet the final 2018 emission limits. As yet, no technology designed specifically to control mercury in coal plants is in use anywhere in the world, or has even undergone long-term testing.

To develop and demonstrate such technologies, EPRI is working with the U.S. power industry and government organizations in a broad program of research and field testing at power plants. The large-scale mercury field testing in the United States was made feasible through significant funding and technical management by the U.S. DOE's National Energy Technology Laboratory (NETL). Important collaborators are the host sites, the developers of the control technologies themselves, and the engineering firms conducting the tests. The overall effort builds on 15 years of EPRI mercury control research.

This important work could not be done without the contributions of the many power companies that offer their plants for field testing. "With federal regula-

The DOE-NETL field test program, which benefits from 15 years of EPRI mercury research, is exploring the effectiveness of a dozen mercury control strategies at over 30 utility plants. The extensive test program is scheduled to continue through 2007. (Photos courtesy URS Corp.)

tion now in place, full-scale testing at the power plant is a critical step in the development of potential technologies," says EPRI President and CEO Steve Specker. "We cannot simulate these conditions in the laboratory and need to determine whether performance in the field can be sustained over a period of time without interfering with the plant's operation." The commitment of the field-test utilities is of tremendous value, considering that a typical coal plant generates tens of thousands of dollars worth of electricity each hour—electricity and revenue that are lost if the plant is shut down to install or tend experimental equipment.

Most emission control strategies for mercury focus on boosting the mercury-capture effectiveness of the standard pollution control equipment already installed at existing coal-fired power plants. This equipment includes flue gas catalysts to control NO_x, scrubbers and spray dryers to capture SO_2, and particulate filters to catch fly ash. These existing technologies capture about 35% of the mercury in flue gases, on average, but performance varies widely from plant to plant. Of the approximately 75 tons of mercury found in the tens of millions of tons of coal delivered to power plants each year, about 25–30 tons are captured in existing pollution controls and 45–50 tons are emitted to the air.

Key to capturing emissions is the chemical form of the mercury—elemental or ionic—as it passes through each pollution control device. Ionic mercury, which is soluble in water, is absorbed in scrubbers, whereas elemental mercury is not. Thus, the mercury-control challenge in a coal plant is primarily one of chemistry. For plants with existing or impending SO_2 controls, the objective is to increase the proportion of ionic mercury—either during combustion of the coal or in the flue gas itself—by some kind of oxidation process. Those without SO_2 controls may need to install mercury-specific technology.

The choice is neither simple nor obvious. Chemistry and economics dictate that most coal plants will employ one mercury control approach rather than a combination, and the choice must be determined plant by plant because of the wide difference in coal plant designs, the pollution equipment they have, and the coal types they burn. “For any given regulation, we must have options for all the combinations of coals and existing air pollution controls used by the industry,” says George Offen, EPRI’s technical executive for air emissions. “It’s no ‘one-size-fits-all’ situation.”

Sunflower Electric’s Holcomb Station near Garden City, Kansas, was host to a full-scale field test of sorbent injection for mercury capture under the DOE-NETL program. Conventional sorbents injected into the flue gas duct (far left) before the plant’s spray dryer unit achieved only modest results in removing mercury. However, use of a new, chemically enhanced sorbent removed 90% of the mercury at low-to-moderate injection rates. The sorbent is collected by the plant’s fabric filter, and the cleaned flue gas exits the stack at right. (Photo courtesy ADA-ES)

Modifying Coal and Combustion

Mercury control starts with the source, coal. This presents the first difficulty, because coal is a sedimentary rock that has no fixed composition. In coal, as in many similar sediments, mercury occurs as a trace element at about one part per million. Although coals come in a great variety—the chemistry and characteristics varying with the amount of heat and pressure a coal has experienced over its long history—most U.S. power plants burn one of two broad types, according to which is regionally available. In the East, plants generally fire harder bituminous coal, and in the West, softer subbituminous or lignite coals are the typical choice. The behavior of these coal types varies significantly with regard to mercury emissions: most—more than 60%—of the mercury released from the combustion of eastern coal is in the soluble and more easily captured ionic form, whereas only 20–30% of mercury released from western coal is ionic. Thus, even though eastern coals typically contain one-third more mercury than western types, plants firing western coal generally will require more aggressive approaches to control mercury emissions.

Precombustion cleaning increases the mercury difference between coal types, because eastern coal can be cleaned prior to use whereas western types generally cannot. Cleaning removes noncombustible materials and, for eastern coals, reduces mercury content by about one-third on average. For western coals, various dewatering treatments have been explored to improve combustion properties; such dewatering appears to also remove mercury—up to 70% in tests—and may become commercial in the future.

Cleaned or not, once coal reaches a power plant, several mercury control strategies are possible. First, the combustion process can be modified to increase the yield of unburned carbon in the fly ash, which can adsorb mercury emissions; the additional carbon may also increase the percentage of ionic mercury. These changes may be accomplished by staging the flow of air or coal in the boiler or by adding halide salts or other treatments to the coal or directly in the boiler.

“Several of our research projects have shown that adding a little halogen to promote oxidation significantly improves short-term mercury capture on western coals,” says Ramsay Chang, EPRI’s technical leader for air emissions. DOE-NETL is following up on these results in 2005 by cofunding longer-term tests of halogen additives at two power plants burning western coals.

Increased yield of ionic mercury or adsorbent carbon ash can also be accomplished by blending different types of coal. In short-term tests at Sunflower Electric's 360-MW Holcomb Station, located near Garden City, Kansas, EPRI researchers found that mixing modest amounts of bituminous coal with the subbituminous Powder River Basin (PRB) coal fired at the plant reduced mercury emissions by up to 80% without any other changes.

"The emissions control equipment at Sunflower's Holcomb Station is typical of many power plants in the West," says EPRI's Specker. "It has exactly the same configuration as most of the new plants being planned that will burn PRB coal. This makes the results particularly significant." Indeed, EPRI recently honored Sunflower Electric with its 2005 Technology Achievement Award for Rural Electric Cooperatives for hosting this work.

Tests at Holcomb Station are part of EPRI's work with DOE-NETL to perform extensive longer-term mercury control technology testing for coal plants in the 2004–2007 timeframe. EPRI is coordinating with the power industry to shape the design and content of the DOE-NETL tests. It's a big job: in addition to government agencies and host Sunflower Electric, the Holcomb test alone involved ADA-ES, Inc., NORIT Americas, Arch Coal, Western Fuels Association, Kansas City Board of Public Utilities, Westar Energy, Empire District Electric Company, Nebraska Public Power District, Kansas City Power and Light, Tri-State Generation & Transmission, Missouri Basin Power Project, Wisconsin Public Service, Associated Electric, Southern Minnesota Municipal Power Agency, the City of Sikeston, TransAlta Utilities, and TransAlta Energy.

Co-Benefit Approaches

The mercury-control potential of combustion modifications at many plants may be limited by the chemistry governing plant efficiencies, by boiler corrosion from halide salts, or by the economics of coal transport. But "co-benefit" modifications are possible that can boost mercury capture in equipment already installed to control SO_2 and NO_x emissions.

SO_2 is captured by routing flue gas through large liquid-filter flue gas desulfurization (FGD) scrubbers or through spray dryers that work with an injected slurry of a calcium compound. Such SO_2 controls capture nearly all of the ionic mercury emissions but almost no elemental mercury. Consequently, mercury control based on SO_2 controls and combustion modifications work best at plants firing eastern coal. FGD additives are being developed to retain the mercury in the scrubber liquid once it is captured and prevent its re-release in elemental form, which some experiments show may be a concern.

NO_x in flue gas is usually controlled using selective catalytic reduction (SCR) approaches. These catalysts also convert a large fraction of elemental mercury in flue gas to soluble ionic mercury, which can then be captured in FGD scrubbers. Mercury-specific catalysts can be used at plants lacking SCR equipment and at those firing western fuels whose mercury emissions are relatively unaffected by SCR treatment. EPRI and DOE-NETL found catalysts to convert 65–90% of elemental mercury to ionic mercury in the gas streams at a Great River Energy plant and a City Public Service of San Antonio plant, both firing soft western coal; further pilot-scale tests are planned for western and eastern coals in 2005 and 2006.

As more and more SO_2 and NO_x controls are installed to comply with the new Clean Air Interstate Rule, mercury emissions are expected to fall before the cuts required by the Clean Air Mercury Rule phase in. This multi-pollutant co-benefit approach is central to EPA's plan to reduce mercury from power plants. Indeed, a number of vendors are developing integrated environmental control technologies that simultaneously remove mercury, NO_x, SO_2, and other pollutants, as an economical option for plants installing controls for multiple pollutants at once.

Mercury-Specific Options

Many plants without SO_2 controls will still need to deal with their mercury output, and even those that do have scrubbers in place may need additional mercury controls to meet the final EPA cap. Today's leading mercury-specific approach, adapted from technology devised for solid waste incinerators, is the injection of fine-powder sorbent material—typically activated carbon—into the flue gas flowing from the boiler. A sorbent works by attracting and binding mercury to its surface; the sorbent and mercury together are then captured by a downstream particulate filter such as the electrostatic precipitators (ESPs) fitted at most plants to control fly ash. Short-term tests in 2002 and 2003 indicated high effectiveness—80–90% mercury capture for eastern coals and 60–70% for western coals—but also raised questions of sorbent cost and long-term performance.

To explore possible cost reductions, EPRI and DOE-NETL are cofunding studies of various sorbents. In a four-week test as part of the larger program at Sunflower Electric, a new chemically enhanced sorbent removed more than 90% of the mercury produced at Holcomb Station relatively inexpensively. Without this sorbent, the plant's standard emission controls captured almost no mercury. A combination of conventional activated carbon sorbent and a proprietary additive also proved potentially cost-effective at Holcomb.

"From the perspective of a power producer, this has been a very important test program, and we are quite pleased with the results," said Wayne Penrod, senior manager of environment and production planning at Sunflower Electric. "We were able to determine that there are perhaps three methods from which we can choose in deciding how Sunflower will comply with future mercury reduction requirements."

