SUMMER 2010

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

THE OTHER FOOTPRINT

How will a 'low carbon footprint' change electric infrastructure?

ALSO IN THIS ISSUE:

ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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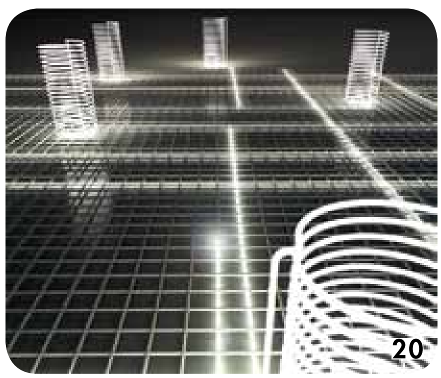


FIRST PERSON WITH MIKE HOWARD

FEATURES

DEPARTMENTS

FIRST PERSON *with Mike Howard*

'WE HAVE TO LISTEN AND LEAD'

This September, Dr. Michael Howard will succeed Dr. Steven Specker as president and CEO of the Electric Power Research Institute. For the past five years, as EPRI's senior vice president of research and development, Howard has overseen EPRI's entire research portfolio. Previously he served as president and CEO of EPRI Solutions, Inc., formerly a wholly owned subsidiary of EPRI. Following his election by the EPRI Board, Howard sat down with *EPRI Journal* to provide his perspective on the electricity sector, its research and development needs, and EPRI.

EJ: You have been a key member of EPRI's senior management team for several years. As you become president and CEO, what will change? What will stay the same?

Howard: I'm very excited to step into a greater leadership role at EPRI. Under Steve's leadership, EPRI has become more technology focused and has provided thought leadership for challenging issues. I want to continue the focus on research that addresses solutions needed by electricity providers and the public. That's our mission, and that's not going to change.

Our objective, vendor-independent assessment of technologies is critical if the industry is to make the right decisions with the right data to decarbonize affordably. Examples of the right decisions include integrating renewable energy with the power delivery system, increasing energy efficiency, using electro-technologies to reduce direct combustion of fossil fuels, advancing carbon capture and storage technologies, and ensuring that our nuclear fleet continues to operate safely and reliably.

We'll continue to emphasize such areas as the smart grid—or as I call it, the "smarter grid"—which will help us operate our power delivery system as efficiently and reliably as possible and enable consumers to actively manage their energy consumption more economically and efficiently.

"... we have to listen and lead. Listen to our members, our industry advisors, and—equally important—our advisors from outside the industry and from organizations that play key roles in technology development."

I think our research activities are focused in the right areas, and I hear our members saying the same thing. However, we can't be complacent and must continue to evaluate the research portfolio to be sure our work is technically relevant and that we are providing the leadership our members expect and all stakeholders in the electricity enterprise expect from EPRI.

EJ: You emphasize that people whose primary focus is research and development also must keep their eye on the business. From a business perspective, where do you think EPRI needs to put its focus in the next couple of years?

Howard: In order to provide solid technical knowledge and thought leadership, it is not enough to just understand the technology. We have to articulate the issues in a compelling, objective way to our members and society in general. That's a key focus for EPRI at all levels. At the same time, we've got a business to run, and that also needs to be a key focus for everyone working at EPRI. I'd like to see us reach a point where every member of our research staff can easily answer such questions as, What's your R&D funding and spending, How many members are engaged, and—most important—What value are you creating through the research? The research staff should know and own the numbers, understand their business, and understand how their research activities increase the value of the results.

We have to be rigorously objective; EPRI's continued success requires that. And we have to ensure that our collaborative research is applied for the public benefit. I intend to continue strengthening this collaboration. Technical excellence coupled with business operations excellence will make us the provider of high-value R&D to our members and to the public at large.

EJ: In terms of understanding R&D and our members' business, how do we make sure we're aiming at the right targets?

Howard: To do that, we have to listen and lead. Listen to our members, our industry advisors, and—equally important—our advisors from outside the industry and from organizations that play key roles in

> "In order to provide solid technical knowledge and thought leadership, it is not enough to just understand the technology. We have to articulate the issues in a compelling, objective way to our members and society in general."

technology development. These include government, regulators, NGOs, universities, and industry suppliers. We must develop new ideas for our R&D portfolio that address today's challenges and anticipate tomorrow's challenges. We must also read, a lot—technical journals, the *Wall Street Journal*, the Web—to stay right on top of the issues. I read at least two hours a day to stay up to date on key business drivers. It's a challenge to be out in front of our industry advisors and to understand their world, where they sweat it every day, but we need to do that.

Listening and leading means paying particular attention to those with different viewpoints and understanding the basis for their views—not just knowing that they may disagree with EPRI's thinking. Without close listening, EPRI cannot develop relevant technology and successfully transfer it so that it can be applied. If we don't listen, we can't lead, and we cease to exist.

EJ: From the R&D perspective, what are the so-called megatrends in the electricity sector?

Howard: The biggest trend is decarbonizing our electricity sector in ways that allow society to have affordable, reliable, and environmentally responsible electricity. So, what does that mean? We find the means for an economical transition to low-carbon generation and use this low-carbon electricity to decarbonize transportation and other sectors that use direct combustion of fossil fuel. But we must recognize that we will not and cannot instantaneously move away from coal. We need to press forward on technologies that will allow us to continue using coal as a fuel but do it in a way that will minimize its environmental impact. Nuclear and renewable energy will continue to be our focus, too.

At the same time, we must become more energy efficient. We must develop more efficient technologies, including LED lighting and more efficient power supplies for billions of proliferating consumer electronic devices. What role will renewable energy resources play, and how can we better integrate them into the system? How will we deploy the smarter grid? Electric vehicles can help us decarbonize, but if they're going to compete, we must integrate them with the grid and make energy storage affordable and reliable.

Energy storage will have profound impacts on the electricity sector, and we're seeing progress. For example, I recently read that lithium-air batteries may have an energy density around 4,000 watt-hours per kilogram. Existing lithium-ion batteries have an energy density of 110 watt-hours per kilogram. A 4,000-watt-hour per kilogram battery gives us the equivalent energy density of a gasoline engine. That's a potential game-changer for electric vehicles. Batteries like these could play a very important role in both electric transportation and renewable energy.

EJ: What message would you like to deliver at the beginning of your tenure as EPRI CEO about the need for R&D funding?

Howard: There is tremendous societal benefit to investing in research, but the research must be further developed, deployed, and applied to make a real difference. For example, it's very expensive to develop advanced materials for power plants. We must understand and evaluate their benefits in terms of improved plant efficiency and reliability. A key EPRI role is to analyze whether the benefits warrant the investment. Before R&D dollars are invested, utilities, policymakers, regulators—and society—have to understand where we're headed and why it makes sense to get there. We have to listen and communicate on relevant topics.

We can't develop a new material that will last for 50 years, that won't crack or corrode, by just throwing things together. But we can't just ask for more money. We must be able to articulate why we need it, and the benefit. We also need to leverage fund-

The Oak Ridge Boys

A remarkable coincidence links Chauncey Starr, EPRI's founder and first CEO, with its newest CEO, Michael Howard. Separated by more than three decades, both worked in the same research building in Oak Ridge, Tennessee. Howard recalls how Starr, who died in 2007 at age 95, offered the benefit of his personal perspective to the newly arrived executive when Howard became EPRI's senior vice president of research and development in early 2006. Howard recalls:

"When I took on the R&D job at EPRI, Chauncey brought me into his office and we chatted for probably an hour. He said he was going to send me something. It was a five-page, typed letter outlining his thoughts on the history of the electric utility industry, his vision for EPRI, and the important role for research and development. I was absolutely blown away. I wish he had signed it. His name was typed—Chauncey Starr—at the bottom.

"My first summer engineering job was in 1977 at a DOE facility in Oak Ridge, Tennessee, called Y-12. The building looked like a very large concrete bunker, almost the size of a football field, where in decades past, huge magnets had been used to separate uranium isotopes. Chauncey told me that in the early days of the Manhattan Project in Oak Ridge, he had worked to get that facility up and running. In my 1977 summer job, I was assigned to that building to organize boxes and boxes of technical papers for preservation. I'm sure many of the boxes included Chauncey's papers. I didn't think anything else about that summer's project until I met Chauncey and he asked me about my educational and work experience. Turns out he knew some of my wife's relatives, who are also from Oak Ridge and who had connections with the Manhattan Project and Floyd Culler, who worked with Chauncey at Oak Ridge and would later become EPRI's second CEO. Whenever we talked, I think it took him back to those days, and he would always tell me, 'I have the fondest memories of my years working in Oak Ridge, Tennessee.'"

ing, not just from the electricity industry but also from state and federal entities that are working toward developing technologies for the electricity sector. Analyses such as our Prism/MERGE work are excellent tools to articulate an industry vision. Achieving the vision requires research, development, demonstration, and deployment of technology. That takes money. But EPRI has to show the value of the funding.

"I'll continue to ask whether EPRI offers the right programs focused on the right technologies. Is our overall strategy right? We must make sure we are objective, independent, and credible."

EJ: Should we see a greater sense of urgency with respect to electricity sector R&D?

Howard: There's a growing consensus that we need to do more, but we have to recognize that with global financial pressures and increased debt, everybody is financially squeezed. At EPRI we must make sure that we use every R&D dollar to its fullest potential. That is extremely important. Operational excellence in executing our R&D projects, leveraging our members' funding with state and federal support, and collaboration with universities and national labs will help us respond with a greater sense of urgency to the challenges facing the electricity sector.

EJ: Looking ahead, what aspects of EPRI's work will get your particular attention?

Howard: Our people—developing the staff, the managers, and the leaders we need as an organization and as an industry. It's our responsibility to teach, to mentor, and to develop technical and business leaders. I'll continue to ask whether EPRI offers the right programs focused on the right technologies. Is our overall strategy right? We must make sure we are objective, independent, and credible. For example, if research has demonstrated that a promising low/no-carbon generation solution can be accommodated only to a limited degree without impacting reliability or creating other adverse environmental consequences, we must say so. We must provide the scientific and technical data that support that conclusion, we must listen to and understand those who may disagree, and we must continue the search for solutions. Objectivity is what EPRI is all about. We cannot compromise on that.

SHAPING THE FUTURE

Innovative approaches to upcoming challenges

DC-Powered Data Centers

Demand is surging for Internet-related services, from digital video and music delivery to online gaming, web-page shopping, and Internet-based telephony. Internet companies serve this growing appetite with vast data centers, each of which might host thousands of servers and consume several megawatts of power. With energy consumption by data centers expected to double from 2006 levels by 2011, various options are being considered to improve the efficiency of these facilities.

One option is to power the centers with direct current (DC) rather than conventional alternating current (AC). EPRI has been investigating the advantages and drawbacks of this approach for a number of years and conducted one of the first demonstration projects in 2006. In addition to efficiency, advantages of a DC architecture include higher reliability, smaller footprint, and lower capital cost. Data center operators may actually be most interested in this method because it can allow them to achieve reliability approaching that of the telecom industry. Results of the demonstration and other work on DC data centers are available in an EPRI white paper (1020818) published earlier this year.

DC demonstration at a Sun Microsystems data center

Avoiding Conversion Losses

Power entering a data center undergoes several AC/DC and DC/AC conversions as it passes through the facility's power-conditioning and uninterruptible power supply systems. In each conversion, energy is lost in the form of waste heat. By eliminating as many intermediate conversion stages as possible, DC architectures can improve efficiency, simplify the design of power supplies, and reduce the building's cooling requirements—a substantial issue for temperature-sensitive servers.

EPRI's 2006 demonstration, carried out in cooperation with the Lawrence Berkeley National Laboratory and other industry partners, compared a conventional AC architecture with two different DC configurations at a Sun Microsystems data center. The demonstration indicated that DC data centers would consume 7%–28% less power than conventional AC systems. Subsequent projects in the United States, Sweden, France, Japan, and South Korea have shown similar efficiency improvements.

By reducing power conversions, a DC facility can use simpler, more compact circuit designs, and the number of circuit breakers may be cut by half. This reduction, combined with smaller cooling systems, can reduce the center's physical footprint significantly. An Intel study showed that a DC data center could occupy a third less space than a comparable AC configuration.

Also, with a DC power bus, DC data centers could directly integrate distributed energy resources such as photovoltaic arrays without concerns about synchronizing with the AC grid. Such tie-ins would allow opportunistic dispatch of renewables, reducing the amount of electricity that needed to be purchased from the grid during expensive peak demand periods and delivering lower operating costs. These setups could garner further savings through incentives such as renewable energy credits.

Challenges for Further Research

Adopting DC data centers as a mainstream technology will require further research and testing, as well as new standards in a number of areas. Because DC current does not have a zero crossing like AC current, it is more difficult to interrupt, and simple disconnection will cause arcing; new DC connectors that extinguish arcing during disconnects already have been developed to increase data center personnel safety.

Theoretically, the power quality impacts of DC architectures could be significantly lower than those of AC systems, since there are no harmonics and no power factor correction circuits. But this area remains to be investigated in detail, especially with regard to potential effects of cell phones and other radio-frequency transmitters, which could introduce disturbances onto the distribution network. DC bus faults and startup transients also may present problems, and appropriate grounding and over-current protection strategies need to be developed. EPRI is actively pursuing power quality research for DC facilities, beginning with system simulations to determine the impacts of such disturbances.

Interest in DC data center architectures is already spurring considerable work on new design, operation, and safety standards, as well as on training to ensure worker safety in this unfamiliar power distribution environment.

For more information, contact Brian Fortenbery, bfortenbery@epri.com, 865.218.8012.

Building the Framework for Demand Response–Ready Devices

Demand response (DR) remains relatively underutilized in the United States, despite its potential benefits to utilities, consumers, and society. According to the U.S Federal Energy Regulatory Commission (FERC), demand response potential in the United States today is approximately 37 gigawatts (GW), which represents about 4.6% of the nation's summer peak demand of 810 GW. Most of today's capability derives from large businesses that participate in interruptible tariffs that obligate them to shed load at the request of their utility in return for a reduced electricity rate.