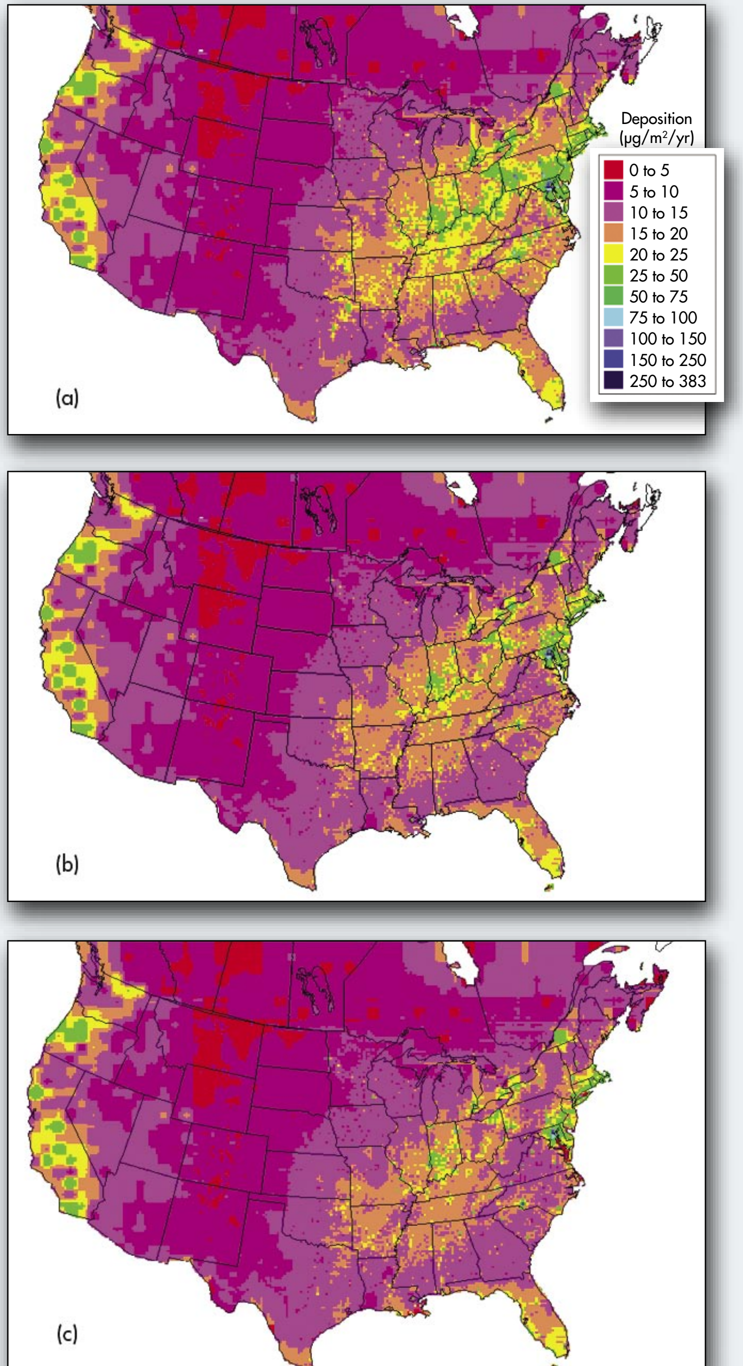
Long-term performance of sorbents will be studied in full-scale power plant tests later in 2005 and in 2006.

EPRI research is also addressing a major problem with using sorbents to control mercury emissions: contamination of fly ash. Currently, a significant amount of fly ash from coal plants is sold to cement makers for use as a concrete additive. This market benefits the environment by reducing CO_2 emissions from cement plants and minimizing landfill. However, conventional sorbents, which are captured along with fly ash, change the properties of the ash and render it unsuitable for use in concrete. Power plant operators who choose sorbents not only stand to lose profitable ash sales, they face large new costs for disposing of millions of tons of ash waste each year.

New TOXECON™ technology patented by EPRI avoids this contamination by separating the capture of fly ash from the collection of mercury-containing sorbent. The process captures mercury as well as or better than conventional sorbent approaches, as demonstrated in 2001–2002 full-scale tests at Alabama Power's Plant Gaston and in long-term tests conducted in 2004.

TOXECON works by delaying sorbent injection into flue gas until after the fly ash has been collected in a plant's primary particulate filter; the mercury-laden sorbent is then captured in a secondary filter, or baghouse, installed further downstream. In addition to preserving fly ash for concrete sales, this process requires less sorbent to achieve high levels of mercury capture because the sorbent has greater exposure to mercury in the ash-free gas stream. Consequently, TOXECON is attractive for any power plant that needs to retain ash sales, and it earned runner-up status in the environmental category of the *Wall Street Journal's* 2004 Technology Innovation Awards.

"We've now licensed five companies to use the system, and We Energies has purchased the technology to install in its Presque Isle Station in upper Michigan,"



EPRI global and regional models of mercury deposition (considering all global emission sources) show the expected results of the new Clean Air Mercury Rule. Comparisons of deposition for (a) 2004 and (b) 2020 indicate that the cap-and-trade approach will indeed reduce deposition in the East. However, because mercury emissions from outside the United States are so much higher than domestic emissions, even if U.S. coal-plant contributions (about 40% of U.S. emissions) were completely eliminated (c), overall U.S. deposition would drop by only 9%.

Hot Spots, or What Goes Up Must Come Down—Eventually

The Clean Air Mercury Rule regulates emissions, but the goal is not to improve air quality per se—the highest concentrations of mercury vapor in domestic air run less than one-thirtieth the lowest EPA risk level—but rather to control mercury in fish. The ultimate goal is to protect women and their unborn children by minimizing mercury concentrations in fish that may be eaten by pregnant mothers. Misunderstandings about how coal plant mercury emissions connect to mercury in fish and humans are the sources of much of the controversy over the recent EPA rulemaking.

Most of the major U.S. sources of mercury entering the environment have been controlled by various regulations over the past decades. The major human health concern about mercury pollution is potential neurological damage in fetuses that may result when pregnant women consume certain fish. Bacteria in water transform a fraction of the mercury that enters a lake, a river, or the ocean—whether from human or natural sources—into a compound called monomethylmercury, CH_3Hg^+, usually referred to simply as "methylmercury." Fish pick up methylmercury through their food chain and, because it degrades only slowly, larger fish accumulate more and more methylmercury from each smaller fish they eat. Through such biomagnification, methylmercury concentrations can reach significant levels in top predator fish such as pike, walleye, and swordfish.

Although the level at which methylmercury in fish is risky to fetuses is unknown—no explicit cases have been recorded and studies are obviously impractical—the federal Centers for Disease Control and Prevention has extrapolated from other data to conclude that, at any time, one in six American women of childbearing age has mercury levels in her blood that might put a fetus at risk. At least 43 states issued mercury warnings for lakes and rivers at different times in 2002.

EPA devised the Clean Air Mercury Rule to reduce the impact of mercury on children as much as is practicable. Because mercury deposition levels cannot be known or measured everywhere across the country, rulemaking was informed extensively by computer modeling. Both EPA and EPRI employed state-of-the-art—although slightly different—model sets, both of which are well regarded and give similar results. Each shows that well more than half of the mercury deposited in the United States comes from non-domestic sources (mostly Asia) and that deposition at only a few U.S. locations is dominated by domestic coal plant emissions.

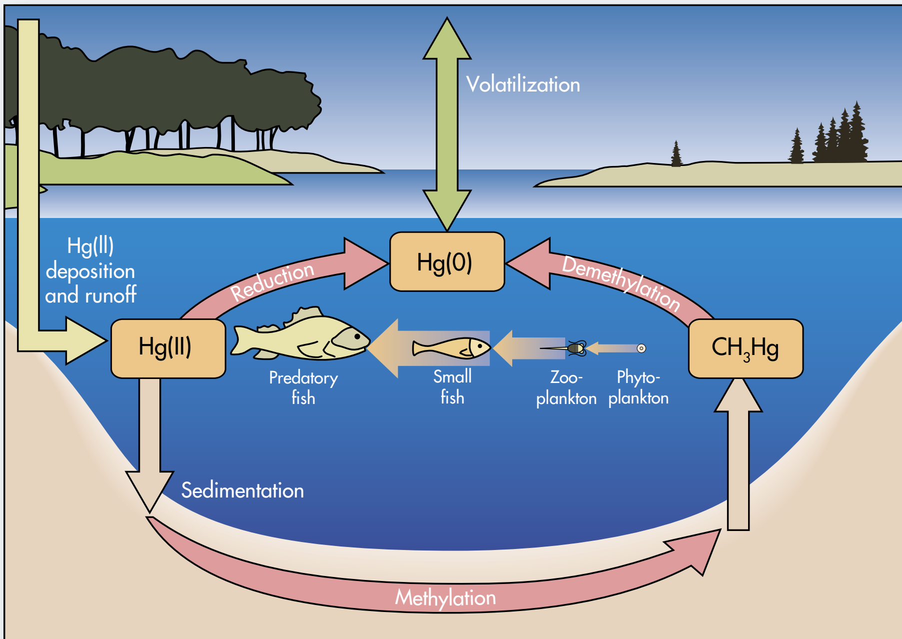
Modelers found—and ground studies confirm—that rather than falling to earth near emission sources, most mercury from coal plants is dispersed throughout the global atmosphere and resides there for up to a year. Eventually the mercury comes down to earth. Because mercury emissions from non-domestic sources are so much higher than those from domestic sources, even if all U.S. coal-plant mercury air pollution were eliminated, overall U.S. mercury deposition would drop by only 9%.

Accordingly, EPRI modeled different mercury control proposals to identify which would provide the maximum benefit at reasonable cost. A proposal to regulate mercury emissions at every plant to a specified emission limit under the Clean Air Act's Maximum Achievable Control Technology (MACT) provisions was found to reduce average domestic mercury deposition by about 5% at a total cost of about $10 billion (net present value). By contrast, the cap-and-trade approach, as selected, cuts mercury deposition by 7% at an expected cost of $2 billion. EPA modeled the cap-and-trade approach as well, with similar results.

says EPRI's Offen. The Presque Isle installation, expected to come on-line later in 2005, is cofunded under DOE's Clean Coal Power Initiative—a program that encourages the use of new technologies by sharing their cost with private industry.

TOXECON is not without competition. New alternative sorbents are being formulated that may not impact fly ash. In early tests these alternatives appear less effective than conventional sorbents, but they may prove less costly than TOXECON. In the meantime, EPRI is testing a lower-cost variant technology called TOXECON II that avoids the need for a polishing (second) baghouse. In this variant, sorbent injection occurs near the back end of the primary filter, just ahead of the last one or two collection fields but after most of the fly ash has been collected. The final fields then collect the mercury-bearing sorbent separately from the ash, but without a baghouse. Early tests indicate TOXECON II captures 50–70% of mercury in flue gas from western coal. DOE plans longer-terms tests of alternative sorbents and TOXECON II in 2005 and 2006.

The last chance to capture coal plant mercury occurs at the exhaust stack. Here fixed adsorption structures—plates or honeycombs coated with mercury sorbents such as gold or metallized solid polymer electrolytes—can collect much of the mercury remaining in flue gas after other treatments. These technologies, such as EPRI's Mercury Capture by



Mercury entering lakes—by direct deposition from the atmosphere or via terrestrial runoff—typically includes elemental mercury, Hg(0), and oxidized mercury, Hg(II). An organic form, monomethylmercury, CH_3Hg, may be produced when anaerobic bacteria in the water and sediments methylate oxidized mercury through a metabolic process. Plankton and other organisms bioaccumulate the CH_3Hg, passing it up the food chain to fish, where it may concentrate to levels of concern for human health.