One barrier to greater demand response availability and participation is utilities' costs of installing equipment to enable load control and demand response, such as programmable communicating thermostats and sensors on air conditioners, appliances, water heaters, and other large end uses that contribute to peak demand. Also, most customers are reluctant to have unfamiliar controls installed in residences or businesses. However, such barriers could be overcome if energy-consuming appliances came ready to participate in demand response programs out-of-the-box, or "DR-ready."

Such appliances in the market would obviate the need for utilities to install special equipment on customer premises, spurring lower-cost, more widespread deployment of demand response resources. DR-ready appliances also could enable customers to adjust electricity use according to price or other market signals, without compromising their quality of service.

Making "DR-Ready" Ready for Prime Time

One key to this capability is the need to define a single interface for all major appliances or devices. A built-in socket could provide power to a communication device that an appliance owner would plug in after purchase, just as generic Wi-Fi cards work in various personal computers. Work is under way to define such a connection, allowing appliances to communicate via any chosen medium and protocol.

Another prerequisite for DR-ready appliances is a functional specification of what constitutes "DR-ready" for specific types of appliances, enabling manufacturers to develop qualifying products.

Researchers at EPRI's Knoxville laboratories have demonstrated the transformation of existing consumer electronics devices into DR-ready resources by adding software that allows consumers to set controls and manage energy consumption according to prevailing grid or market conditions. This highlights demand response potential for consumer electronics, which represent a large and fast-growing source of load that already incorporates intelligence and network capability.

Overcoming Consumer Resistance

Research on traditional demand response reveals that up to 80% of customers fail to understand its value proposition, with 60% balking when installation is described. The bottom line: only 6% of the targeted consumers subscribe to utility-sponsored programs. With a simplified, built-in customer interface, DR-ready programs are far more likely to succeed, yet they must address some fundamental challenges. For example, utilities and manufacturers need to collaborate on a simple, standardized system with effective customer communication to support it. Whirlpool Corporation research on time-of-use appliances highlighted the business risk associated with introducing overly complex products that are not "user friendly."

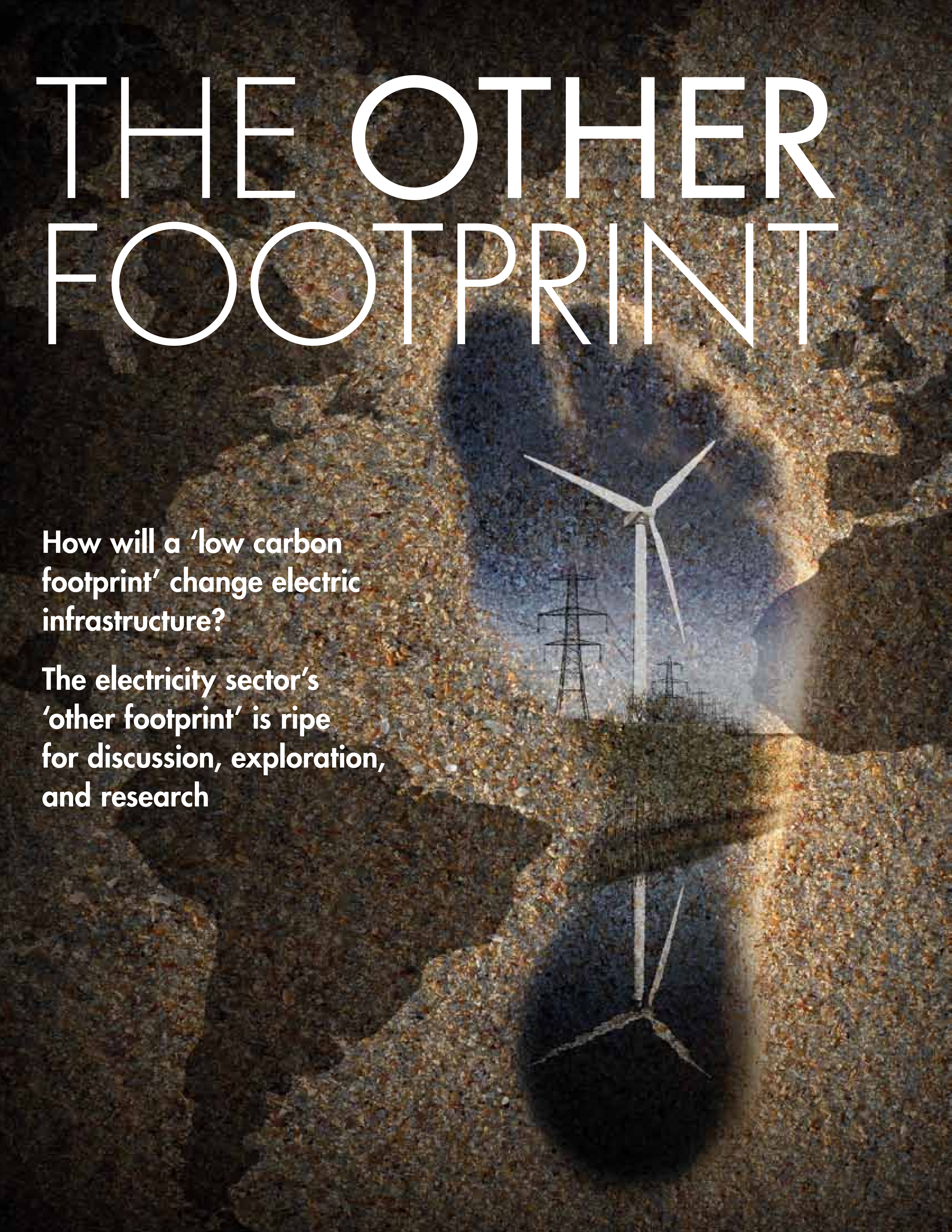
EPRI is addressing these and other barriers to implementing DR-ready systems, such as the lack of an optimal communication protocol and guidelines for product attributes desired by utility and other stakeholders. Ultimately, DR-ready appliances will become available in the market through research, collaboration, and large-scale field trials.

For more information, contact Omar Siddiqui, osiddiqui@epri.com, 650.855.2328.

THE OTHER FOOTPRINT

How will a 'low carbon footprint' change electric infrastructure?

The electricity sector's 'other footprint' is ripe for discussion, exploration, and research



THE STORY IN BRIEF

The electricity sector is developing technologies and programs to reduce its greenhouse gas emissions while meeting growth in demand. New technologies and system expansion could profoundly change today's electricity system and its impacts on the environment, resources, and communities, prompting new research and new perspectives on this "other footprint."

Nebraska Public Power District's Ainsworth Wind Energy Facility: The state's largest wind facility has 36 wind turbines whose 60 megawatts of capacity produce enough electricity to supply an average of 19,000 residences per year. (Courtesy NPPD)

The other footprint will not be easy to describe or measure. To do so will require advances in fields as diverse as engineering, geology, ecology, chemistry, physics, and political science. The electricity sector is already focusing on a number of key areas, and research needs are expected to grow significantly.

'Energy Sprawl'

In August 2009, The Nature Conservancy released a report, *Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America.*

It illustrated "the land-use impact to U.S. habitat types of new energy development resulting from different U.S. energy policies." It focused in part on land-use intensity of different energy production technologies, including renewables. A key point of the report is that climate policy could drive deployment of technologies such as wind and biomass, significantly affecting grassland and forest habitats, respectively, but that "sprawl" could be mitigated through energy efficiency.

A recent EPRI analysis determined that if wind-powered generation were to account for 25% of the projected U.S. electricity consumption in 2030 (at a 42% capacity factor), it would require about 20,400 square miles of land, or 40 acres per installed megawatt of capacity. Assume a 35% capacity factor, and the land requirement increases to 24,500 square miles. Nuclear, by comparison, at 1.1 acres for each megawatt of capacity and a 90% capacity factor, could produce the same amount of electricity using only 260 square miles.

Other factors come into play. Most of the wind acreage would be available for agriculture and other uses. Some wind generation will be built offshore. The nuclear figure does not account for upstream land uses such as mining. New wind generation may require relatively more new transmission lines than nuclear, which can rely more on sites closer to demand and on existing plant sites. Bird and bat mortality on wind farms can be an issue but can vary from site to site.

Beyond Acreage

Some questions related to an infrastructure's footprint may not be prominent until it is built on a large scale. With wind farms, for example, issues such as noise or television signal interference may emerge only as they are built in proximity to more communities.

Many such questions will only be answered by combinations of in-depth research and operating experience at commercial scale.

Consider ocean and tidal energy. Doug Dixon, EPRI technical executive for water and ecosystems, points to the potential interactions with marine life and seabirds, interactions with coastal sedimentary processes, and conflicts with activities such as navigation and fishing. A critical point, he adds, is that researchers also must account for avoided impacts.

"If we are successful in scaling up tidal power and wave power, we avoid such impacts as emissions, waste products, and disturbance of terrestrial ecosystems."

The Rise of Water

In any scenario, water will be crucial. Deserts may offer solar generation abundant land and sunshine but limited water.

Cara Libby, project manager in EPRI's renewables generation program, notes that water is essential for maintaining solar efficiency.

"Mirrored collectors for solar thermal technology must be washed regularly—as often as once a week in the desert," Libby said. "Photovoltaic panels typically require less frequent washing, depending on rainfall and dust buildup in a given location."

Solar thermal facilities concentrate solar energy to produce heat to drive or augment a steam cycle and typically require cooling water. Libby points out that some facilities use slightly more water per kilowatt-hour relative to fossil or nuclear plants because their lower steam temperatures result in slightly lower thermal efficiency. Many future plants will operate at higher temperatures and use dry or hybrid cooling options to mitigate this.

Also, water or chemical binding agents may be required for dust suppression, and vegetation may need to be stripped for solar thermal landscapes to avoid fire hazards. These will have to be accounted for as these facilities cover more of the landscape.

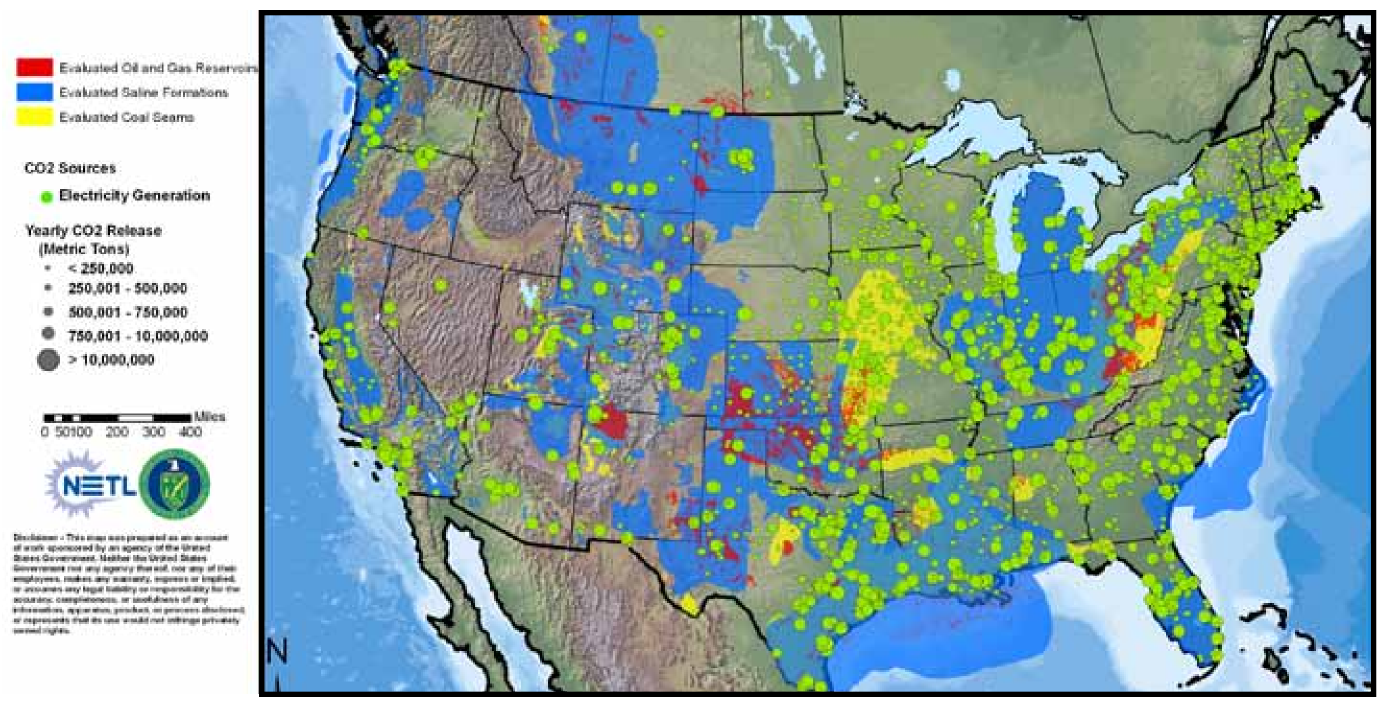
Mirrored collectors at solar thermal plants must be washed as often as once a week.

Big Changes for a Big Contributor

Because about half of U.S. electricity comes from coal combustion, any policy to reduce electricity's carbon footprint will rely on carbon capture and storage (CCS). The scale of CCS systems and the potential footprint of a national CCS program will be significant.

Des Dillon, project manager of EPRI's advanced generation project, says water will be an important aspect.

"We will require additional water consumption (up to 30%) for postcombustion removal of CO_2," said Dillon, "and when you



This map shows the locations of major "sinks" in which captured CO_2 could be sequestered, relative to the locations of power generation sources of CO_2 emissions. This provides some indication of where networks of pipelines and other facilities would be required to transport the captured CO_2 from the source to the sink. (Courtesy NREL: 2008 Carbon Sequestration Atlas of the United States and Canada*, U.S. Department of Energy, National Energy Technology Laboratory, http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html)* factor the reduced generation capacity because of CCS's parasitic load, it increases the water required per megawatt-hour as much as 10%."

A recent EPRI study indicated that an ultra-supercritical coal plant with postcombustion carbon capture could use as much as 19.2 gallons per minute per megawatt compared to 9.16 for the same plant without carbon capture. A significant share of this is due to the output lost to the capture technology's parasitic load.