With the cap-and-trade Clean Air Mercury Rule, EPRI finds that the average risk of excess exposure to coal plant mercury for Americans will fall by a factor of 15, from about a 0.6% chance to 0.04%. Reductions will vary across the country, with the smallest changes in low-deposition western states and the greatest reduction in higher-deposition West Virginia. No "hot spots," with increased mercury deposition, will be created. Although some plants may delay or avoid mercury reductions (because of the availability of emissions credits or because they already meet future mercury emission requirements), emissions nationally would still decline, as an overall cap on emissions would need to be reached. EPRI modeling finds that none of the 600 power plants with mercury emissions over 100 pounds per year in 2004 would actually increase their emissions. Emissions at only six plants would remain unchanged, and two of these plants already meet the new mercury emission requirements. Additionally, the cost of purchasing credits still motivates power plants to reduce emissions as much as possible. Thus, when the new national cap on mercury emissions is implemented by EPA and the states, a movement away from higher deposition of mercury to waterways would be expected.

EPRI computer analyses of the entire United States show that areas of high mercury deposition are not dominated by electric utility mercury emissions (the largest area, Chesapeake Bay, results from a municipal incinerator). Indeed, EPA analyses show that growth in emissions from domestic non-utility sources will continue to drive deposition changes even following the new power plant rule.

Finally, to address the global nature of mercury control, the United States leads an effort in the United Nations Environment Programme (UNEP) to establish partnerships that would help developing countries reduce mercury emissions. The idea is to leverage technology transfer, resources, expertise, and information exchange to cut mercury use and emissions. This effort accelerates the work of the UNEP mercury program proposed by the United States at the 2003 UNEP Governing Council meeting.

Adsorption Process (MerCAP™), are mostly in early development.

The Final Cost of Control

Today there is no question that coal plant mercury emissions can be captured, but the long-term effectiveness of the different control strategies remains uncertain. Extensive field tests involving U.S. government organizations, EPRI, and the power industry are expected to confirm by the end of the decade that appropriate approaches can be confidently deployed to the nation's coal plants to meet the phased emission reductions required by EPA's mercury rules.

The final cost of the Clean Air Mercury Rule remains largely unknown as well, but EPA projects that the expense to the nation will run some $2 billion (net present value). For the residential consumer, EPRI estimates this cost will add 0.1–0.3¢/kWh to the 6–8¢/kWh typically paid in the Midwest—an increase of about 1.5–3.5%. Better estimates await the conclusion of the ongoing power plant test program. "If the results we get at the end of these field tests are consistent with our process understanding, we'll be in a good position," says Offen. "If not, we have more work ahead of us."

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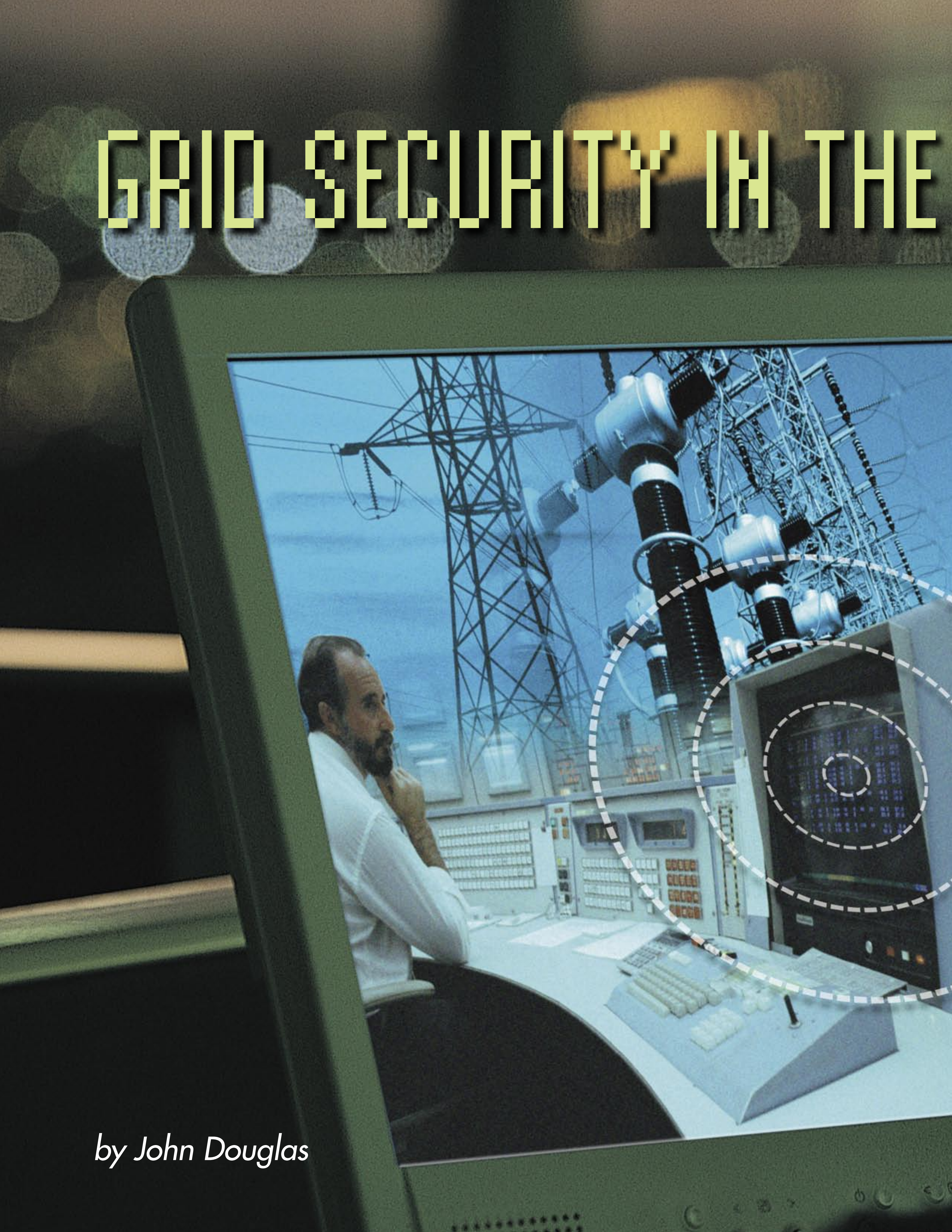
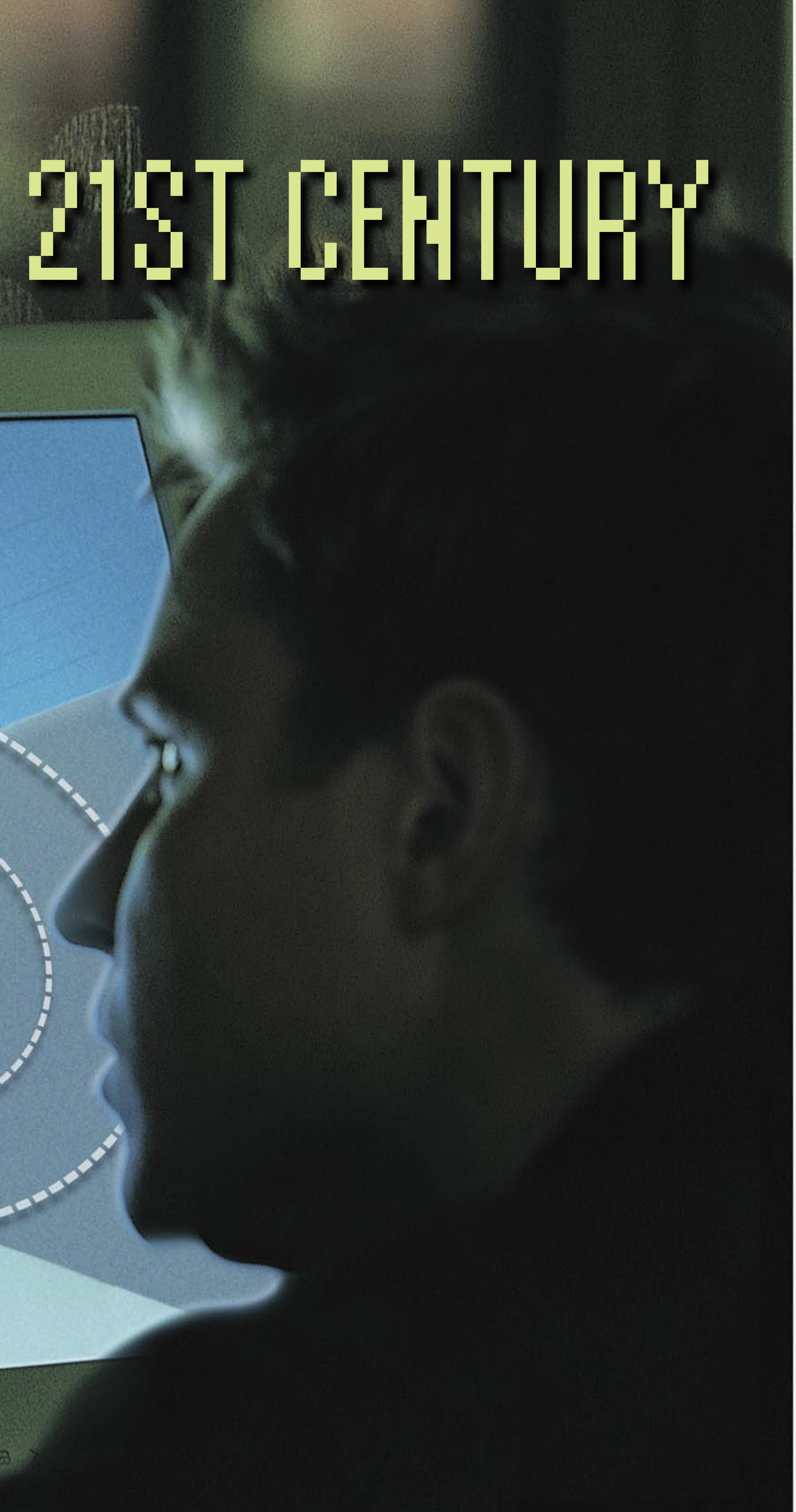
GRID SECURITY IN THE



by John Douglas



The Story in Brief

The rise of terrorism in the modern world necessitates a closer look at the vulnerability of the power grid to physical and cyber assaults. A new, industrywide initiative focuses on protecting electric power systems from hackers and worse.

Because electricity drives virtually all of the nation's critical infrastructures—from telecommunications to waterworks—the electric power system presents an inviting target for international terrorists. A coordinated attack on major power plants or substations could trigger a cascading blackout with major social and economic impacts. Depending on the extent and success of such an attack, daily life and business could be disrupted for several days across a wide area of the country, and a complete return to normalcy could take months to years.

Especially worrisome in a time of increasing industry dependence on the Internet is the fact that a devastating attack need not be directly physical: The perpetrators could remain anonymous and remote, achieving their goals by disrupting a utility's computer network or power system controls. A successful cyber attack, for example, could potentially allow a terrorist to destroy equipment by sending false control signals or by disabling electricity grid protective relays. Every day, a typical large electric utility must fight off hundreds or even thousands of cyber intrusions that appear to originate with hackers trying to disrupt normal business, obtain sensitive data, or exert control over parts of the grid.

Most utilities, of course, have already enhanced their efforts to protect both physical facilities and computer networks. The fact that virtually all of the illegal entry attempts so far have failed indicates the effectiveness of these security measures. "Utilities throughout North America have made significant strides to implement cyber and physical security," says Luther Tai, senior vice president, central services, Consolidated Edison Co. "While these have greatly reduced the vulnerabilities, there is more that can be done through the research and development work that is now under way at EPRI."

Part of the problem is that, with electric power networks so tightly interconnected, a significant security breach anywhere on the system can have an effect on the system as a whole. Since there are many different types of utilities in the United States, each at a different level of cyber preparedness, there is a compelling incentive to improve the coordination of security precautions taken by all utilities.

Utility decision makers face a number of challenges in this area. The broad scope of the security issue has led to development of multiple and sometimes overlapping requirements from various government agencies. At the same time, utility efforts to increase security are often constrained by limited access to useful information produced by these agencies and others, either because of the highly classified nature of the data or because the data are distributed across multiple locations. As a result, utility executives have often been forced to make security-related decisions on the basis of sparse, uncertain, or anecdotal information. A further challenge for electric utilities involves internal communications—how to effectively communicate security weaknesses identified by utility operations, planning, and engineering personnel to higher-level management.

Since 2001, a number of individual utilities have pioneered important cyber security efforts, each producing valuable results. However, a lack of effective technology transfer and broad industry support has limited the effectiveness of these results for the industry as a whole. Because security is only as strong as the "weakest link" in the chain of interconnected information and communication systems that utilities use, increased industry support, participation, and successful implementation of new security tools are crucial for effective industrywide cyber security.

In order to help provide the needed coordination and establish a unified response to cyber threats, EPRI and other leading industry organizations have formed the PowerSec Initiative. In addition, important new results are emerging from EPRI's own long-standing R&D work on electricity infrastructure security as a whole.

Early Efforts to Enhance Security

EPRI was leading an industrywide effort to reinforce U.S. power infrastructure security well before September 11, 2001. But as with most of the nation's protection and emergency response programs, the terrorist attacks sparked a fundamental rethinking, expansion, and refocusing of utility security efforts. While earlier concerns largly centered on the effects of natural disasters, system control anomalies, and small-scale vandalism, the twenty-first-century equation clearly must include protection against calculated assaults designed to disrupt American life and commerce on a large scale. EPRI's Infrastructure Security Initiative (ISI) was launched in response to these challenges and was designed to develop both prevention countermeasures and enhanced recovery capabilities.

As part of the work to provide utilities with immediately useful countermeasures, ISI is documenting lessons learned from actual terrorist attacks and other catastrophic events at utilities around the world for use by ISI participants. One of the highlights of this effort came in 2004 with the receipt of a draft report from Israel Electric Corporation on best practices they have developed to defend their grid against terrorist attacks. The countermeasures project is also providing utilities with information on new ways to protect their physical facilities, including a covert detection system that uses a magnetic field to identify potential intruders by size, speed, and electrical conductivity. Another system uses artificial intelligence technology to automatically analyze the streaming video from cameras in remote locations to detect, for example, whether an intruder has dropped a suspicious object.

Among potential infrastructure targets attractive to terrorists, high-voltage transformers represent a critical vulnerability. These transformers cost several million dollars each and usually take one to two years to procure, build, and install. In response to this threat, ISI came up with the concept and developed preliminary designs for a new type of transformer that can be easily stored, transported, and installed for emergency use. An important milestone in development of this so-called recovery transformer was achieved in 2004 with completion of preliminary designs for two units, rated at 500 kV and 345 kV. Both can be transported by truck, rail, or military cargo plane, and once all parts are available on site, they can be installed in about 48 hours.

The design studies for the recovery transformers indicate that they will be about 30% lighter and smaller than conventional units, have an efficiency of 99%, and have an expected life of about 35 years. EPRI is currently working with the Department of Homeland Security (DHS) seeking sponsorship for the production of prototypes for these transformers. EPRI would provide funding through ISI for the factory testing efforts to ensure that electric utility short-circuit criteria and other critical performance requirements are met.

In addition, ISI is in the process of developing emergency recovery plans for substations that have been knocked out by a terrorist attack or other devastating event. These plans identify methods that utilities can use to assess which equipment is still salvageable, to identify the need and availability of spare parts, and to attempt to "harden" key sites against possible attack.

Emergency communications technologies are also being evaluated by ISI in order to recommend the best alternatives for use in case of emergency. The aim is to provide utilities with secure ways of communicating with each other and with emergency services after a successful, multi-regional terrorist attack. This work is being coordinated with related projects being carried out by government agencies and in other countries. In particular, the use of satellite phones—which support both voice and data communication—is being explored.

Dealing With Cyber Vulnerability

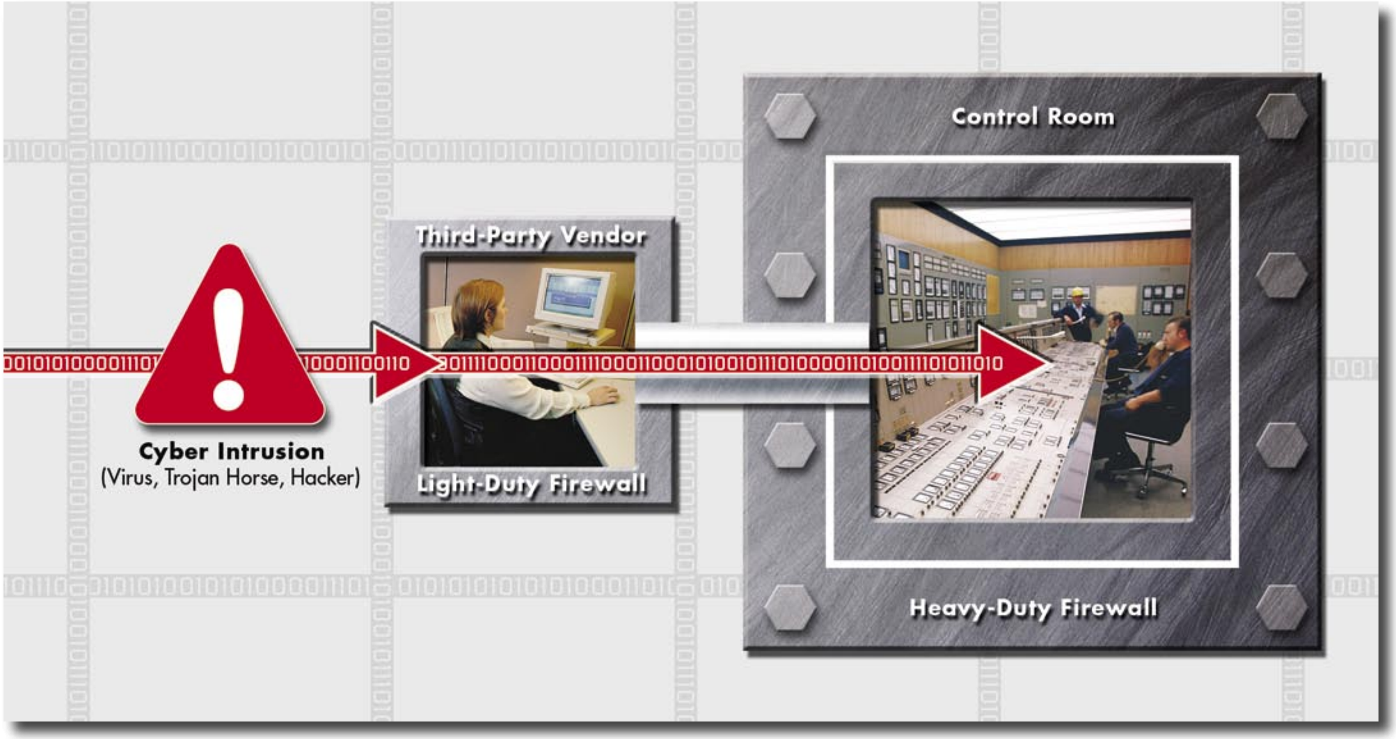
In this age of ubiquitous digitization, phys ical attacks are far from the only concern. The known successes of cyber attacks on a surprising variety of industries offer chilling testimony to the need for countermeasures against computer-based intrusions.

While physical assaults—be they facility break-ins, weapon attacks, or bomb explosions—are certainly frightening possibilities, cyber attacks have the potential to be every bit as destructive and carry the insidious added threats of stealth and long-distance control. "If a cyber terrorist is able to get through a company's firewall and other protection systems, it doesn't matter if he's on the other side of the world," points out technical executive Robert Schainker, who manages EPRI's security work. "If he's linked in through the Internet—which is available virtually everywhere—and he penetrates the protections to your operational systems he may as well be sitting in your control room."

Indeed, the incredible power and flexibility of the Internet has made cyberspace part of the global battlefield, and several nations have incorporated explicit plans for attacking information systems into their military preparations. Russia, for example, has documented successes in cyber attacks against key Chechen web sites. India and Pakistan have pursued competing preparations for electronic warfare. China has formulated an official cyber warfare doctrine, and North Korea has experimented with offensive cyber technologies. Terrorist organizations in the Middle East have shown increasing sophistication in the use of information technologies and have made no secret of their intent to attack critical American infrastructures.

The U.S. government has long been concerned over the wide-ranging effects that computer-based attacks could have on the nation's key infrastructures. After the Morris computer worm brought 10% of the country's Internet systems to a standstill in 1988, the Defense Advanced

Modern-day security threats can be both physical and cyber-based. An intruder could destroy a substation transformer with a bomb or by setting a fire, but a computer hacker could accomplish the same end by sending the transformer overload signals, causing it to rapidly overheat and explode.



While utilities go to great lengths to protect their critical facilities from cyber intrusion, their connections with third-party vendors can be an unrecognized weak spot. Hackers stopped by strong firewall systems protecting the control room, for example, may be able to make it in through weaker, standard security measures protecting vendors that provide procurement or billing services. Once in the "back door," the intruder may be able to move to a utility's grid operation and control systems.

Research Projects Agency (DARPA) set up the Computer Emergency Response Team (CERT) Coordination Center at Carnegie Mellon University to monitor cyber threats and respond to serious security incidents. According to CERT, keeping ahead of the trouble is no easy task: "Along with the rapid increase in the size of the Internet and its use for critical functions, there have been progressive changes in intruder techniques, increased amounts of damage, increased difficulty in detecting an attack, and increased difficulty in catching the attackers."

Earlier this year, DHS set up the Process Control Systems Forum (PCSF) to focus specifically on threats to the computerized automated control systems that underlie operation of most of the country's critical infrastructures, including the electric power grid. The PCSF will leverage security knowledge currently dispersed among different infrastructures and stimulate cross-functional discussions between those responsible for information technology and operations. EPRI is coordinating with the PCSF to ensure that the utility industry's security concerns and solutions are shared on a confidential basis.