Kent Zammit, EPRI senior program manager for water and ecosystems, points out that generation technologies that rely on a steam cycle can have similar water requirements, depending on the cooling technology used. "Nuclear, coal, biomass, and solar thermal can all require similar gallons per megawatt-hour," said Zammit. "That's why it's to our advantage to develop advanced cooling technologies that can be applied to all."

The CCS infrastructure will spread across diverse landscapes as pipelines, compressors, injection wells, and monitoring stations are constructed to gather, transport, and inject CO_2 in a variety of geologic formations.

As EPRI senior technical executive for generation environmental controls, George Offen does not anticipate major issues regarding the thousands of miles of pipelines that will move the CO_2 from power plant to sequestration. "We have already built a similar infrastructure to move natural gas and other fuels, and I think we'll build this new infrastructure much as we did that one—in stages," Offen said.

He says it will be important to develop and prove leak detection systems and to demonstrate that resources such as underground drinking water are not affected by CO_2 sequestration—that geologic storage must be demonstrated safe and permanent. "We'll have a lot of work in characterizing the various formations, which will be expensive, time-consuming, and involve a lot of drilling," he said.

Offen characterizes the probability of CO_2 and brine leaking from underground reservoirs as "highly unlikely," given the stringent permitting requirements currently proposed by the U.S. Environmental Protection Agency, but said, "We are asking what might happen if this occurs."

As an EPRI senior project manager for generation environmental controls, geologist Robert Trautz also is focused on CCS.

"We're looking at such potential impacts of CO_2 leakage on groundwater, its ability to acidify groundwater and potentially dissolve and mobilize trace metals in sediments and rock," Trautz said. "We'll need to look at the potential for CO_2 stored in deep reservoirs to displace saline waters into shallow aquifers of potable water. We expect the CO_2 to be injected below 800 meters, where it will behave like a supercritical fluid. At this level it's very dense, so we can store much, much more in a unit of space, but there could be questions about how it will dissolve organic compounds and potentially transport them to groundwater."

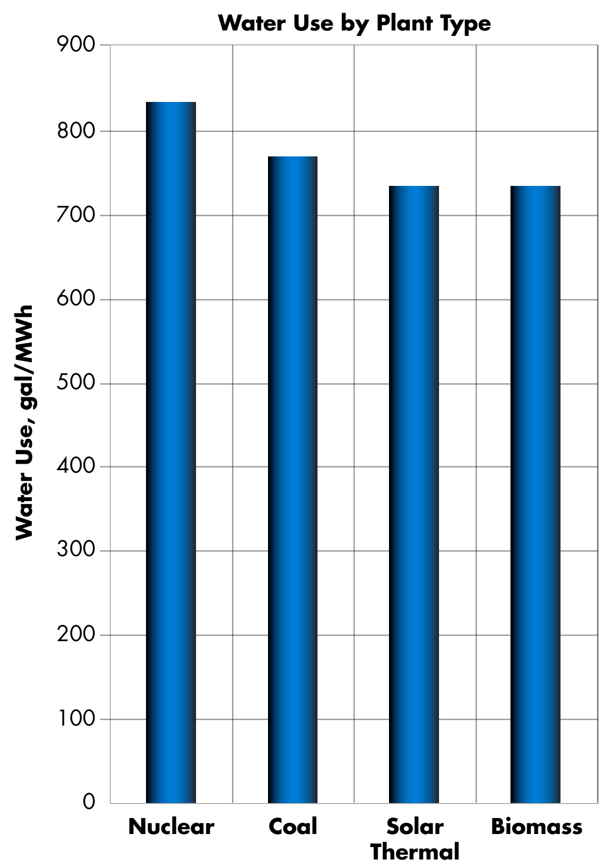
Two Questions for Biomass: Land Use and Carbon Neutrality

Areas with abundant rainfall can produce enough biomass to serve as a fuel. Today, most of the 10.5 gigawatts of U.S. biomass generation is fueled by waste from forestry and from pulp and paper production.

Significant reliance on biomass could result in more widespread harvesting of forests or the cultivation of forests and croplands as "energy plantations." At a large enough scale these could contribute to energy sprawl.

John Hutchinson, senior project manager for EPRI's Energy Technology Assessment Center, recently completed an assessment of biomass and this issue.

"It's likely that the first biomass plants will take advantage of the significant amounts of residues available from forestry and agriculture," Hutchinson said. "But as biomass generation grows and competes with biofuels for feedstocks, biomass generation will have to be fueled with dedicated energy crops. The land required to grow energy crops is an order of magnitude higher, even, than the area needed for wind generation to produce the same amount of electricity."



Biomass and solar thermal generation can require nearly as much water per megawatt-hour as conventional thermal power plants.

Stan Rosinski, EPRI renewable generation program manager, says sustainability is at the heart of the matter. "Whatever your source, you need a sustainable supply. If you don't replace the biomass you harvest, then you're negatively affecting the carbon balance, but if you can sustain the resource, you can be carbon neutral."

The Grid Will Grow

Utilities and federal and state governments are looking at expansion of the high-voltage transmission system necessary to meet projected demand growth and to connect regions of renewable power generation with demand.

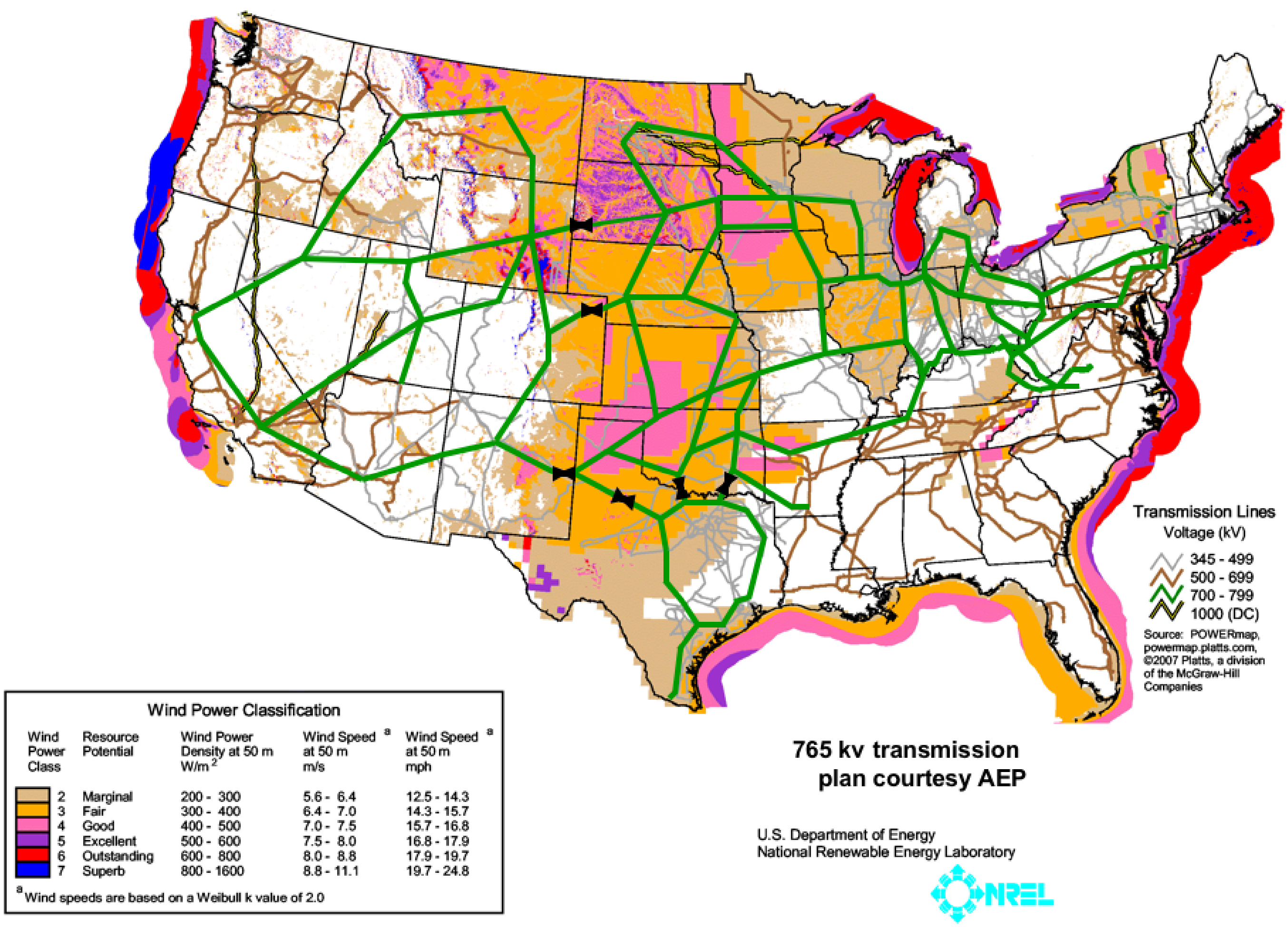
Rich Lordan, director of grid operations and planning for EPRI, calls the potential deployment of renewable energy "unprecedented" and says that the transmission system will expand and change significantly as a result.

Lordan illustrates the point in two ways. One is a map showing the distances separating U.S. wind resources from areas where consumers are concentrated. The second, a graph, shows the hourly variability of power output for a wind generation facility for each of 29 days. No one day resembles another, meaning the output is highly variable.

"The grid will have a bigger overall footprint as it is expanded to connect production with demand," Lordan said. "Equally important will be changes that the average customer is unlikely to see—from the operations tools to the ways that we visualize what's happening instantaneously on the system."

When it comes to building the new lines, John Goodrich-Mahoney can visualize what's coming. The EPRI senior project manager for land and groundwater works with utilities to enhance line siting and develop integrated vegetation management for rights of way. He sees the principles in that framework as essential to expanding the system sustainably.

"It's all there," said Goodrich-Mahoney, "community relations, understanding ecosystem dynamics, having an array of treatment options, and understanding effects and tolerances. There are ten



American Electric Power and the American Wind Energy Association (AWEA) developed a conceptual interstate transmission plan to serve as a basis for the electricity sector and its stakeholders to discuss infrastructure expansion necessary to connect wind resources with load centers. This map provides one example of the potential scale of such expansion. (Courtesy NREL, AEP) principles altogether, and they are the key to effective management and public acceptance."

Planning for Infrastructure and Sustainability: Global, Local, or Globalocal?

The challenge for every technology is to maximize its beneficial aspects and minimize the detrimental aspects. Both global aspects, such as CO_2 emissions, and local aspects will require consideration.

Tina Taylor, director of EPRI's Environment Sector, overseeing work on water, sustainability, and environmental aspects of renewable energy said, "Sustainable energy planning is not a one-size-fits-all proposition. It's very important to consider the local context when planning the best use of resources with the least impact to the environment. Unlike greenhouse gases, which have a shared effect based on total emissions, some impacts really must be considered for their local effects. The best approaches will combine an understanding of the potential benefits and negative impacts of each technology with the local resources and environmental priorities."

New Research to Look at Environmental Aspects of Renewables

EPRI is forming the Environmental Aspects of Renewable Energy Interest Group in 2010 to help launch a new research program on this subject in 2011 that will provide the power industry with the understanding needed to improve planning, siting, and operation of renewable energy. Interest group advisors will:

- Define and prioritize new research in this area and work with nonutility organizations for additional input on research needs;
- Assemble a "knowledge base" of available information on environmental impacts;
- Identify research gaps; and
- Propose research projects.

Projects under consideration include managing impacts on endangered and protected species; methods to assess present and future renewable energy resources; impacts of large-scale renewable technology deployment; sustainability of biomass production; life cycle impacts of renewables; and safety for wind turbine technicians.

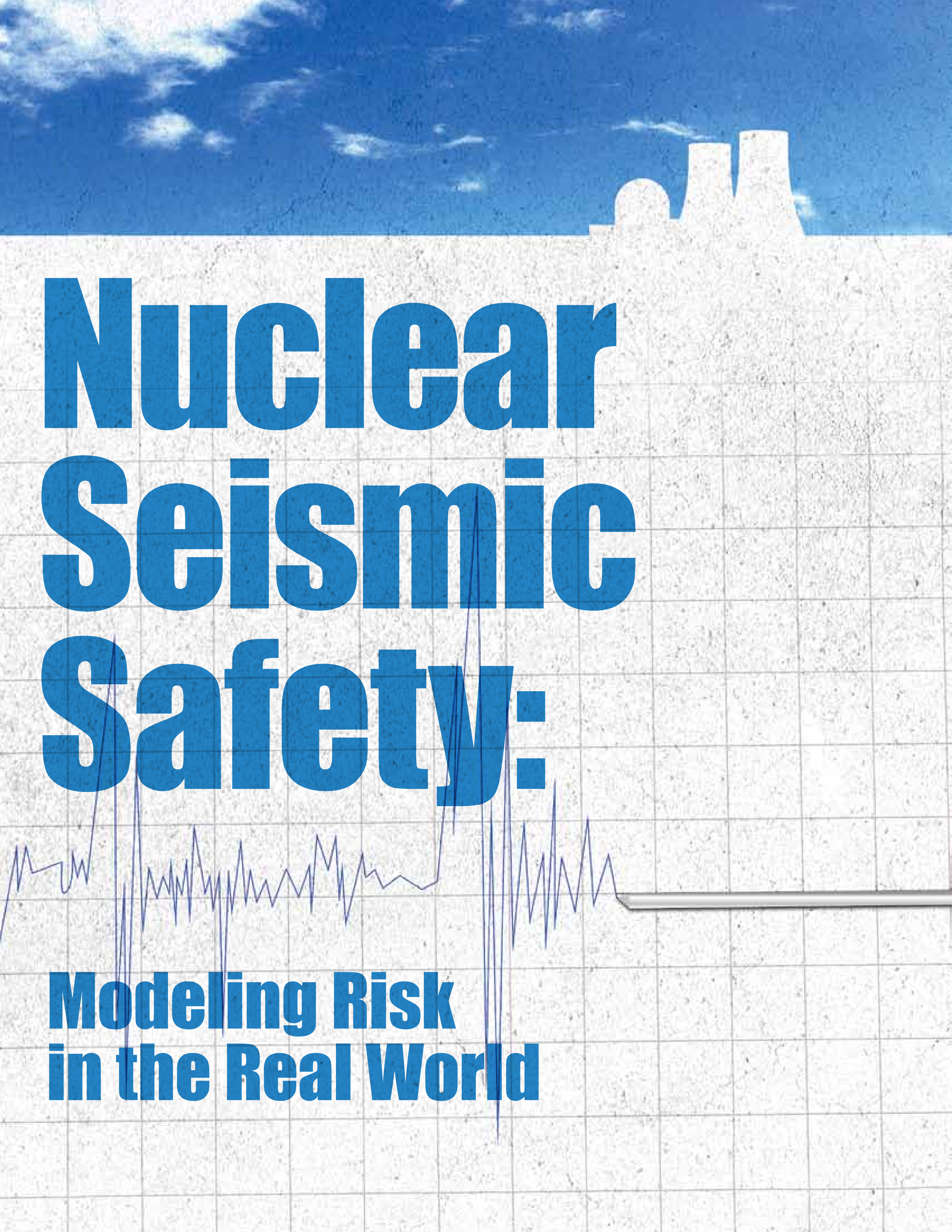
Life Cycle Analysis Can Help Provide a Full Accounting of Sustainability

One EPRI research program focuses on ways to understand impacts and sustainability issues related to a particular and familiar part of the electricity infrastructure: utility poles. Senior Project Manager Mary McLearn is working with life cycle analyses that can provide comprehensive and uniform assessments.

"Consider life cycle analysis in a simple way," said McLearn. "Think of a treated wood utility pole. Start with a tree, grow it, transport it, cut it, treat it, transport it again, install it, use it, remove it, and dispose of it. Now think of a way to account for all of its costs and environmental impacts along the way. Now do the same thing for a steel pole or one made of composites.

"There are costs and impacts for each. It may cost less but have greater environmental impacts to import a wood pole from Asia to the United States. But the Asian pole may be the better option elsewhere. A pole made from tropical wood may not require chemical treatment, avoiding those costs and environmental impacts, but there are costs and impacts associated with its transport. Life cycle analysis can tell us which is the preferred pole for a particular situation, but it will probably not tell us there is one universally best pole."

McLearn sees life cycle analysis re-emerging as an important tool for the electricity sector. "Life cycle thinking is multidimensional," said McLearn. "It looks at everything from resource depletion to impacts on specific species and their habitats."



Nuclear Seismic Safety:

Modeling Risk in the Real World

On January 12, 2010, a magnitude 7.0 earthquake struck Haiti, killing more than 200,000 people. The next month, a magnitude 8.8 earthquake struck Chile. Though the Chilean earthquake released about 500 times as much energy as the one in Haiti, the death toll was only about 500. Clearly the Richter scale alone does not capture the dangers or risks posed by specific quakes.

The American poet Ralph Waldo Emerson said, "We learn geology the morning after the earthquake." It's an interesting thought from a poet, but it is not good enough for engineers, particularly where nuclear safety is concerned. To reduce the chances that seismic activity could impact nuclear plant safety, EPRI is participating in several projects to help the industry better understand seismic risks and how to minimize damage in the event of an earthquake. EPRI also is engaged in a range of initiatives with government agencies and research institutions to learn how the type and intensity of earthquakes can vary with local geology.

Despite the nearly 1,000 magnitude 5.0 or greater earthquakes that occur each year, and after more than half a century of nuclear generation, earthquakes have yet to cause a single significant safety incident at a nuclear power plant. In 2007, Tokyo Electric Power Company's 8,212-megawatt (MW) Kashiwazaki-Kariwa Power Station was hit by a magnitude 6.8 earthquake—a temblor that significantly exceeded the plant's design level—and all operating reactors were shut down safely (see "Damage Assessment: A Case Study," page 16). Continued development of procedures and protocols for the construction and operation of power plants can maintain that unblemished record.

THE STORY IN BRIEF

Researchers know—and recent events have demonstrated—that the risks and challenges posed by earthquakes go beyond a simple magnitude number on the Richter scale. Ground motion and its effects on buildings and other structures depend on the type of fault, vibration frequency, local geology, and other factors. EPRI and the nuclear power industry are developing new data and advanced analytical tools to create a more accurate picture of seismic risk at nuclear plants.

Assessing Risk

Seismic research has dealt primarily with ensuring that plants can withstand earthquakes characteristic of the Pacific Rim. Other parts of the world may be subject to earthquakes of a different character.

"The earthquakes west of the Rockies and along the Pacific Rim are vastly different from those east of the Rockies," said EPRI senior project manager Bob Kassawara. "Earthquakes in the West are powerful in the frequencies of concern for nuclear power plants—up to 15 Hz. East of the Rockies, nuclear plants are designed for those same kinds of earthquakes, but the ones that occur there are typically at a higher, less dangerous, frequency."

EPRI is working with the U.S. Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) on the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project. This is the first comprehensive look at earthquakes and their effects on nuclear power plants in that part of the country in more than 20 years. The final report is expected by the end of 2010.

"The central and eastern United States has a lot of seismic activity, although this is not commonly recognized because much of the most damaging activity occurred many years ago," said Jeff Hamel, EPRI program manager. "Documenting the historical activity and understanding what it has to say about future seismic risks is front and center for our project. This is a great example of a truly collaborative effort by the nuclear industry."

The study will replace a 1989 EPRI study, reflecting updated research and generating a new model of seismic activity that can be used to assess risks at existing and proposed plants. The project has brought together experts from industry, government, and academia to analyze previous earthquakes in the central and eastern United States and produce an updated earthquake catalog that will be made available to the public.

"Drawing from this broad pool of experts, we have gathered a great deal of information and gained consensus on key technical issues," said Hamel. "Observers from South Africa, Japan, France, Switzerland, Germany, and other countries are interested in how we're conducting the project so they can apply the process to seismic assessments in their countries."

For new plants, the NRC requires a site-specific probabilistic seismic hazard analysis for plant licensing. The analysis quantifies seismic risks posed by the site under various conditions. Seismic source characterization—the first step in such an analysis—estimates the magnitude of the earthquake at its source, the type of fault, and the site conditions. By incorporating relevant data from thousands of earthquakes

Damage Assessment: A Case Study

Tokyo Electric Power Company's 8,212-MW Kashiwazaki-Kariwa Nuclear Power Station is the world's largest. Four of TEPCO's seven units were operating on July 16, 2007, when a magnitude 6.8 earthquake hit the area. Although the operating reactors were shut down safely, there was some damage to nonsafety equipment and structures: a transformer caught fire, pipes broke, part of the fire suppression system failed, and air ducts were damaged.

"This earthquake was up to three times the design level of the plant, and they experienced no safety-related issues," said EPRI senior project manager Bob Kassawara. "This shows a tremendous amount of margin in the design and what it is actually capable of resisting."

EPRI technical executive Ken Huffman happened to be en route to Tokyo at the time of the earthquake, touching down in Japan about two hours after it struck. At TEPCO's request, he met with TEPCO senior technical management and provided input on a plant assessment strategy, as well as U.S. postearthquake evaluation practices contained in EPRI documents. In September an EPRI review team inspected the structures, systems, and components for earthquake damage.

"EPRI had an established evaluation process for conducting postearthquake walkdowns to assess the condition of the plant," said Huffman. "These existing guidelines included what critical equipment to look at and what features to evaluate."

EPRI found that the safety equipment was all intact and that the nonsafety systems had minimal damage. Although there was no visible damage to safety equipment, questions remained about damage that might not be apparent from plant inspections. Because the earthquake exceeded the plant's design basis, the case had to be made that the units could operate safely. EPRI assisted TEPCO in devising a restart strategy that involved both inspections and testing to ensure that the equipment was undamaged and would operate successfully.

The effort benefited from a knowledge base on plant equipment and structure vulnerabilities, which EPRI had compiled over the years from field observations made at numerous non-nuclear facilities following earthquakes and from seismic equipment qualification laboratory tests.

EPRI reviewed and provided input to analytical studies conducted by TEPCO to calculate the loads resulting from this earthquake, which then were compared with seismic acceptance standards to demonstrate that the equipment could operate safely or to guide prudent structural reinforcement. "EPRI's peer review and presentations at international conferences were especially important to us, as they showed that the methods we developed to check the integrity of our facilities were valid and rational from the point of view of an independent third party," said Kazuyuki Nagasawa, deputy manager in TEPCO's Nuclear Asset Management department.

Following the inspections, analytical modeling, structural reinforcement, and tests, TEPCO received approval to start bringing the reactors back on line. The two largest reactors—Unit 7 and Unit 6—were restarted in May and August 2009, and as of June 2010, Unit 1 was undergoing functional tests prior to returning to commercial operation. Evaluations, inspections, and seismic reinforcement are under way on the other units in anticipation of returning them to service.

over the past 20-plus years with advanced seismic modeling, the Seismic Source Characterization Project will result in a more accurate representation of earthquakes that could affect a given site.

The second step in creating a probabilistic seismic hazard analysis is to look at attenuation—how the energy from a seismic event is transferred from the source over distance, through different rock and soil layers, to create motion at the plant site. "Seismic attenuation models enable you to estimate how a given earthquake would have been felt at your plant site," said Kassawara.

Also in this area, EPRI is participating in research conducted by the Pacific Earthquake Engineering Research (PEER) Center at the University of California at Berkeley. In 2008, the center completed a next-generation attenuation model for the western United States, and in 2010, it launched a corresponding program for the central and eastern United States, to be completed in 2014.

"The West experiences very frequent, shallow earthquakes," said PEER Executive Director Yousef Bozorgnia. "The central and eastern United States experiences infrequent but occasionally very large magnitude earthquakes. Since there are so many nuclear power plants in the central and eastern United States, this is of concern to the nuclear industry."

In addition, the characteristics of the rock, soil, and sediment are different in the East and West, affecting the way earthquake energy is transmitted to the surface. For its attenuation project, PEER has assembled experts and researchers from many U.S. states, Europe, and Australia. Nuclear power plant owners and operators are participating through EPRI. The NRC, DOE, and the U.S. Geological Service also are participating in the project to ensure they will have more robust models to use when evaluating applications for new nuclear plants.

Although the research also will be available for assessing risks to bridges, buildings, and other infrastructure, it aims primarily to help the nuclear industry improve plant safety and to support an efficient, effective permitting process. All of the publications and attenuation models will be available free of charge, and PEER will create and place on its web site a database of recorded and simulated ground motion.

Sharing the Wealth

With the renewed interest in nuclear power plants worldwide, EPRI is conducting the research needed to build and operate plants safely and economically. "Much of our research has focused on evaluating whether seismic regulations are commensurate with real seismic hazards," said Kassawara. "Nuclear power plants are designed conservatively for large western earthquakes. An analysis is performed for each site to ensure that the design is adequate for the earthquakes that actually could occur at that site, according to the hazard analysis."

In addition to the work discussed above, EPRI has assembled a range of data and models on soil-structure interaction to study how plant buildings themselves—hundreds of thousands of tons of steel and concrete—affect the ground motion beneath them, and how individual pieces of equipment are affected by these modified motions. Taken together, these findings can help ensure integrity and operability of plant components.

Historically, the safety of plant buildings and components is assured by giving them strength adequate to resist the motions and forces resulting from earthquakes without becoming overstressed, damaged, or inoperable. Office buildings, bridges, and other conventional structures rely on seismic isolation, which involves building the structure on flexible devices, or isolators. These shift the vibration frequency of the combined system downward, below the frequencies of the damaging ground motions. Because isolators absorb energy and change the nature of seismic motion, a structure and its interior components are subjected to significantly gentler, relatively slow swaying motions.

So far, two nuclear plants have used seismic base isolation: the Cruas plant of Electricité de France (EDF), near Montelimar, France, and Eskom's Koeberg Power Station, near Cape Town, South Africa. At these plants, each reactor sits on 1,800–2,000 neoprene pads, which measure about 2 feet on a side and several inches thick. Seismic isolation concepts have improved since these plants were built in the 1980s, and EPRI is evaluating further study of seismic isolation's wider use in the design and construction of nuclear plants.

Experience has proven that current methodologies have resulted in safe nuclear plant designs with effective margins for earthquake risk. It is also clear that opportunities exist to advance our understanding of earthquake risks and impacts and to give plant location and geologic variables more weight in calculating appropriate design requirements. EPRI is pursuing both conventional and advanced design and analysis concepts to inform rule making and to ensure that nuclear plants will continue to respond safely to seismic events.

This article was written by Drew Robb. For more information, contact Jeff Hamel, jhamel@epri.com, 650.855.2095; Ken Huffman, khuffman@epri.com, 704.595.2555; or Bob Kassawara, rkassawa@epri.com, 650.855.2775.

Jeffrey Hamel, program manager of Advanced Nuclear Technology, oversees research on near-term deployment of advanced light water reactor plants, development of GEN IV technology, and technical and commercial support for an integrated spent fuel management strategy. Prior to joining EPRI in 2007, he worked at General Electric as the manager of specialty projects and was responsible for leading new growth for GE's nuclear business. Hamel received a B.S. degree in marine transportation from the Massachusetts Maritime Academy and an M.B.A. from Santa Clara University.

Ken Huffman is a technical executive specializing in plant technology issues, including equipment reliability, instrumentation and controls modernization, risk and safety methods, and development of long-term plant operation solutions. Before joining EPRI in 1991, he served at Westinghouse, leading activities associated with nuclear component design and manufacture. Huffman holds a B.S. degree in mechanical engineering from the University of Nebraska.

Robert Kassawara is a senior project manager in the Nuclear Power Sector's Risk and Safety Management program. His research activities focus on seismic issues for operating and planned nuclear power plants, seismic qualification of equipment, performance-based fire-protection engineering, and physical plant security issues. Before joining EPRI in 1985, he worked at Impell Corporation and at Combustion Engineering. Kassawara received a B.S. in civil engineering from the Polytechnic Institute of Brooklyn and M.S. and Ph.D degrees in civil engineering from the University of Illinois.