Technologically, utility industry restructuring has created several unforeseen effects that increase this vulnerability. Power companies are now much more interconnected than previously, which not only provides more points of entry for an attacker but also means that potential damage may be more widespread. Open (as opposed to proprietary) operating systems and communications protocols were successfully designed to improve ease of use, but they may have made the task of an intruder easier as well. And remote access systems, such as those used to monitor field data and revise set points for relays, may have opened new portals for intrusion.

Changing business practices may also inadvertently open new opportunities for cyber intrusion. For example, an increasing number of businesses—including utility companies—are turning to third-party vendors to provide day-to-day administrative or service functions such as payroll, accounting, and maintenance. As a result, a power plant's operating control system may have direct communication links to a vendor-managed purchase/selling function, such as procurement or billing. But the vendor's computer system may not be as strongly protected from the outside world as the utility's heavily firewalled control room, providing an easier point of entry for hackers or computer viruses. After gaining access to the utility through this "back door," the intruder may be able to move to more critical areas of the plant, unbeknownst to the utility company.

These and other emerging concerns prompted EPRI to add computer-based threats to its portfolio of security R&D. EPRI's focus on cyber security had its beginnings in the development of the first utility open-systems architecture—the Utility Communications Architecture (UCA), used to share data between various computer systems in a company—and was strengthened after the highly successful program to prepare utility computer systems and equipment for the Y2K transition. Growing concern over the possibility of computer-based security breaches led to development of EPRI's Energy Information Security (EIS) program in 2003. EIS was designed to provide tools that individual utilities could use to enhance their own security programs, including cyber security awareness training, information sharing, approaches to assessing control system vulnerability, and risk management protocols.

The EIS program has already produced valuable results. When vulnerabilities were discovered in standard communications protocols, such as those specified in UCA, EIS researchers developed enhancements designed to increase security. Early exploratory work has also been conducted on fast encryption and instruction detection technologies to protect data and control systems. Publication of the *Security Vulnerability Self-Assessment Guideline for the Electric Utility Industry* (1001639) enabled companies to conduct their own risk analyses, while the *Guidelines for Detecting and Mitigating Cyber Attacks on Electric Power Companies* (1008396) provided basic procedures for enhancing network security.

PowerSec: A Coordinated Approach

Much progress has been made through EPRI's ISI and EIS programs. But considering the complexity of the nation's power infrastructure, the ever-increasing capabilities of cyber attackers, and the diverse nature of current security efforts, a more comprehensive, highly coordinated effort is clearly required. In response—and in cooperation with several industry organizations and the EPRI Board of Directors—EPRI drafted a proposal for an industrywide program, identified ongoing security work at various industry and government organizations, and obtained feedback from more than 60 utilities, representing all segments of the electric power industry. As a result, an alliance has been formed to create the PowerSec Initiative, which initially will bring together EPRI staff, a variety of industry organizations, and several industry experts to address the cyber threat issue.

By examining threats, vulnerabilities, and potential consequences, the PowerSec Initiative will evaluate the industry's current cyber attack readiness, identify gaps in this readiness, and specify existing best practices for filling these gaps. In some cases, even current best practices will not be sufficient to handle emerging attack techniques; the initiative will therefore also identify vulnerabilities that require new solutions and specify what R&D work is needed to develop and test these solutions.

One important goal of PowerSec is to consolidate and leverage ongoing and completed cyber security work from utilities, government, regulatory agencies, and others. Appropriate information on best practices will be disseminated to the industry using methods consistent with the safeguard of confidential or classified information. In addition to integrating and sharing disparate information, the initiative will serve as a model of how the utility industry, regulators, and government can work together to solve complex security problems.

"EPRI has long been a leader in building security awareness in the electric power industry," says Tom Kropp, EPRI project manager for electric power critical infrastructure protection. "Now the information and products we have developed over the years can help form the foundation of a coordinated, industrywide effort."

Early Goals

The PowerSec Initiative will focus first on electric utility supervisory control and data acquisition (SCADA) systems and energy management systems (EMS), both of which have been identified by experts as critical systems to secure. Identifying and filling existing security gaps in communication and control systems will make it more difficult for potential intruders to gain access and cause damage. Improvements in these systems will also tend to increase overall levels of power system reliability, providing a more secure business environment for wholesale power markets and enabling utilities to offer better service to their customers.

EPRI and its members have defined a set of general objectives for the PowerSec Initiative, the first of which is to develop an overview of the electric power industry's current cyber security posture. From this, the initiative will provide utilities with a list of vulnerabilities for each major type of SCADA and EMS control system commonly deployed across North America and will tailor this information to reflect the particular combinations of systems in use. A comprehensive, prioritized list of viable cyber threats will also be developed, along with the compendium of best practices with recommendations on how to maximize cyber security using currently available tools and methods. A compendium of current cyber security projects being pursued by both government and private industry will be developed to clarify which areas are being adequately studied and which need more attention.

Together, these results will be used to identify gaps between viable threats and defenses, both current and planned; the analysis will lead to an R&D action plan for developing technologies to eliminate any gaps, identified or perceived.

Clearly the first order of business for PowerSec will be to assess the vulnerability of information and control systems currently used by utilities and system operators. This work will begin with onsite interviews and inspections and will be supplemented by evaluation of past or ongoing security analyses by individual

Artificial intelligence software offers new tools to help identify physical threats. In this airport baggage claim area, a video surveillance camera is able to automatically monitor and analyze the activities of groups and individuals. When the man circled in yellow sits down and then leaves the scene without the small bag he was carrying, the system identifies the unattended object (red box) and alerts security that there is a suspicious situation. (Photos courtesy ActivEye, Inc.)

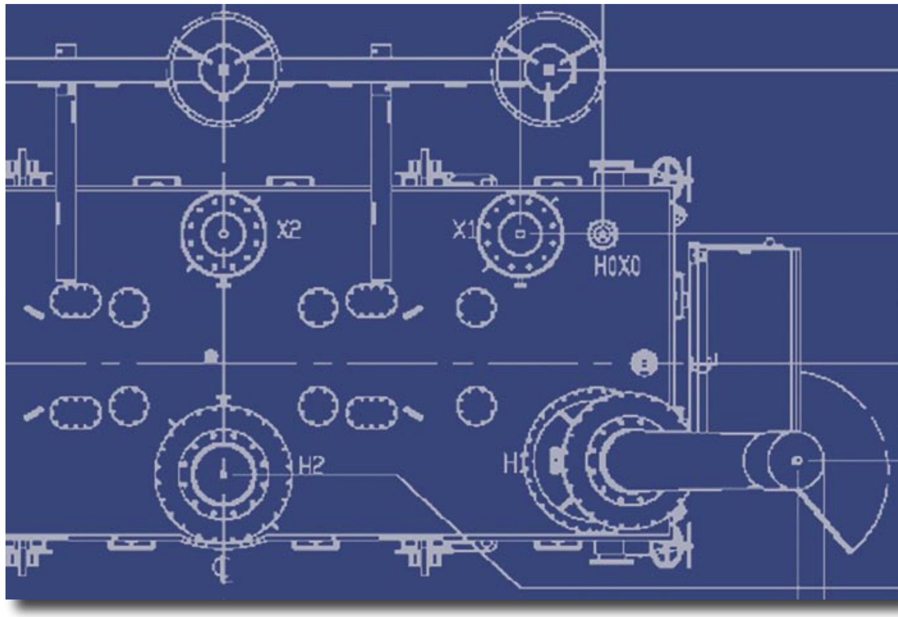
utilities, EPRI, and government organizations. Researchers will also examine existing information systems directly to determine their cyber vulnerability, and in some cases, conduct "red teaming" (mock intrusion) exercises at selected host utility sites. Particular emphasis will be placed on examining SCADA and EMS systems to help prevent hackers from using them to take over control of critical utility equipment.

Each PowerSec participant will receive a confidential document identifying the strengths and weaknesses of its own SCADA and EMS systems. Because the report will identify the best practices for those particular systems, PowerSec participants will have the advantage of being able to enact available countermeasures immediately to reduce the threat of successful cyber attack.

Information gleaned from the vulnerability assessment process is also intended to complement ongoing security standards development by the North American Electric Reliability Council (NERC) and the Federal Energy Regulatory Commission. The Urgent Action Cyber Security Standard 1200 adopted by NERC in 2003 already specifies actions to be taken to protect utility systems in 16 areas, such as access control, information protection, personnel training, incident response, and recovery planning, among others. This standard, which was originally adopted as a temporary measure, is now being extended and modified for development into a set of permanent security standards: CIP-002 through CIP-009.

PowerSec's assessment phase—expected to take about a year—will provide an objective assessment of the industry's cyber security. If significant security gaps are identified, EPRI staff will work with PowerSec participants to propose solution approaches to be developed and tested in later phases.

The effectiveness of PowerSec results will be evaluated using independent test-bed exercises at the Idaho National Laboratory and Sandia National Laboratory, as appropriate. These facilities are capable of testing the new tools on a variety of SCADA and other cyber systems provided by manufacturers. Evaluations will also be conducted at individual utilities. The PowerSec team will use the confidential results of these evaluations, together with feedback from the deployment process, to revise vulnerability assessments and enhance the alert system by adding new attack mitigation actions.



Loss of a high-voltage transformer is of particular concern for grid security because replacement units typically take one to two years to procure, build, and install. EPRI's Infrastructure Security Initiative is dealing with this problem by sponsoring designs for a smaller, lighter "recovery transformer" for emergency use that can be easily stored, transported, and installed in days. (Courtesy ABB)

An Eye to the Future

After developing the draft proposal for the PowerSec Initiative, EPRI submitted the plans to member utility executives for comment and suggestions. This feedback provided important insights on how to proceed with PowerSec formation. The comments revealed that utilities believe they have made considerable progress toward protecting their own cyber systems but recognize that key vulnerabilities remain across the industry as a whole. The executives generally believe that cyber attacks are likely, from domestic and/or international terrorists, and that disgruntled past or present employees also represent a potentially dangerous threat. They also say that PowerSec should ultimately address a combination of cyber and physical threats and vulnerabilities, because successful physical attacks may involve very long recovery times. An area of particular concern is how to ensure the availability of spare parts for long-lead-time equipment.

The PowerSec Initiative will help participants come quickly up the learning curve about cyber security risks and vulnerabilities and will give them enhanced capabilities to assess cyber-related threats on their own systems. Access to government and regulatory thinking on security issues could also help participants better prepare for potential changes in cyber regulations that impact utilities. "The biggest issue today is the incomplete and anecdotal aspects of the situational data available," concludes Schainker. "Such uncertainties prevent utilities from positioning themselves effectively for dealing with security issues. A more comprehensive understanding of the situation will allow PowerSec participants to better allocate financial and personnel resources to their security preparedness." Ultimately, it is hoped that PowerSec will help focus future government cyber security regulations, spur the development of innovative mitigation tools and methods, and promote enhanced cyber security preparedness by the industry at large.