DATELINE EPRI

News and events update

EPRI GHG Offset Workshop Looks at Programs, Mechanisms

WASHINGTON, D.C. – EPRI hosted its eighth workshop on greenhouse gas offsets, exploring how existing offsets programs, such as the Clean Development Mechanism and the Climate Action Registry, address key policy and technical issues: methodology development, determinations of additionality and baselines, and approaches to monitoring, reporting, and verification. Participants came from the electricity sector and from policymaking, environmental, industrial, financial, and research organizations.

DOE Establishes New Nuclear Hub

WASHINGTON, D.C. – The U.S. Department of Energy awarded a multiyear, $122 million contract to a team including EPRI that will establish and operate the new Nuclear Energy Modeling and Simulation Energy Innovation Hub. Led by Oak Ridge National Laboratory, the team also includes Idaho National Laboratory, Los Alamos National Laboratory, Massachusetts Institute of Technology, North Carolina State University, Sandia National Laboratories, Tennessee Valley Authority, University of Michigan, and Westinghouse Electric Company. The Hub will use advanced capabilities of the world's most powerful computers to make significant leaps forward in nuclear reactor design and engineering. EPRI will be instrumental in ensuring the modeling and simulation efforts reflect real-world conditions and can provide practical value to commercial nuclear power plants.

Research Program to Look at Advanced Corrosion Monitoring

NANTICOKE, Ont. & ROCKPORT, Ind. – EPRI's Boiler and Turbine Steam and Cycle Chemistry program recently launched a fossil plant corrosion control optimization study at Ontario Power Generation's Nanticoke Generating Station in Ontario, Canada, and American Electric Power's Rockport Plant in Rockport, Indiana. The study is examining the benefits of employing advanced corrosion monitoring techniques.

Program Manager Briefs NRC

ROCKVILLE, Md. – EPRI program manager John Kessler participated in a briefing to the Nuclear Regulatory Commission on used nuclear fuel management and regulation. Kessler addressed near-term to long-term options for managing the aging of used fuel storage systems and also highlighted EPRI's role in launching a collaborative program on extended storage that will provide the technical bases to ensure safe, long-term used fuel storage and future transportability.

EPRI and E.ON Engineering Host International Renewables Workshop

RATCLIFFE-ON-SOAR, U.K. – EPRI and E.ON Engineering hosted the International Renewables Workshop in June to discuss the technology development needed to realize the full potential of renewable power generation. Participants from Europe and the United States discussed the research critical for facilitating greater penetration of renewables. This was the seventh in a series of workshops held since 2008 to discuss key aspects of renewable power generation. Previous workshops have addressed integration, wind, solar, biomass, and geothermal power generation.

International PDU Council Looks at Renewables, Launches Initiative

MADRID – EPRI held its fourth International Power Delivery and Utilization Council meeting, hosted by Red Eléctrica de España, Unión Fenosa, Iberdrola, and UNESA. The meeting focused on renewable energy and included technical tours of Red Eléctrica's Transmission Control Center, with an emphasis on its renewables integration desk, and the Iberdrola Control Center for Renewable Energy, where Iberdrola's worldwide renewable asset base is monitored and controlled. The meeting also launched an international transmission efficiency initiative, an extension of an initiative launched by EPRI with the support of U.S. Federal Energy Regulatory Commission chairman Jon Wellinghoff.

EPRI Program Helps ENDESA Tackle HRSG Issues

SAN ROQUE, Spain – Members of EPRI's Heat Recovery Steam Generator (HRSG) Dependability program staff met with their counterparts at ENDESA Generación's plant in San Roque, Spain, to address thermal transients stemming from the design of the plant's HRSGs. ENDESA said it is confident the modifications recommended in EPRI's report will result in a significant decrease in boiler tube failures. The company also is translating EPRI's field guides on boiler tube failures and outage inspections into Spanish for its staff.

EPRI Participating in UN Global Mercury Negotiations

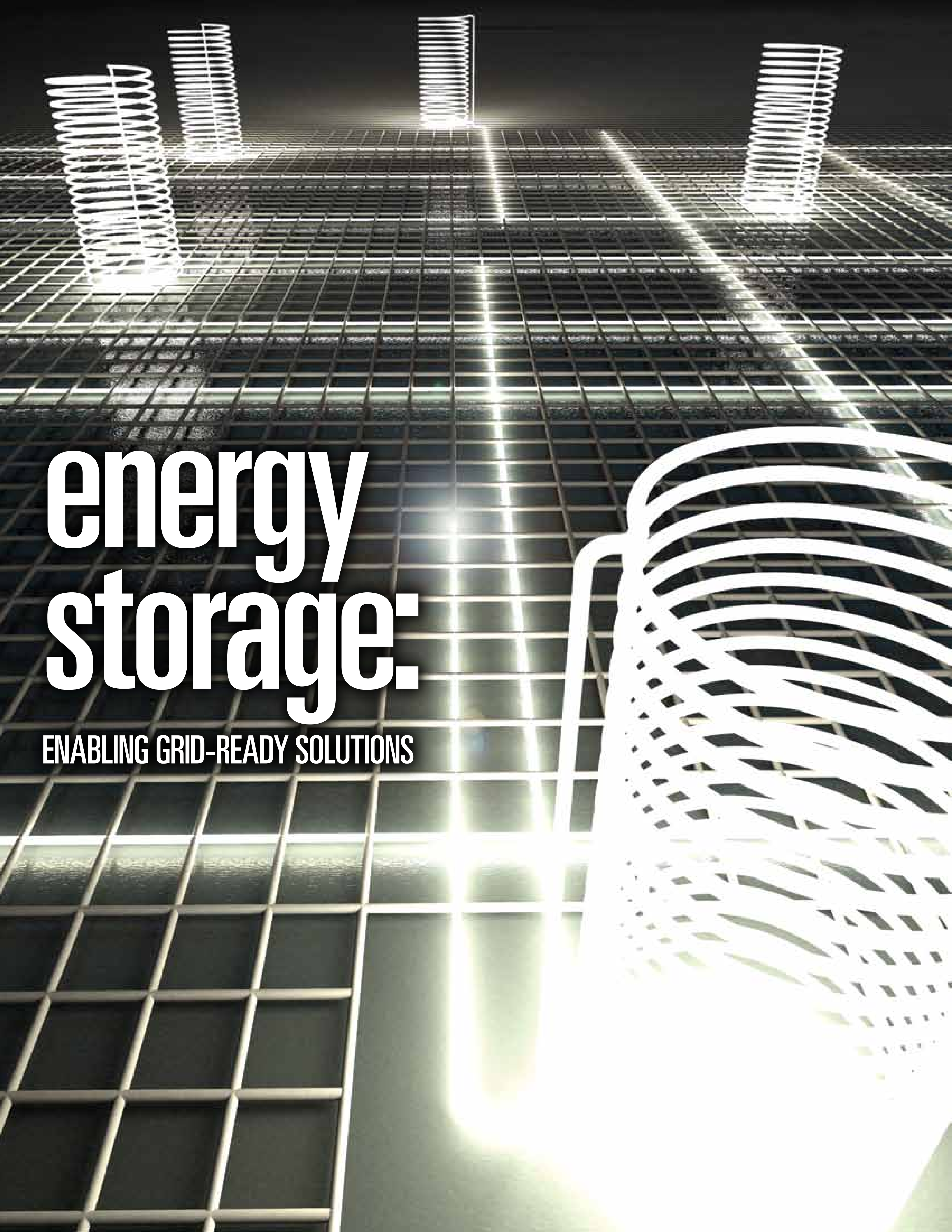
STOCKHOLM – EPRI's Leonard Levin joined delegates from 70 nations at the first in a series of United Nations–sponsored negotiations on a binding agreement to control mercury releases around the globe. Four more negotiations are planned through 2013, each including discussion of mercury releases to the atmosphere. EPRI helped prepare technical background for the negotiations by participating in the United Nations Mercury Fate and Transport workgroup and providing technical briefings to staff at the U.S. Department of State.

Conference Sheds Light on Coal Combustion Materials and Sustainable Construction

ANCONA, Italy – The importance of coal combustion products (CCPs) in sustainable construction was examined during a three-day conference on sustainable construction held at the Università Politecnica delle Marche. EPRI's Ken Ladwig chaired a session that focused on the use of CCPs and presented an overview of EPRI research in the area.

Three EPRI Scientists Selected as Lead Authors for IPCC 5th Assessment

GENEVA – The Intergovernmental Panel on Climate Change (IPCC) selected three scientists from EPRI's Global Climate Change Program as lead authors for its fifth assessment report on climate change, which will be released in 2013–2014. They will serve on the writing team of the Working Group III report, *Mitigation of Climate Change*. Richard Richels, the program's senior technical executive, will serve as a lead author of the chapter titled "Drivers, Trends, and Mitigation." Geoffrey Blanford and Steven Rose, senior research economists in the program, were named lead authors for the chapter titled "Assessing Transformation Pathways."



energy storage:

ENABLING GRID-READY SOLUTIONS

Energy storage has played a relatively minor role in the power system, but as intermittent renewable resources, distributed generation, and advanced technologies transform the traditional power grid, storage may become a key enabler of the low-carbon, smart power grid of the future.

THE STORY IN BRIEF

Energy storage technologies could perform two essential roles in the evolving low-carbon, smart power grid: balance variable renewable generation and increase grid reliability. EPRI energy storage researchers aim to provide proven, grid-ready storage technologies within five years while pursuing longer-term efforts to develop advanced storage technologies with higher performance and lower costs.

Moving Electricity Through Time

"Transmission and distribution systems deliver electricity where it's needed, but energy storage systems deliver electricity *when* it's needed," said Daniel Rastler, EPRI's program manager for energy storage and distributed energy resources. "By moving electricity through time, energy storage provides benefits along the entire electricity value chain."

Although there are numerous applications for energy storage, they can be grouped into two basic categories, according to Haresh Kamath, strategic program manager in EPRI's Technology Innovation organization. "The first role is balancing variable renewable generation. The second is increasing the reliability and asset utilization of the grid. Both of these roles are becoming more important because the power grid, as we know it, is changing."

In today's grid, electricity flows in one direction from central generating stations through the transmission and distribution systems to serve industrial, commercial, and residential customers. Generation is always balanced with load. But the traditional grid is undergoing fundamental changes. The addition of wind and solar resources on a large scale introduces variable generation controlled by forces of nature as much as by grid operators. Distributed generation, such as rooftop photovoltaic systems, can cause power to flow upstream in localized areas, creating voltage stability issues. Further accelerating the transformation are possible changes in energy markets and the coming smart grid, which will give consumers and utilities more control over how energy is used.

"As a result of these changes," said Kamath, "energy storage may soon be playing a more prominent role throughout the grid." Extended drop-offs in wind energy can affect operational scheduling, and clouds passing over photovoltaic systems can cause abrupt drops in power that can affect local system stability. Energy storage systems at the transmission level represent one way to increase the operational flexibility of the bulk power system to accommodate the greater penetration of renewables. Meanwhile, smaller storage systems can give utilities more control over power flows at the distribution level, increasing reliability and allowing the deferral of capacity expansion.

Energy Storage at EPRI

EPRI's energy storage strategy includes near-term and long-term goals. The near-term goal is to achieve grid-ready energy storage solutions by 2015 in three areas:

- Large-scale bulk storage as a balancing resource for renewables (providing more than 50 MW for 6 to 10 hours);
- Substation storage to allow upgrades in transmission and distribution assets to be deferred (1 to 10 MW for 2 to 6 hours); and
- Distributed energy storage systems at the neighborhood level (15 to 25 kW for 2 to 4 hours).

Grid-ready in this context means cost-effective, safe, and reliable and refers to products with proven track records. EPRI, in collaboration with utilities and technology developers, is producing a set of functional specifications that will serve as a target for energy storage products in these three areas.

"Cost has been the biggest barrier to energy storage deployment," said Rastler. To quantify the barrier, the EPRI energy storage program performed detailed application and value analyses of storage systems in 10 different applications to better estimate the total value and thus the allowable installed costs for storage systems. Findings are presented in an EPRI report, *Energy Storage Market Opportunities: Application Value Analysis and Technology Gap Assessment* (1017813), and a white paper, *Electric Energy Storage Options* (1020676), to support business case assessment for energy storage investments (see "Assessing the Cost and Value of Energy Storage," page 22).

Near-Term Focus: CAES and Lithium-Ion Batteries

From the analysis, EPRI researchers identified two leading energy storage candidates for near-term demonstrations: compressed-air energy storage (CAES), which is considered the most cost-effective bulk storage technology for long discharge durations, and lithium-ion batteries, potentially the most cost-effective option

Assessing the Cost and Value of Energy Storage

A new EPRI analysis offers the latest information on the applications, benefits, and value of energy storage technologies, from large utility-scale systems providing bulk storage for wholesale energy services to small systems providing backup power for home offices. Findings are presented in the report *Electric Energy Storage Options* (1020676), which informs industry stakeholders about available and emerging storage technologies and their status and provides cost and application value information to support business case assessment for energy storage investments.

EPRI researchers identified the top 10 key applications for energy storage in order to estimate their value and market potential. The analysis compared the present value of benefits for each application with the total costs of installing an energy storage system. These estimates are analogous to the Total Resource Cost test, which compares costs and benefits for a region as a whole, regardless of who actually pays the cost or receives the benefits.

"Each of the 10 applications is centered on a specific operational objective but provides multiple benefits," said Dan Rastler, EPRI's program manager for energy storage and distributed energy resources. "Because of the current high installed capital costs of most energy storage systems, applications—for either utilities or end users—must be able to realize multiple operational uses across the energy value chain."

According to EPRI modeling analyses, the highest-value applications are the following:

- Wholesale services with regulation;
- Commercial and industrial power quality and reliability; and
- Stationary and transportable systems for grid support and T&D capital expansion deferral.

Key customer applications are commercial, industrial, and home energy management. Most of the larger markets have estimated application values of less than $500 per kilowatt-hour of storage.

The results imply that the total energy storage market opportunity might be on the order of 17 gigawatts if energy storage systems could be installed for a capital cost of about $700–$750/kWh and the benefits estimated could all be monetized. Actual installed costs would have to be lower to accommodate life-cycle and maintenance costs. Niche high-value market sizes were estimated to total approximately 5 GW if energy storage systems could be installed for $1,400/kWh and all benefits could be monetized.

for short durations.

"Many storage technologies are relying solely on utility customers to achieve scale," said Kamath. "But it's hard to see how these technologies will achieve adoption at intermediate price points. Lithium-ion batteries and CAES technologies each have a clear, broad path to scale based on other markets—and that will bring down costs. EPRI is leading demonstration efforts with the objective of having products using these two technologies ready by 2015."

CAES plants use off-peak power to pump air into a storage reservoir, which may be an underground salt cavern, rock formation, or depleted gas field or an above-ground vessel. When power is needed, the air is withdrawn, heated, and run through a turbine to generate electricity. Two CAES plants are in operation today, a 110-MW 26-hour plant in Alabama and a 290-MW 4-hour plant in Germany. The Alabama plant, constructed as an EPRI collaborative demonstration project, has operated reliably since 1991. CAES plants respond rapidly to load fluctuations and can perform ramping duty to smooth the intermittent output of wind power as well as provide spinning reserve and frequency regulation to improve overall grid operations and stability.

In late 2009, the U.S. Department of Energy (DOE) awarded Smart Grid grants for the construction of 150-MW 10-hour and 300-MW 10-hour advanced second-generation CAES units to New York State Electric & Gas (NYSEG) and Pacific Gas and Electric (PG&E), respectively. NYSEG plans to use an underground salt cavern for the air storage system, and PG&E hopes to use underground porous rock or a depleted gas field for air storage. EPRI and utilities are planning to participate in these two projects to help build, perform technology transfer, and demonstrate these advanced, second-generation CAES systems.

Lithium-ion batteries are commonly used in consumer electronic products, which make up most of the worldwide production volume of 10 to 12 gigawatt-hours per year. Lithium-ion also is positioned as the leading technology platform for plug-in hybrid and all-electric vehicles. Compact and highly efficient, lithium-ion batteries also are prime candidates for stationary energy storage markets, such as community energy storage, commercial peak shaving, home backup energy management, frequency regulation, and smoothing the variable output of wind and solar generation.

The huge investment in lithium-ion battery fabrication facilities to serve the budding electric vehicle market presents opportunities for the electric utility and electric transportation industries to increase production volume to reduce

EPRI tested this 6-kW/20-kWh lithium-ion battery system at its Knoxville laboratory and is planning to evaluate a 25-kW/50-kWh scale-up by the end of the year. (Photo courtesy Greensmith Energy Management Systems)

Battery modules configured from lithium-ion cells are being considered for neighborhood grid support, outage mitigation, and peak management. Larger modules may provide substation support on the megawatt scale. (Photo courtesy International Battery)

costs. To that end, EPRI is evaluating a demonstration project building on the synergies between electric transportation and stationary storage applications. The project is intended to demonstrate several high-value applications for lithium-ion energy storage systems with electric utilities and evaluate the performance of technology exposed to various operating conditions. The project may involve 15 to 20 MW of lithium-ion storage systems in applications including grid support, distributed storage, energy management, renewables integration, and frequency regulation.

Long Term: Moving the Dial

Looking beyond 2015, EPRI aims to support and accelerate the development of advanced energy storage technology options with superior performance and lower costs, as well as strategic tools to improve the value of storage.

"There are gaps in our applications matrix that aren't served by our present storage technologies," said Kamath. "For example, we don't have a good solution yet that provides four to six hours of discharge in the 1-MW range. And while the costs of CAES and lithium-ion are promising for utility application, we'd like to see costs fall even further."

Among the promising advanced energy storage technologies are zinc-air batteries, a next-generation technology that offers the potential for higher energy densities and lower costs than lithium-ion. Zinc-air shares the same path to scale as lithium-ion—with initial application in portable electronics, where cost is barely an issue, followed by electric vehicles and then stationary storage. Ultimately, volume production will bring costs down. EPRI is supporting zinc-air technology as a developer-partner, providing seed funding and cost sharing to developers of fundamental technologies.

EPRI is taking a more active leadership role in the development of a no-fuel (pure adiabatic) CAES technology. Existing CAES plants require a fuel input during the generation cycle and so are not carbon-neutral. Adiabatic CAES plants store the heat of compression in thermal energy storage systems and heat the air from the thermal store during the plant's generation cycle to eliminate the fuel requirement. EPRI is developing adiabatic CAES technology in-house, with the goal of establishing proof of concept.

One Vital Part of the Solution

"No single energy storage option meets every need," said Rastler. "Instead, a portfolio of storage options that meet cost, performance, and durability requirements will be needed. But much more research is required in order to understand how storage can best be deployed in different sections of the electricity value and supply chain, and ultimately how the benefits of the various applications can be monetized."

In the low-carbon power system of the future, energy storage may play a significant role in balancing renewables, increasing grid reliability, and enabling smart grid capabilities, along with facilitating demand response, transmission expansion, and efficient use of the power delivery system.

"The only real solution is a combination of technologies and approaches," said Kamath. "And storage is a vital part of the mix. That's why we'll need grid-ready storage by 2015."

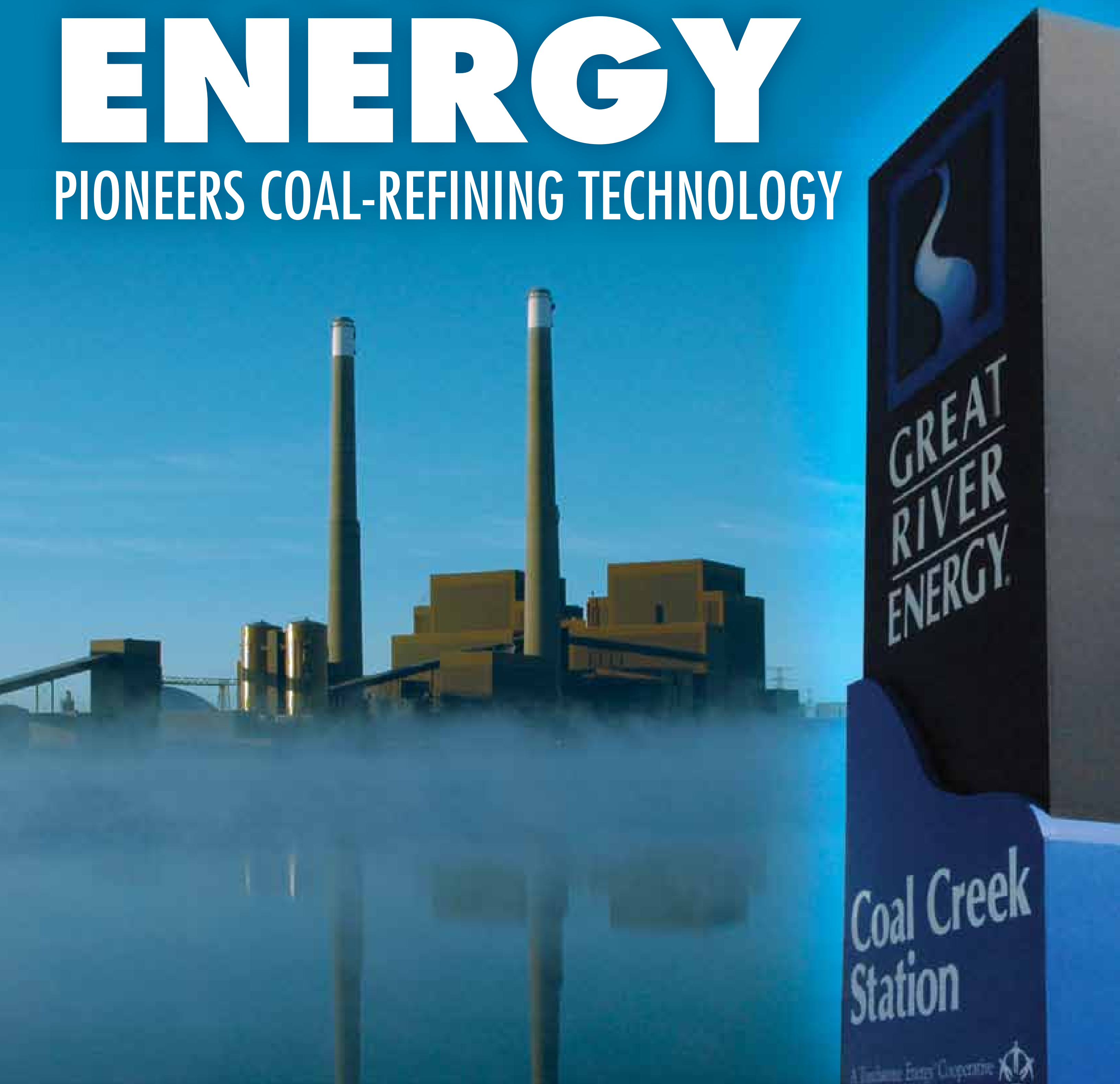
This article was written by David Boutacoff. For more information, contact Dan Rastler, drastler@epri.com, 650.855.2034, or Haresh Kamath, hkamath@epri.com, 650.855.2268.

Daniel Rastler is the program manager for energy storage and distributed energy resources in EPRI's Power Delivery and Utilization Sector. He also has managed projects in technology assessment, market analysis, and electrical integration. Before joining EPRI in 1981, he spent five years in General Electric's nuclear power business. Rastler received a B.S. in chemical engineering from the University of California at Davis and an M.S. in mechanical engineering from the University of California at Berkeley.

Haresh Kamath is a strategic program manager in EPRI's Technology Innovation program and a senior project manager in the Power Delivery and Utilization Sector, where his current research activities focus on the development, assessment, and application of energy storage technologies for both transportation and grid storage applications. Before joining EPRI in 2002, he worked at Lockheed Martin Space Systems as a product engineer responsible for spacecraft batteries. Kamath holds B.S. and M.S. degrees in chemical engineering from Stanford University.

GREAT RIVER ENERGY

PIONEERS COAL-REFINING TECHNOLOGY



Fire and water. These elemental opposites are combined in coal—especially low-rank coals such as lignite, which is a relatively short geological step removed from peat (partially decayed vegetation). Compared with higher-rank, more "mature" coals, lignite is wet, with a moisture content of 35% or more.

That makes burning lignite and its geologic cousin, subbituminous coal (including the widely used Powder River Basin variety), a challenge for electricity generation. Together, they represent about 47% of the world's coal reserves, and their price is competitive with that of other coals. But the high moisture content presents challenges to the hundreds of power plants around the world using these low-rank coals, lowering generating efficiency and increasing emissions. About one-third of U.S. coal-fired generation—285 units representing about 115 gigawatts—relies on these coals.

High moisture content also is a constant challenge to the thousands of people who run those plants—people like Charlie Bullinger and Mark Ness at Great River Energy (GRE), a not-for-profit power generation cooperative that operates 11 power plants and serves about 1.7 million consumers through 28 distribution co-ops in Minnesota.

"It was a Friday afternoon in 1997. We had all the other brush fires put out for the week and we were thinking long term," said Bullinger, then the engineering leader at GRE's Coal Creek Station in Underwood, North Dakota. "The moisture we were throwing into the boiler, and all the energy we had to spend to raise that water to steam temperature, bothered me. And it had bothered me for a lot of years."

"We ran the numbers and found we had 21% in boiler efficiency losses, and 13% was due to water and hydrogen in the fuel," Ness said. "About 8 of that 13% is due to making water, which is carrying the direct heat of vaporization out the back of your boiler. Our question was, can you get that water out of there?"

THE STORY IN BRIEF

It began as a Friday afternoon conversation between two plant engineers. Early tests relied on such basic hardware as 55-gallon drums. The combination of utility tenacity, public and private investment, and collaborative support produced a technology that reduces fuel requirements, improves plant efficiency, reduces emissions, and offers potential benefits for carbon-reduction technologies.

Testing the Concept

Coal drying isn't new, and the benefits are well known. It increases the energy density and hence the value of the coal; it reduces the volumes of coal combusted and flue gas produced, reducing emissions and saving wear and tear on a variety of plant systems; and it improves overall plant efficiency.

"Mark's a really intuitive guy, and together we decided we should see if we had enough residual heat at the plant to drive off a productive increment of the water that comes in with the coal," said Bullinger, now senior principal engineer at Coal Creek Station. "We were driven by a mission, he and I, to prevent having to build larger emissions capture boxes on the back ends of our plants, perhaps by reducing the flue gas volume that goes through the environmental equipment. We knew that nearly 40% of what gets delivered to the boiler on an hourly basis was water that we had to push through the environmental equipment to be treated, just like flue gas."

That conversation provided the kindling for an idea. A conference Bullinger attended in Wiesbaden, Germany, ignited the spark. "There were two things that impressed me—what the Europeans were doing in putting their waste energy to work, and it was much more than we had done on this continent, and how they weren't afraid to integrate the coal yard with the turbine if it offered an advantage," he said.

Both points resonated with Bullinger and Ness in their quest to improve plant efficiency. From his long experience at GRE, and as chairman of EPRI's CoalFleet for Tomorrow® program advisors, Bullinger knew that even a 1% improvement in heat rate—the number of British thermal units (Btus) required to produce a kilowatt-hour of energy—can save an average power plant a million dollars a year or more in fuel costs.

The idea appealed to members of the GRE staff and their counterparts at the nearby Falkirk Mine, which supplies the plant's lignite. A GRE-Falkirk team conducted small-scale tests that showed it is possible to reduce the moisture in lignite by about 6% using low-temperature air.

"We did one test with a barrel—a 55-gallon drum," said Bullinger, now the project leader. "We just ran hot water through a barrel with coal in it and measured how much volume changed with low temperature. Then we did some modeling. We were looking for a show-stopper, something that would show it wouldn't work, and we didn't find any."