But if continued attacks on the grid are inevitable, as many industry leaders believe, prevention will only be part of the answer to grid security concerns. "We've got a lot of smart people working on this problem, but the field of opportunity for intrusions is very broad," says Wade Malcolm, EPRI's vice president for power delivery. "We have to assume that sooner or later an intruder will succeed in breaching our defenses. This is why a long-term program for increasing overall system resiliency becomes crucial—if a hacker or terrorist does manage to compromise a transformer or power line, the grid must be able to withstand the loss without the danger of wide-area cascading outages." EPRI's IntelliGrid[SM] Consortium—another industrywide initiative—is working on adaptive, self-healing technologies that can be built into the nation's electric power delivery system to provide just such resiliency.

"The industry is clearly entering a new phase of security consciousness," concludes Schainker. "Some individual utilities have already done a lot to protect their own cyber and physical systems against terrorist attacks, and now the time has come to expand this work through coordinated, industrywide efforts. If we are successful, the payoff will be large indeed: With PowerSec reducing the probable success of attacks and IntelliGrid features limiting the scope of their effects, tomorrow's power grid will have every potential to meet the challenges of a post-9/11 world."

Background information for this article was provided by Robert Schainker (rschaink@epri.com) and Thomas Kropp (tkropp@epri.com).

Technology at Work

Member applications of EPRI science and technology

TAG® Info Links Technology With Business Planning

To implement strategic technological solutions on their systems, utility planners must match appropriate technology options with their ongoing business planning; making the right choices in this process requires consistent, credible, up-to-date information on the performance and cost of conventional and emerging technologies. When it comes to electricity generation technologies, EPRI's Technical Assessment Guide (TAG®) is widely considered the industry standard for such data, providing a level of detail unavailable elsewhere. EPRI's data screening, sifting, and evaluation process ensures credible, high-quality information to serve the industry's capital investment planning needs. As recent experiences of MidAmerican Energy and East Kentucky Power Cooperative demonstrate, TAG information can be valuable in a great many applications, from R&D and facilities engineering to resource planning, market assessment, and financial and legal issues.

MidAmerican Energy recently used TAG to support its resource planning and capital investment decisions related to a number of development projects in Iowa. TAG's objective cost data on alternative generation options formed the basis for the company's market price forecasts, unit screening studies, and economic expansion analyses. By providing MidAmerican with data that would be time-consuming and expensive to develop independently, TAG was able to substantially reduce the consultant fees and employee time required for optimizing their capital investments. Over the longer timeframe, TAG keeps the company informed of emerging technologies and trends, providing assistance in long-range capacity planning, financial plan development, asset evaluations, long-term price modeling, and response to regulatory inquiries.

One of TAG's most valuable attributes is its ability to consider the factors affecting a generation technology over each stage of its life cycle. This long-term perspective allows planners to assess a technology's technical and economic viability with respect to such factors as fuel availability and cost, regulatory climate, emissions control requirements, and land and water issues. Such capability helps planners not only compare the capital requirements associated with different technologies, but also assess the risk/return aspects of a decision over time.

Dale Stevens, manager of market development for MidAmerican Energy, actively promotes the use of TAG results by other departments—for example, in development of avoided capacity costs for MidAmerican's energy efficiency plan—and is exploring customization of the results for applications such as forecasting regional electricity market trends.

Meanwhile, East Kentucky Power Cooperative (EKPC) has been using TAG for over a decade in developing regional case studies and benchmark costs for inclusion in the resource planning documents it must file periodically with the Kentucky Public Service Commission. More recently, it turned to TAG to help with pressing resource planning and capital investment decisions during a period of major growth. EKPC used TAG to help determine the cost of adding a new cooperative to its system, pricing the new company's assets both independently and as part of the existing EKPC system. This approach proved very beneficial in EKPC's winning proposal to secure a new member for the co-op.

"As a respected outside source of information on technologies and costs, the EPRI TAG has benefited East Kentucky Power Cooperative's owners and customers in many ways over the years," says EKPC's Kim Hood. "TAG has been a valuable tool that helps us make informed decisions that optimize capital investment, supports development of our Integrated Resource Plan, and helps keep EKPC's power costs among the lowest in the nation."

For more information, contact G. (Ram) Ramachandran, gramacha@epri.com.

Guided-Wave Sensor Surveys Piping in San Antonio

City Public Service (CPS) of San Antonio, Texas, has about three miles of insulated, 12-inch-diameter piping that supplies fuel oil to the boilers of its VH Braunig plant. Two summers ago, the piping developed a fuel leak caused by corrosion under the insulation. The standard approach for such a problem would be to remove the insulation from all three miles of piping and conduct visual and ultrasonic inspections—an expensive, time-consuming proposition. CPS called on EPRI's Fossil Nondestructive Evaluation (NDE) Center to ask if there was a way to inspect the piping for external corrosion without insulation removal.

The NDE Center proposed using a new long-range, guided-wave magnetostrictive sensor (MsS) system designed to cost-effectively collect comprehensive inspection information on long lengths of power plant piping. The center had

recently evaluated the MsS system—developed by Southwest Research Institute—for buried pipe inspection, with good results. MsS offered the potential to conduct complete inspections, rather than sampling, but without the need to remove insulation or perform other expensive preparations. CPS decided to try the new technology to identify heavily corroded locations before the fuel oil pipeline developed more leaks.

Over 1500 feet of piping were examined during the two-day MsS field trial: straight runs, road crossings with elbows, and elbows and straight sections associated with expansion loops. The tests showed that some 300 feet of supply line and 140 feet of return line were moderately to heavily corroded. CPS subsequently removed insulation from areas indicated as having heavy corrosion and confirmed the MsS results via conventional methods. In addition to accomplishing accurate inspection at low cost, the guided-wave technology also avoided the effort and cost of roadway excavation for those pipe portions running under roads, for a combined calculated cost savings of $100,000.

Conventional inspection methods would have required removal of all piping insulation, followed by visual and ultrasonic examination—a process that may have taken months to complete. "MsS allowed us to screen large areas of pipe in just a couple of days, and that helped us quickly assess the cost of replacing damaged piping," notes CPS's Paul Barham.

For more information, contact Stan Walker, swalker@epri.com.

Operator Training Simulator Improves Skills, Reliability

In the modern digital economy, reliability of electric service is more important than ever: loss of power brings computer-based business and manufacturing to a standstill, with substantial financial losses. Well-trained, highly skilled power system operators are the first line of defense against events that jeopardize power system reliability. In light of this, enhanced operator training has now been mandated by the North American Electric Reliability Council—a direct result of deficiencies in operator preparedness identified in the Midwest and labeled as one of the root causes of the August 2003 system blackout in the eastern United States.

With reliability a top commitment for its customer service, New York Power Authority (NYPA) recently took action to help its power system operators acquire the experience and skills needed to manage systems on today's complex, highly interconnected power grids. NYPA installed an EPRI/Siemens Operator Training Simulator (OTS), which realistically replicates the dynamic behavior of a power system as it responds to changes in operating conditions or system events. The OTS's system-specific training scenarios help NYPA supplement other training tools in the development of a comprehensive operator training program.

Functioning similarly to an aircraft flight simulator, the OTS allows extreme system situations to be presented to trainees, enabling them to practice their responses when there is no real consequence for mistakes. Such exercises accelerate the acquisition of experience and skills needed to deal with real power system emergencies. Because the training scenarios were custom-developed to reflect the workings of the NYPA system, new operators can gain familiarity with both normal operations and unexpected contingencies.

Initially, the OTS has been used as a dispatch power flow tool that allows trainees the opportunity to observe real-time simulations of actual operator actions performed in an interactive training environment. As training resources are augmented at NYPA, the OTS will be used more in the mode for which it was originally designed, with the system-specific training scenarios applied in direct, one-on-one exercises. This final phase of the coordinated training program got under way earlier this year. When broadly applied by the industry, EPRI's OTS will help ensure that power system operators receive the training they need to manage systems on today's complex grids and to deal confidently with system emergencies.

For more information, contact David Becker, dbecker@epri.com.

Technical Reports & Software

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com). Visit EPRI's web site to download PDF versions of technical reports (www.epri.com).

Environment

Chemical Constituents in Coal Combustion Product Leachate: Boron
1005258 (Technical Report)
Program: Groundwater Protection and Coal Combustion Products Management
EPRI Project Manager: Kenneth J. Ladwig

Carbon Supply From Changes in Management of Forest, Range, and Agricultural Lands of California
1005465 (Technical Report)
Program: Greenhouse Gas Reduction Options
EPRI Project Manager: Richard G. Rhudy

EPRI Ergonomics Handbook for the Electric Power Industry
1005574 (Technical Report)
Program: Occupational Health and Safety
EPRI Project Manager: Janice W. Yager

Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air
1008492 (Technical Report)
Program: MGP Site Management
EPRI Project Manager: Babu Nott

Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes
1010112 (Technical Report)
Program: Section 316(a) and 316(b) Fish Protection Issues
EPRI Project Manager: Douglas A. Dixon

Impingement and Entrainment Survival Studies Technical Support Document
1011278 (Technical Report)
Program: Section 316(a) and 316(b) Fish Protection Issues
EPRI Project Manager: Douglas A. Dixon

Entrainment Abundance Monitoring Technical Support Document
1011280 (Technical Report)
Program: Section 316(a) and 316(b) Fish Protection Issues
EPRI Project Manager: Douglas A. Dixon

Measuring and Monitoring Plans for Baseline Development and Estimation of Carbon Benefits for Change in Forest Management in Two Regions
1011585 (Technical Report)
Program: Greenhouse Gas Reduction Options
EPRI Project Manager: Richard G. Rhudy

Baseline Greenhouse Gas Emissions and Removals for Forest, Range, and Agricultural Lands in California
1011586 (Technical Report)
Program: Greenhouse Gas Reduction Options
EPRI Project Manager: Richard G. Rhudy

Laboratory-Scale Evaluation of the Mercury Chemical Reactions Across SCR Catalysts
1011649 (Technical Report)
Program: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: Paul Chu

LARK-TRIPP RY2004, Version 1.1
1011997 (Software)
Program: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: Naomi L. Goodman

Generation

Metallurgical Guidebook for Fossil Power Plant Boilers
1004509 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David W. Gandy

EPRI Coal Flow Loop: Evaluation of Extractive Methods
1004744 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Richard A. Brown

Application of Strain Gage Technology for Slag Deposition Monitoring
1004821 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Ramesh Shankar

Maintenance Task Work Package Library
1004828 (Technical Report)
Program: Maintenance Management and Technology
EPRI Project Manager: Ray H. Chambers

Guidelines for Performance-Based Contracts for Fossil-Fueled Power Plants
1004829 (Technical Report)
Program: Maintenance Management and Technology
EPRI Project Manager: Ray H. Chambers

Cycle Chemistry Guidelines for Fossil Plants: Oxygenated Treatment
1004925 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: Barry Dooley

Thermal Fatigue of Fossil Boiler Drum Nozzles
1008070 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: Kent K. Coleman

Guidelines for Controlling Flow-Accelerated Corrosion in Fossil and Combined-Cycle Plants
1008082 (Technical Report)
Programs: Boiler Life and Availability Improvement Program; Boiler and Turbine Steam and Cycle Chemistry; Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Barry Dooley

Diagnostic/Troubleshooting Monitoring to Identify Damaging Cycle Chemistry or Thermal Transients in Heat Recovery Steam Generator Pressure Parts
1008088 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Barry Dooley

Electromagnetic Nondestructive Evaluation (NDE) for Heat Recovery Steam Generators (HRSGs)
1008093 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: Stan M. Walker

Repair Welding Technologies for Heat Recovery Steam Generators
1008094 (Technical Report)
Program: Heat Recovery Steam Generator (HRSG) Dependability
EPRI Project Manager: David W. Gandy

Status and Performance of Best Available Control Technologies
1008114 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: Charles E. Dene

Demonstration of Advanced Boiler Instrumentation Technologies
1008144 (Technical Report)
Program: I&C and Automation for Improved Plant Operations
EPRI Project Manager: Ramesh Shankar

Operations Assessment Guideline
1008250 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: Wayne C. Crawford

Protecting Potentially Sensitive Information
1008261 (Technical Report)
Program: Operations Management and Technology
EPRI Project Manager: Wayne C. Crawford

Quality Assurance/Quality Control Guidelines for Mercury Measurements
1008267 (Technical Report)
Program: Continuous Emissions Monitoring
EPRI Project Manager: Charles E. Dene

Combustion Turbine Guidelines: Conventional and Advanced Machines
1008317 (Technical Report)
Program: Combustion Turbine (CT) and Combined-Cycle (CC) O&M
EPRI Project Manager: David W. Gandy

Gas Market Transition: Impacts of Power Generation on Gas Pricing Dynamics
1008329 (Technical Report)
Program: Understanding Power and Fuel Markets and Generation Response
EPRI Project Manager: Jeremy B. Platt

RE Calculator 1.1—Renewables Calculator, Version 1.1
1008367 (Software)
Program: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: Charles R. McGowin

Wind Power Integration: Energy Storage for Firming and Shaping
1008388 (Technical Report)
Program: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: Charles R. McGowin

Wind Power Integration: Smoothing Short-Term Power Fluctuations
1008852 (Technical Report)
Program: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: Charles R. McGowin

Materials Solutions for Waterwall Wastage—An Update
1009618 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Anthony Facchiano

2004 Workshop on Selective Catalytic Reduction
1009627 (Technical Report)
Program: Post-Combustion NO_x Control
EPRI Project Manager: David R. Broske

Development of Code to Predict Stress Corrosion Cracking and Corrosion Fatigue of Low-Pressure Turbine Components
1009690 (Technical Report)
Program: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: Barry Dooley

FGD Remote Monitoring
1009772 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: Ralph F. Altman

Applications Guide for Guided Wave Inspection Technology
1009776 (Technical Report)
Program: Fossil NDE Technology and Training
EPRI Project Manager: Stan M. Walker

Hydropower Technology Roundup Report
1009798 (Technical Report)
Program: Hydropower, Emerging Issues and Technologies
EPRI Project Manager: Douglas A. Dixon

Guidelines for the Development of an Initial Systematic Training Program
1009849 (Technical Report)
Program: Workforce Training and Development Research
EPRI Project Manager: Richard Pennington

Guidelines for the Evaluation of Cold Reheat Piping
1009863 (Technical Report)
Program: Boiler Life and Availability Improvement Program
EPRI Project Manager: Richard Tilley

The Fate of Mercury Absorbed in Flue Gas Desulfurization (FGD) Systems
1009955 (Technical Report)
Program: Integrated Environmental Controls (Hg, SO_2, NO_x, and Particulate)
EPRI Project Manager: Richard G. Rhudy

All Eyes on LNG: U.S. Gas Supply Options and Prospects for Relief
1009965 (Technical Report)
Program: Understanding Power and Fuel Markets and Generation Response
EPRI Project Manager: Jeremy B. Platt

Generator On-Line Monitoring and Condition Assessment: Partial Discharge and Electromagnetic Interference
1010207 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Jan Stein

2005 EPRI Heat Rate Improvement Conference
1010321 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jeffrey Stallings

Catalyst Reaction (CATREACT) Version 1.0
1010332 (Software)
Program: Post-Combustion NO_x Control
EPRI Project Manager: David R. Broske

SOAPP-REPO Combined-Cycle Repowering Workstation, Version 3.0
1011032 (Software)
Program: New Combustion Turbine/Combined-Cycle Design, Repowering, and Risk Mitigation
EPRI Project Manager: Dale S. Grace

Generator Expert Monitoring System Knowledge Base
1011441 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Jan Stein

Emission Control Options for Distributed Resource Generators
1011482 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: Daniel M. Rastler

Numerical Simulation of Induced Flue Gas Recirculation (IFGR) Operation at American Electric Power's Plant Welsh Unit 1
1011500 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Richard A. Brown

Solar Thermal Electric Technology in 2004
1011615 (Technical Report)
Program: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: Alejandro Jimenez

Advanced Steam Labyrinth Seal Design
1011932 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Stephen H. Hesler

Hydroelectric Assessment Study of Existing and Planned Water Systems on the Big Island
1011993 (Technical Report)
Program: Renewable Technology Options and Green Power Marketing
EPRI Project Manager: Alejandro Jimenez

Biogas-Fueled Electric Power
1012019 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: David Thimsen

Nuclear Power

Evaluation of Constant Elevated pH Demonstration at Comanche Peak Steam Electric Station
1003408 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeffrey C. Deshon

Materials Reliability Program: Destructive Examination of the North Anna 2 Reactor Pressure Vessel Head (MRP-142)
1007840 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christine King

BWRVIP-140: BWR Vessel and Internals Project, Fracture Toughness and Crack Growth Program on Irradiated Austenitic Stainless Steel
1008189 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Anne-Genevieve Madelein Demma

Effect of Hydrazine on Flow-Accelerated Corrosion
1008208 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith P. Fruzzetti

Initial Acceptance Criteria Concepts and Data for Assessing Longevity of Low-Voltage Cable Insulations and Jackets
1008211 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Gary J. Toman

Human Reliability Analysis Calculator (HRA Calculator) Version 3.0
1008238 (Software)
Program: Nuclear Power
EPRI Project Manager: Frank J. Rahn

Life Cycle Management Sourcebook for Nuclear Plant Service Water Systems
1008282 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Neil Wilmshurt

Cask Loader, Version 2.1
1009256 (Software)
Program: Nuclear Power
EPRI Project Manager: Marian McKenna

EPRI NDE Center Products Catalog 2004 Update
1009616 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank V. Ammirato

Risk-Informed Asset Management (RIAM)
1009632 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: George E. Sliter

2004 EDF/EPRI Collaboration on Life Cycle Management and Nuclear Asset Management
1009634 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: George E. Sliter

Preliminary Development of Declarative Modeling for Probabilistic Risk Assessments
1009644 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Ken Canavan

Generic Qualification and Dedication of Digital Components
1009659 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Raymond C. Torok

Guidance for Performing a Simplified Risk-Informed Turbine Missile Analysis
1009665 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Stephen H. Hesler

A Framework for the Treatment of External Events in Configuration Risk Management
1009675 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John P. Gaertner

Analysis of Pressurized Water Reactor Unqualified Original Equipment Manufacturer Coatings
1009750 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Timothy Eckert

Spent Fuel Transportation Applications: Fuel Rod Failure Evaluation Under Simulated Cask Side Drop Conditions
1009929 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert J. Machiels

Qualification of Random-Wound Continuous Duty Motor Insulating Systems, for Use in Nuclear Power Plants—Test 1
1009972 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Leigh Aparicio

Failed-Fuel Analysis on Fuel Rods From Exelon BWRs
1011100 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kurt W. Edsinger

EOOS 3.4: Equipment Out of Service, Version 3.4
1011195 (Software)
Program: Nuclear Power
EPRI Project Manager: Frank J. Rahn

CAFTA 5.2 Fault Tree Analysis System—Part of R&R WS
1011196 (Software)
Program: Nuclear Power
EPRI Project Manager: Frank J. Rahn

FastTrack Generic Data Link Version 1.0
1011228 (Software)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Proceedings: 2004 EPRI International Low-Level Waste Conference and Exhibit Show
1011410 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

Proceedings: 2004 ASME/EPRI Radwaste Workshop
1011411 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Sean P. Bushart

BWRVIP-139: BWR Vessel and Internals Project, Steam Dryer Inspection, and Flaw Evaluation Guidelines
1011463 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

BWRVIP-18-A: BWR Vessel and Internals Project, BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines
1011469 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

BWRVIP-42-A: BWR Vessel and Internals Project, LPCI Coupling Inspection and Flaw Evaluation Guideline
1011470 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Analysis of the Thermal Hydraulics of Steam Generators/Steam Generator Analysis Package, Version 3.0-S
1011514 (Software)
Program: Nuclear Power
EPRI Project Manager: James M. Benson

BWRVIP-126, Rev. 1: BWR Vessel and Internals Project, Radiation Analysis Modeling Application Fluence Methodology, Version 1.10
1011516 (Software)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Proceedings of the International Conference on Water Chemistry of Nuclear Reactor Systems
1011579 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Paul L. Frattini

Summary of Analytical Electron Microscopy Observation of Intergranular Attack and Stress Corrosion Cracks in Alloy 600 Steam Generator Tubing
1011683 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Allan R. McIlree

BWRVIP-123, Revision 1: BWR Vessel and Internals Project, Removal and Analysis of Material Samples from Core Shroud and Top Guide at Susquehanna Unit 2
1011695 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Evaluating the Effects of Aging on Electronic Instrument and Control Circuit Boards and Components in Nuclear Power Plants
1011709 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Joseph A. Naser

Maine Yankee Decommissioning—Experience Report
1011734 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christopher Wood

Yucca Mountain Licensing Standard Options for Very Long Time Frames
1011754 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Kessler

Program on Technology Innovation: EPRI Yucca Mountain Total System Performance Assessment Code (IMARC) Version 8
1011813 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Kessler

Neutron Transmission Through Boral™: Impact of Channeling on Criticality
1011819 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert J. Machiels

Materials Reliability Program: Management of Thermal Fatigue in Normally Stagnant Non-Isolable Reactor Coolant System Branch Lines (MRP-146)
1011955 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John J. Carey

Pilot Study of Delta's Mururoa Protective Suit at McGuire Nuclear Power Station
1011970 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Dennis Hussey

BWRVIP-123: Revision 1NP: BWR Vessel and Internals Project, Removal and Analysis of Material Samples from Core Shroud and Top Guide at Susquehanna Unit 2
1012016 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert G. Carter