Ness said the tests showed the moisture content could be reduced to as low as 10%, but that created new issues. "Your boiler depends on gas flow, which means there are limits to how much you can dry your coal before you affect heat transfer

Had it not been removed from the coal, the water vapor leaving the DryFining™ system stacks at the Coal Creek Station would have become flue gas and added to the plant emissions.

performance and lose superheat temperatures. You could spend more money and modify your boiler, but that also gets you into permitting issues."

The next step was installation in 2002 of a 2.5-ton-per-hour (TPH) fluidized-bed dryer, which processed 350 tons of crushed lignite (quarter-inch-sized pieces). Supported in part by the Bismarck, North Dakota–based Lignite Research Council, this pilot project showed the same promise as the earlier lab tests. It also showed the value of refining the lignite, which led to the process name—DryFining™ (drying + refining).

"That's where we learned about segregation, when we found a dense fraction of the coal materials lying in the bottom of this fluidized bed as the coal moved across," Bullinger explained. "We discovered a significant amount of the sulfur and mercury is in there, and two of our patents involve kicking them out." Those unburned particles are returned to the mine, and the refined lignite enters the plant again through the mills and boiler, as it did before. "We intercept it, perform our magic, and then return it to the belt," Bullinger said.

With support from EPRI, GRE applied for and received funding from the U.S. Department of Energy (DOE) through its Clean Coal Power Initiative for the next phase of tests of what now was known as the Lignite Fuel Enhancement System. The $31.5 million project was managed by DOE's National Energy Technology Laboratory (NETL), with Lehigh University, EPRI, and several other companies participating in the support team.

"With the collaborative agreement, the DOE helped share the risk and gave us the courage to go ahead with the project," said Coal Creek Station manager John Weeda, "because when you're developing a new technology, it doesn't come with any sort of guarantee."

Moving to Full Scale

In the project's first phase, a 115-TPH prototype supplied as much as one-sixth of the coal for the station's 546-megawatt Unit 2. That led to Phase II—a full-scale commercial demonstration featuring four full modules for Unit 2, each capable of processing coal at 135 TPH. And because the prototype had worked so well, GRE's board also approved installing four more modules for Unit 1.

Rick Lancaster, GRE vice president, generation, said that was the second time the team asked the board for more money. "We have a board that believes in putting us through our paces and making sure we know what we're talking about," he said. "Each time, they agreed we were doing the right thing … and even though there were times I wished we only were doing one unit, now that it's all done, it's nice to have the entire plant on the system."

Keeping operational disruptions to a minimum during such a large addition was important to Weeda, and he was not disappointed. "You're constructing a major addition to the plant, in the middle of the plant, with two units that are very important to keep running," he said. "We designed the integration of the facility into the plant, scheduled construction in coordination with our planned outages, and achieved commercial operation without losing a megawatt of production."

Construction was completed in late 2009. A crowd of about 600, including North Dakota governor John Hoeven and North Dakota's congressional delegation, gathered at Coal Creek Station June 3, 2010, for the dedication. There David Saggau, president and chief executive officer

Great River Energy CEO David Saggau spoke to several hundred guests who came to the facility's dedication in June.

of GRE, along with other speakers, touted process benefits:

- Lignite moisture reduced from 38.5% to 29%
- Heat content increased from 6,200 to 7,100 Btu per pound
- Fuel input reduced 14% by weight
- Overall power plant efficiency increased by 2% to 4%
- Stack emissions reduced—sulfur dioxide (SO_2) by more than 40%, mercury by more than 40%, nitrogen oxides (NOx) by more than 20%, and carbon dioxide (CO_2) by 4%
- Wear in the mills and conveying lines reduced

Saggau echoed Weeda's praise for the construction team. "During the two years of construction of DryFining™, the Coal Creek Station was running at full load the entire time," he noted. "Not once, including the day we switched from lignite coal to beneficiated lignite, did the plant miss a beat. It was a very successful transition, and it took every employee at Coal Creek to do that."

"This project is heading to commercialization, which makes this an important occasion," added Dr. Joseph Strakey, chief technology officer at NETL.

A Technology for the Future

The improvements in plant efficiency and reductions in CO_2 emissions are especially important as DOE and the power industry continue developing new carbon capture and storage technologies, which can impose formidable cost and energy penalties. Strakey's colleague, Dr. Sai Gollakota, NETL manager of the Lignite Fuel Enhancement project, said the project exceeded its goals and offers some intriguing additional benefits. The improved operation of the fuel-air flow system allows reduction of nitrogen emissions. DryFining™ can be retrofitted to existing plants and can lower the capital costs of new plants. And Gollakota, as a participant in several current DOE-funded carbon capture and storage (CCS) projects, can see another important role for DryFining™.

Charlie Bullinger, right, who led the GRE DryFining™ project, was interviewed by Joel Heitcamp of local radio station KFGO-AM during a live broadcast from the project dedication.

"The advantage of including it in the design of new CCS systems is that it will reduce the downstream CO_2 output to the system. Because it increases the plant efficiency, it reduces the carbon emissions and the cost of constructing and operating the CO_2 capture and sequestration systems," Gollakota said. "And because you're now dealing with reduced quantities of other pollutants like sulfur and nitrogen, it costs less to clean up flue gases and get the higher concentrations of CO_2 needed for capture."

GRE and DOE now are looking to commercialize the technology, which received the Lignite Energy Council's Distinguished Service R&D Award, an EPRI Generation Technology Transfer Award, and the American Council of Engineering Companies of Minnesota's 2007 Engineering Excellence Award. GRE selected the WorleyParsons Group to market DryFining™ to other companies, including about 15 that have signed confidentiality agreements with GRE.

"This project is unique in our experience, because it's such a large project and provides so many benefits to the plant," GRE's Lancaster said. "We're not a research organization. We normally rely on EPRI and DOE for that, and they both provided important support. But we're very proud that a couple of our own engineers had a bright idea, started testing it, and it worked out even better than expected. And that our whole organization got behind it and said, Let's turn this into something real."

"GRE did all the testing and the nuts-and-bolts work. We were involved in a supporting role, looking at alternative designs and evaluating test data," said John Wheeldon, an EPRI advanced generation senior project manager. "We had worked on a number of fluidized-bed projects, and we were able to share the knowledge gained, helping GRE avoid problems others had experienced.

"The GRE team showed a lot of competence and had the courage of their convictions. Their endeavors produced design information that is applicable to subbituminous coal, not just to lignite, and so benefits a wide swath of the industry."

Members of the GRE team are already looking for their next challenge. "Right now, the water we drive off goes up into the air," Bullinger explained. "We're talking to the DOE about another project that would use that water for makeup, so we'd need to take less water from the rivers and streams and wells. It's a significant amount on an annual basis.

"You're never satisfied. You're always looking for ways you can make something better or use it in new ways. You keep having those Friday afternoon conversations about the problems that are bothering you and the things you can do to solve them."

This article was written by Jeff Brehm.
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New Tool for Generator Dynamics Validation Reduces Costs and Downtime

The Western Electricity Coordinating Council (WECC) requires periodic validation of the computer simulation models used to represent power plant equipment to ensure that the models reasonably represent a plant's actual dynamic performance. To perform such model validation, dynamic fluctuations are "staged" during scheduled maintenance outages as part of a series of predefined tests, including small (~10% of the unit's rating) megawatt and megavar rejection tests and off-line and on-line voltage reference step tests. The recorded test data are used to validate models of the plant's generator and control systems to ensure that the models adequately capture the plant's expected response to system events.

Because generating units are required to be out of commercial service during these procedures, utilities may lose revenue for the 4 to 6 hours typically required for a large unit. Consultants needed for the testing can add to costs. And although experience has demonstrated a low risk of damage to equipment during testing, some utilities believe that tests such as megawatt load rejection can cumulatively reduce the service life of the turbine-generator shaft and potentially expose the unit to other damage.

EPRI has developed a computer simulation program that eliminates the need for such staged testing. The software tool uses real-time data captured from the plant during an actual grid disturbance to validate the model of the plant and its controls.

Setting Up for Real-Time Data

In 2009, Tri-State Generation and Transmission Association successfully applied the Power Plant Parameter Derivation software tool on its system. With EPRI's help, Tri-State configured digital fault recorders at its Craig Station to provide data on multiple system disturbance events. Tri-State already had digital fault recorders installed at the plant, and modifications involved the addition of a few more recorder signals for the model validation process. It took only a few weeks to collect baseline data and prepare the tool for data processing. This one-time setup process is likely to be streamlined in future applications as experience is gained at more plants.

Over 17 months, the demonstration project captured data from seven disturbances, including grid faults and loss of large generating units elsewhere on the interconnected power system. The software was used to process these data and validate the models for the electrical generator, the excitation system (including the power system stabilizer), and the turbine governor.

The validation work was submitted to WECC, which has confirmed that the information meets certification requirements and that it will certify Tri-State's validation testing for these units. This will be among the first certifications of large thermal generating units based on analysis of data from on-line disturbance monitoring rather than from staged physical testing.

Tri-State Generation and Transmission Association's Craig Station

A Timely Innovation

Acceptance of EPRI's validation method is particularly valuable and timely, considering that the North American Electric Reliability Corporation is expected in the near future to institute nationwide requirements similar to WECC's regional mandate. Staged testing will still be prudent and necessary for determining baseline data when commissioning a generating unit or retrofitting the unit with new equipment or controls. For routine model revalidation, however, the Power Plant Parameter Derivation software significantly reduces the cost and introduces no additional risk, since users are simply monitoring the unit during normal operation and recording machine response during disturbances.

According to Chris Pink, senior power systems planning engineer at Tri-State, "Validation of generator dynamic models using real-world disturbance data will enable us to provide accurate and timely model validation, reduce costs and downtime on our generating units, and maintain system reliability according to WECC and NERC requirements."

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Simpler Circuits May Benefit Nuclear I&C Systems

As utilities replace aging instrumentation and control (I&C) systems in nuclear plants, they are considering an electronic alternative to microprocessors in such systems, particularly for safety-related applications. Called field programmable gate arrays (FPGAs), these comparatively simple integrated circuits can be configured to perform specific functions very rapidly, without overhead functionality not needed for the specific application.

I&C systems for most of today's nuclear plants originally relied on conventional relay and analog electronics technologies, and many of these systems are now being replaced with microprocessor-based equipment. But microprocessors tend to become obsolete much more quickly than the analog systems, and replacing them can be complicated and costly. Also, gaining regulatory approval can be difficult and expensive.

In contrast, an FPGA system operates more like the hardwired electronics previously used in analog systems, with multiple data streams processed independently and in parallel. Relying on FPGAs for I&C upgrades allows for discrete functions to be separated at the circuit level, enhancing reliability and testability, and can mean that only specific components need be replaced. This approach can keep costs lower—by up to an order of magnitude—than upgrades involving microprocessors.

While an FPGA application chip is created using complex software development and verification tools—and will be treated much like software-based applications by regulatory reviewers—the unit operates as hardware, with no external software interface. By avoiding the complexity of microprocessor-based systems and processing individual signal paths using only hardware, FPGAs are expected to reduce the cost of upgrading nuclear I&C systems and ease the process of gaining regulatory approval.

Guidance on Application

Although FPGAs have been used extensively in military and aerospace applications, many utilities are not familiar with the technology and its potential benefits. To provide an information resource, EPRI recently published *Guidelines on the Use of Field Programmable Gate Arrays in Nuclear Power Plant I&C Systems* (1019181). The report begins with a primer on FPGA technology, followed by a discussion of potential advantages and limitations, including insights culled from experience in previous applications. Examples of these applications include the Wolf Creek main steam and feedwater isolation system and the Advanced Boiling Water Reactor power range neutron monitoring system.

The report also provides specific guidance on specifying and selecting FPGA-based systems, while taking into account the full life cycle: requirements, design, verification, and validation. Two primary resources are also described regarding safety justification and gaining regulatory approval—the recent U.S. Nuclear Regulatory Commission approval of an FPGA-based safety system application and an upcoming international standard specifically directed at FPGAs and related devices.

Benefits and Limitations

FPGA technology also may offer some advantages over conventional microprocessor-based systems for cyber security, increasing the level of difficulty that would be faced by a would-be attacker. For example, FPGA-based systems that directly implement I&C functions do not contain higher-level, general-purpose components that could be diverted more easily for malicious purposes. Some FPGA technologies currently used for safety applications can also be implemented in ways that would require physical access to I&C equipment in order to alter their programming.

FPGA systems do, however, have important limitations that need to be taken into account when utilities update their control rooms. In particular, FPGAs are not well suited for systems involving complicated human-system interfaces, such as those used by control room operators. For these applications, software-based menus and multiple-window interfaces provide broader functionality and greater ease in selecting ways to display information and manage complex systems.

"FPGA technology offers many potential benefits for nuclear I&C systems, and I believe its use will increase rapidly as more products become available," said technical executive Joseph Naser. "EPRI's guidelines can help utilities become more familiar with FPGA-based systems and learn how to implement them so as to maximize their advantages."

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Circuit Breaker Ranking Tool Saves Con Edison Millions

Historically, maintenance of high-voltage circuit breakers has been based on service time and, to a lesser extent, on operations count—the number of times the breaker has been operated. This simple approach has served the industry well for many years. But concerns about aging infrastructure, limited maintenance resources, and rising expectations for reliability are prompting maintenance and asset managers to investigate other, more sophisticated approaches to circuit breaker maintenance.

EPRI assessments have shown that for most breaker components, wear is not time-dependent, and the number of operations is not the only factor driving deterioration. Circuit breaker failure largely depends on breaker design, location, and application. Some breakers see more severe service duty than others because of their position in the power system.

In response to this new understanding, EPRI has developed a data-driven maintenance decision methodology that better reflects each breaker's actual condition and operating environment. The new tool allows a company to rank the condition of its entire breaker fleet and direct resources to the units most in need of attention. The methodology has been applied at several utilities with success.

Making Use of Existing Data

"Companies produce a lot of data on breaker condition in the course of normal operation and maintenance, but this valuable information is often underused because it's not in a form that can be easily applied in decision making," said project manager Bhavin Desai. "We have been developing algorithms for a number of years to convert the data into useful information that can drive meaningful actions without the expense of further data gathering."