Experience-Based Seismic Verification Guidelines for Overhead Crane Systems
1012022 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Kassawara

Experience-Based Seismic Verification Guidelines for Piping Systems
1012023 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Kassawara

Materials Reliability Program, Materials Handbook for Nuclear Plant Pressure Boundary Applications (MRP-150)
1012039 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

Effect of Polymer Dispersant on Flow-Accelerated Corrosion of Steam Generator Materials
1012056 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Keith P. Fruzzetti

Power Delivery and Markets

Guide for Non-Destructive Diagnosis of Distribution Cable Systems
1001731 (Technical Report)
Program: Underground Distribution Systems
EPRI Project Manager: Robert J. Keefe

Material Identity Card
1001865 (Technical Report)
Program: Underground Transmission Systems
EPRI Project Manager: Walter Zenger

Power Quality Diagnostic System (PQDS), Version 1.4
1008502 (Software)
Program: Power Quality Analysis Tools and Testing
EPRI Project Manager: Robert B. Schainker

Power Quality Implications of Transmission and Distribution Construction
1008506 (Technical Report)
Program: Power Quality Solutions for Transmission and Distribution
EPRI Project Manager: Robert B. Schainker

Power Quality Impacts of Distributed Generation
1008507 (Technical Report)
Program: Power Quality Solutions for Transmission and Distribution
EPRI Project Manager: Robert B. Schainker

Correlating Power Quality Indices With System Reliability Indices
1008508 (Technical Report)
Program: Power Quality Solutions for Transmission and Distribution
EPRI Project Manager: Robert B. Schainker

Development of a Framework for a Service Quality Index
1008509 (Technical Report)
Program: Power Quality Solutions for Transmission and Distribution
EPRI Project Manager: Robert B. Schainker

Automated Evaluation System for Capacitor Switching Transient Concerns
1008510 (Technical Report)
Program: Power Quality Solutions for Transmission and Distribution
EPRI Project Manager: Robert B. Schainker

Effects of Temporary Overvoltage on Residential Products
1008540 (Technical Report)
Program: Power Quality Mitigative Solutions
EPRI Project Manager: Robert B. Schainker

Industrial Design Guide (IDG), Version 5.0
1008541 (Software)
Program: Power Quality Mitigative Solutions
EPRI Project Manager: Robert B. Schainker

Enhanced Ride-Through for Industrial Power Supplies
1008544 (Technical Report)
Program: Power Quality Mitigative Solutions
EPRI Project Manager: Robert B. Schainker

Electricity Market Transformation: A Risk Management Approach
1008549 (Technical Report)
Program: Electricity Market Transformation
EPRI Project Manager: Hung-po Chao

Asset Performance Database
1008553 (Technical Report)
Program: Power Delivery Asset Management
EPRI Project Manager: William J. Parkinson

Strategic Insights on Security, Quality, Reliability, and Availability
1008566 (Technical Report)
Program: Strategic Management of Security, Quality, Reliability, and Availability
EPRI Project Manager: Robert B. Schainker

EPRI Events

For further event listings, visit EPRI's web site (www.epri.com).

August 2005

15–18
NMAC Large Electric Motor Users Group and Workshop
New Haven, CT
Contact: Linda Parrish, 704.547.6061

16–18
Distribution Planning for Distributed Resources and Automation
Knoxville, TN
Contact: Lisa Wolfenbarger, 865.218.8052

16–18
Reduce Transmission Maintenance Costs and Expand Equipment Life
Palo Alto, CA
Contact: John Chan, 650.855.2452

17–18
EPRI/Regional Distribution Workshop
St. Louis, MO
Contact: Ron Diaz, 317.335.1797

17–18
Midwest Regional Distribution Workshop
St. Louis, MO
Contact: Ksenija Sobajic, 650.855.2621

17–19
8th FACTS User's Group Meeting and TF14 Power Flow Management and Control
Stamford, CT
Contact: Angelica Kamau, 650.855.7987

17–19
Power Electronics-Based Controllers
Hartford, CT
Contact: Abdel-Aty Edris, 650.855.2311

18–19
EPRI Western Environmental Conference
Westminster, CO
Contact: Jeff Crowe, 650.855.8907

22–24
EPRI Workforce Training and Development Working Group
St. Louis, MO
Contact: EPRI Order Management, eprievents@epri.com

22–25
Nuclear Power Advisory Meetings
Chicago, IL
Contact: Melissa Wade, 704.547.6043

22–26
EPRI Turbine/Generator Meeting
Denver, CO
Contact: Linda Parrish, 704.547.6061

23
Overhead Transmission Design for Optimized Life-Cycle Costs
Web Conference
Contact: John Chan, 650.855.2452

23–24
Excitation System Maintenance, Refurbishment, and On-line Testing/Calibration
Denver, CO
Contact: Linda Parrish, 704.547.6061

24
Fuel Reliability Program Senior Representatives and Executive Committee Meeting
Chicago, IL
Contact: Melissa Wade, 704.547.6043

24
Utility Workshop Focused on Today's Customers and Their Future Needs
Charlotte, NC
Josephine Garcia, 650.855.8619

24–26
NMAC Protective and Auxiliary Relay Industry Meeting
Spokane, WA
Contact: Linda Parrish, 704.547.6061

30–September 1
Condenser Technology Seminar and Conference
San Diego, CA
Contact: Megan Wheeler, 415.455.9583

31
Fleet-Wide Monitoring
Web Conference
Contact: Ramesh Shankar, 704.547.6127

September 2005

1–2
Fuel Reliability Program Working Group 1 Meeting
Las Vegas, NV
Contact: Evelyn Simons, 650.855.2728

7–9
JUTG Procurement Forum
Chicago, IL
Contact: Elizabeth Marlowe, 704.547.6036

12–16
Environment Sector and Area Council Advisory Meetings
St. Louis, MO
Contact: Randy Michaud, 650.855.2919

12–16
Service Water Heat Exchanger Testing Training Course
Charlotte, NC
Contact: Elizabeth Marlowe, 704.547.6036

13
Reduce Transmission Maintenance Costs and Expand Equipment Life
Web Conference
Contact: John Chan, 650.855.2452

13–15
EPRI/INPO 2005 Chemistry Managers Workshop
Marietta, GA
Contact: Sara Cruz, 770.644.8378

14
High-Power Transmission and Substation Electromagnetic Compatibility (EMC)
Charlotte, NC
Contact: Brian Cramer, 815.478.5344

16
Power Electronics–Based Controllers
Web Conference
Contact: Abdel-Aty Edris, 650.855.2311

19–20
BWR Condensate Filter Users Group Meeting
Nashville, TN
Contact: Mary Jarvis, 315.698.0834

19–21
Generation Program Advisory Committee Meeting
Addison, TX
Contact: Carol Holt, 650.855.2436

20–21
Power Delivery Applications for Superconductivity
Albany, NY
Contact: Steve Eckroad, 704.717.6424

20–22
2005 Condensate Polishing Workshop
Nashville, TN
Contact: Linda Nelson, 518.374.8190

21–23
Valuing Generation Assets
Washington, DC
Contact: EPRI Order Management, eprievents@epri.com

22–23
Generation Council Meeting
Dallas, TX
Contact: Peggy Roper, 650.855.2133

22–23
Underground Transmission Task Force
Albany, NY
Contact: Walter Zenger, 413.448.2424

26–28
PSAPO Advisory Council Meeting
Charlotte, NC
Contact: Angelica Kamau, 650.855.7987

26–28
Transmission and Distribution Area Council Meeting
Charlotte, NC
Contact: Ray Lings, 650.855.2177

29–30
Power Delivery and Markets Council Meeting
Charlotte, NC
Contact: Josephine Garcia, 650.855.8619

29–30
Value and Risk in Energy Markets Advisory Meeting
Charlotte, NC
Contact: Josephine Garcia, 650.855.8619

October 2005

3–4
Switching Safety and Reliability
Phoenix, AZ
Contact: George Gela, 413.499.5710

3–5
Wireless Technology
Jersey City, NJ
Contact: Lynette Gulledge, 704.547.6194

4–5
NMAC Hoisting, Rigging, and Crane Users Group Meeting
Charlotte, NC
Contact: Linda Parrish, 704.547.6061

5
Switching Safety and Reliability Taskforce
Phoenix, AZ
Contact: Ben Damsky, 650.855.2385

5–7
2005 Technology Management Committee (TMC) Meetings
Knoxville, TN
Contact: Tonia Biggs, 614.880.5044

6
Power Delivery Applications for Superconductivity
Web Conference
Contact: Steve Eckroad, 704.717.6424

12
Switching Safety and Reliability
Web Conference
Contact: Ben Damsky, 650.855.2385

14
Improve Overall Substation Maintenance Optimization
Web Conference
Contact: Barry Ward, 650.855.2717

18
Insulators
Web Conference
Contact: Andrew Phillips, 704.717.6438

18–20
Value and Risk in Energy Markets
Palo Alto, CA
Contact: EPRI Order Management, eprievents@epri.com

19
Increased Power Flow
Web Conference
Contact: Ram Adapa, 650.855.8988

20
Improve Transmission Line Lightning Performance
Web Conference
Contact: Andrew Phillips, 704.717.6438

20–21
Energy Storage for T&D Applications
San Francisco, CA
Contact: Steve Eckroad, 704.717.6424

25
Underground Transmission Task Force
Web Conference
Contact: Walter Zenger, 413.448.2424

27–28
Research Advisory Committee
San Francisco, CA
Contact: Barbara Ryan, 608.513.4494

27–28
Transformer Life Management
Memphis, TN
Contact: Barry Ward, 650.855.2717

31–November 3
Improving Power Quality
Knoxville, TN
Contact: Lisa Wolfenbarger, 865.218.8026

November 2005

1–2
Insulators
Charlotte, NC
Contact: Andrew Phillips, 704.717.6438

3–4
Improve Transmission Line Lightning Performance
Charlotte, NC
Contact: Andrew Phillips, 704.717.6438

3–4
Overhead Transmission Design for Optimized Life-Cycle Costs
Charlotte, NC
Contact: John Chan, 650.855.2452

4
High-Power Transmission and Substation Electromagnetic Compatibility (EMC)
Web Conference
Contact: Brian Cramer, 815.478.5344

7
Transformer Life Management
Web Conference
Contact: Barry Ward, 650.855.2717

8
EPRI On-Line Monitoring Users Group Meeting
Charlotte, NC
Contact: Ramesh Shankar, 704.547.6127

9–10
Improve Safe Live-Line Maintenance Work Practices
Lenox, MA
Contact: Andrew Phillips, 704.717.6438

14
Energy Storage for T&D Applications
Web Conference
Contact: Steve Eckroad, 704.717.6424

15–17
2005 Workshop on Selective Catalytic Reduction Meeting
Louisville, KY
Contact: Katy Ahrens, 415.455.9583

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SUMMER 2005

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