The EPRI tool allows the user to gather information on the circuit breaker fleet from various sources and have it at his or her fingertips. It can rank a breaker's condition relative to the rest of the fleet and gauge the applicability of specific maintenance activities, including diagnostic testing. For a broader perspective, it enables the user to see trends within the breaker fleet, identify potential problem areas, and document the mitigation of failure risk in considerable detail. Because the tool is spreadsheet-based, the user can sort and group the breakers by type, voltage class, specific model, position on the system, and so on.

Early Success

More than a dozen EPRI members have been involved in developing the ranking tool, and several have applied prototype versions on their systems. Last year Consolidated Edison used the program to identify the circuit breakers least likely to need attention. By extending the intervals between major maintenance inspections for these units, the company saved about $3 million for 2009 and expects equivalent savings in the coming years without any reduction in performance.

"One of the biggest challenges for T&D maintenance is dealing with the sheer volume of equipment," said Matt Walther, asset manager for Con Edison's substation operations. "Using the data from the maintenance tool helps us whittle that number down and make better choices on which breakers we perform maintenance on. It really enables our team to focus limited resources on the right equipment, thus improving productivity while retaining a high level of reliability."

James Haufler, a Con Edison senior substations engineer, pointed out that enhanced access to maintenance data can provide ancillary benefits: "In addition to giving us good guidance on breaker risk, the maintenance tool has helped us better identify SF_6 gas leaks, saving money and improving our environmental stewardship. All these benefits have been accomplished with relatively low expenditures."

Such early successes in applying the maintenance decision tool—and the substantial savings—have strongly validated the data-driven condition-monitoring approach. EPRI continues to refine the ranking algorithms with assistance and feedback from its funding members.

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Nondestructive Hydrogen Monitoring for Nuclear Fuel Applications

The channel boxes, commonly referred to simply as "channels," that surround fuel bundle assemblies in today's boiling water reactors (BWRs) are made of zirconium alloys—primarily Zircaloy-2 and Zircaloy-4. Resistant to the high radiation and temperatures of nuclear reactors, these channel materials nonetheless are vulnerable to hydrogen, which is absorbed during corrosion of the Zircaloy alloy. Hydrogen absorption can degrade the mechanical properties of Zircaloy, leading to embrittlement, elongation, and distortion of the channel boxes. Distortion of these channels can interfere with the free movement of the fuel bundles' control blades, causing operational issues, and may pose safety concerns.

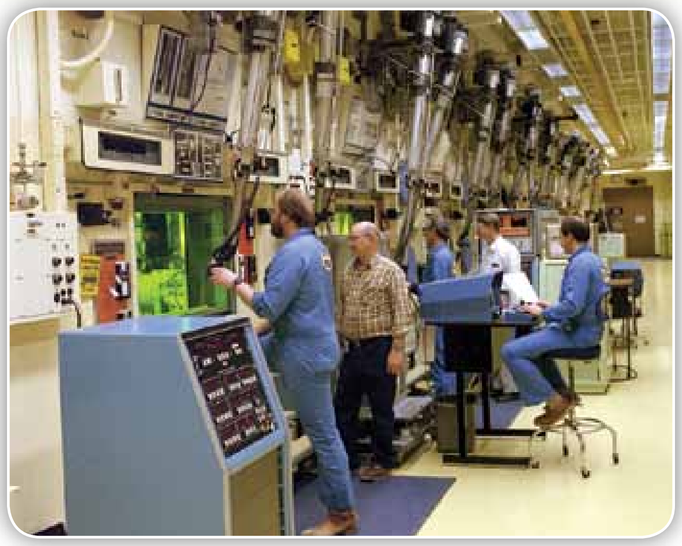
Destructive testing is the only method currently available to accurately detect the amount of hydrogen in a Zircaloy channel. In this procedure, a sample of the channel material is removed for testing—thereby destroying the channel—and shipped to a test laboratory in a shielded cask. Since the original channel is destroyed, a replacement channel must be installed for fuel bundles to be reinserted into the core. All told, this sequence of steps costs considerable time and money.

Because metals in the core become irradiated during service, the assessment must be performed in one of a relative handful of laboratories equipped with a "hot cell" for testing radioactive materials. Each test costs about $300,000–$400,000, providing strong incentive to reduce the costs of hydrogen level assessment in these channels and other nuclear fuel components.

Looking for a Nondestructive Alternative

For decades, EPRI and others have sought a nondestructive, *in situ* method of assessing hydrogen levels in channels and other zirconium alloy nuclear fuel components. Some proprietary methods have been researched but have not been widely demonstrated or made available to the entire industry. Many researchers have tried to quantify hydrogen levels by measuring impedance changes using high-frequency (MHz-level) eddy currents. This method has proved highly sensitive to the temperature of the channels and surrounding water and to irradiation effects, undermining the reliability of the results.

An April 2009 EPRI report (1018541) documented preliminary results showing that electronic property analyses using thermoelectric power and low-frequency impedance measurements can successfully measure hydrogen content in Zircaloy-4. In light of this development, EPRI is examining the use of swept-frequency methods to cover a wider range of eddy-current frequencies—from kHz to MHz—to quantify hydrogen levels without an adverse temperature effect on results.



Testing of Zircaloy channels for hydrogen absorption must currently be carried out in a heavily shielded hot cell facility at great expense.

The goal of this current laboratory research is to develop an *in situ* hydrogen monitor for zirconium alloys commonly used in fuel rods and channels. Zircaloy-4—one of the two predominant zirconium alloys in use—typically is used as fuel cladding in pressurized water reactors and Canadian deuterium/uranium reactors. Zircaloy-2 (a common BWR channel and fuel rod cladding material) and other advanced zirconium alloys also are being tested.

The Research Plan

EPRI research continues on a range of fuel issues related to hydrogen effects:

- Investigate the effects of hydride formation in different zirconium alloys;
- Develop standards and nondestructive characterization techniques based on proven sensor technologies;
- Develop a nondestructive hydrogen evaluation system for eventual demonstrations in hot cells and spent fuel pools; and
- Prepare an in-service inspection procedure and manual for the developed nondestructive evaluation system.

EPRI expects pilot demonstrations at various component-inspection vendors' facilities by the end of 2010. Utility pilot demonstrations will follow if the technology proves feasible.

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Assessing the Reliability of Digital Meters

Electricity customers are accustomed to the rotating disk and numbered dials of traditional electromechanical meters, but many U.S. utilities are upgrading to solid-state electronic meters—often referred to as smart meters.

Manufacturers and utilities use various tests and equipment to verify that these meters meet new and stringent requirements from the American National Standards Institute (ANSI). Typically, each meter is calibrated and verified during manufacturing, and prior to installation utilities often test the accuracy either of each meter or of random samples. States generally have established requirements on how utilities are to check for accuracy.

Nevertheless, some problems and unit failures are inevitable, and solid-state meters have been met with mistrust in a number of early deployments. Most significant are complaints that the meters are inaccurate, resulting in higher electricity bills. EPRI has conducted field tests and performance assessments of solid-state meters (1017833) and has prepared a white paper to help utilities understand and communicate lessons learned from electronic meter replacement programs (1020908).

Accuracy—Real and Perceived

As with most products, meters tend to fail very early or very late in their service lives, with a low, stable failure rate over most of their years of service. The majority of solid-state meters entering service today are elements of advanced metering systems that are being mass-deployed. With an entire meter population being installed at once, failure rates are likely to increase sharply, but not unexpectedly, in the first year or two. If meters develop calibration problems such as high registration after they are put into service, an exaggerated percentage of the customer population could experience higher bills during a new deployment.

Also, software problems or sensitivities in the electronic circuitry can cause accuracy glitches. Such errors, however rare, may be difficult to detect before field deployment and can complicate diagnosing problems for solid-state meters.

The transition from old to new devices also presents bookkeeping challenges. When a meter is replaced, a closing read from the old meter must be made, then combined with consumption measured by the new meter for that billing period. Although replacement is generally automated to minimize human mistakes, this "data splicing" adds opportunity for error.

In some cases, the problem lies with inaccuracy of the old meter. The most common "failure" mode for electromechanical meters is reduced registration. Anything that increases drag on the meter's rotating disk—worn gears, corrosion, moisture, dust, or insects—can cause it to run slow, resulting in reduced charges. If the meter slows gradually over many years, the customer is unlikely to notice and may become accustomed to lower electricity bills. When such meters are replaced, the sudden correction to full accounting can raise doubts about the new meter. EPRI research shows that about 0.3% of old meters may be underbilling by 10%–20% at the time of their replacement. In a service area of a million meters, this would amount to 3,000 residences.

Watching Time of Use

Installation of new meters may enable new rate structures, such as time-of-use or critical peak pricing. These make the grid more efficient by giving consumers incentive to use less energy during times of peak consumption and to use more when energy is readily available.

While new rate structures may benefit customers on average, individual results depend on the degree to which the consumer heeds the high and low price signals. Customers who select time-based rate plans and do not modify their behavior accordingly can incur higher bills, even though lower bills are possible. Because a new rate plan may go into effect at about the same time as a meter replacement, homeowners may mistakenly associate increased bills with metering errors.

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EPRI Testing, AEP Field Application Validate Reliable, Cost-Effective Weld Repair Technique

Nuclear power plants typically contain thousands of socket welds to seal joints in small-diameter piping systems. Plant operators have become concerned in recent years over the increased rate of weld failures due to high-cycle vibration fatigue. Dealing with such failures can be expensive and time-consuming. Standard repairs require that the leak be isolated, the problem joint cut out and replaced, and in some cases the entire pipe section changed out. Outages associated with fatigue failures have resulted in shutdowns as long as seven days, with revenue losses exceeding $300,000 per day.

Faced with a cracked and leaking socket-welded joint in its D.C. Cook Unit 1 pressurized water reactor, American Electric Power (AEP) successfully applied a faster, more economical repair supported by EPRI testing and analysis. EPRI's work and this first-of-its-kind repair have cleared the way for U.S. Nuclear Regulatory Commission (NRC) acceptance of the procedure for future applications.

Nuclear power plants have thousands of socket welds that are susceptible to fatigue failures.

A More Economical Alternative

D.C. Cook personnel discovered the leak during plant heat-up following a refueling outage. The crack was in the plant's reactor coolant system—an ASME (American Society of Mechanical Engineers) Class 1 socket weld in an elbow fitting to a ¾-inch pipe. Traditional repair would have required draining the reactor vessel and removing the reactor vessel head, a complicated procedure that would have added an estimated million dollars in maintenance and downtime costs. To avoid an extended shutdown, D.C. Cook asked the NRC for permission to use the EPRI-tested alternative—applying a weld overlay in accordance with ASME Code Case N-666. The NRC approved the request, and plant personnel proceeded with a successful repair.

The technique uses a structural weld reinforcement that covers the outside surface of the pipe, fitting, and original weld. First, the active leak is controlled by peening weld metal over the fatigue crack. The crack is then sealed with a weld bead over the peened area. Finally, the structural overlay weld is added, using weld metal that matches the base metal composition.

Testing and Analysis

EPRI began developing and testing the procedure in 2001 at its Welding and Repair Technology Center in Charlotte, North Carolina, with the assistance of AmerenUE and Pacific Gas and Electric Company (PG&E). To produce test samples with realistic failure modes and crack development, researchers induced vibration fatigue by mounting pipe specimens on a shake table. The resulting cracks were repaired with the overlay weld technique under various temperature and pressure conditions, and the test specimens were again subjected to high-cycle fatigue until failure, allowing a direct comparison with the original socket weld fatigue life. Tests were performed on ¾-inch and 2-inch pipes of both stainless and carbon steel, and for cracks initiated from both the toe and the root of the original weld.

Test results and corroborating finite-element analyses demonstrated that a joint repaired by the weld overlay method has fatigue strength equal or superior to that of a standard socket weld. As a result, the Board of Nuclear Codes and Standards in 2006 passed Code Case N-666, which specifies the design, fabrication, and examination requirements for the socket weld overlay repair.

EPRI's comprehensive testing and AEP's first-ever application have confirmed the effectiveness and reliability of the overlay weld technique for socket weld repair and facilitated its availability to the industry at large. Code Case N-666 is now listed in Revision 16 of Regulatory Guide 1.147 without conditions. Revision 16 is expected to be approved this year, and as a result, future applications will not require regulatory approval through a relief request.

For more information, contact Greg Frederick, gfrederi@epri.com, 704.595.2571.

Utilities Use EPRI Analyses on the Effects of Climate Policy

Anticipating the effects of climate policy is problematic for utility planners for a number of reasons. Uncertainties about the structure and provisions of emerging legislation make it difficult to predict effective responses. Impacts may be far reaching, as significant constraints on CO_2 emissions will affect investment in new generation and control technologies, generation mix, plant dispatch schedules, purchase of energy and emission allowances, and customer service and pricing policies. Because utilities differ in their finances, physical assets, and operations, no single solution will be appropriate for all. Each company will need to fashion its own response to make the best use of its existing assets and business structures.

EPRI has developed various analyses that can give utilities critical insights into the potential effects of climate policy on their strategic, long-range plans. EPRI's seminal Prism analysis, for example, looks at the potential of a portfolio of advanced technologies to manage CO_2 emissions for the industry as a whole. Other analyses focus on the development of specific technologies and capital investment strategies and on the effects of carbon prices on new generation choices, power system operation, and customer response to electricity prices.

Two utilities with different business models—Tri-State Generation and Transmission Association and Consolidated Edison Company of New York—recently used EPRI analyses to assess the potential risks of emission constraint policies and analyze potential responses.

Tri-State Builds a Roadmap

Tri-State is a wholesale power supplier—a not-for-profit company owned by 44 distribution cooperatives in Colorado, Nebraska, New Mexico, and Wyoming. The utility drew heavily on EPRI work to develop a comprehensive systemwide greenhouse gas management roadmap that identifies technology strategies and compiles its various initiatives, assessments, and studies into a single plan. In addition to the Prism analysis and a site-specific greenhouse gas emissions inventory that EPRI completed in 2007, Tri-State incorporated the many collaborative projects in which it has been involved, including work on carbon capture and sequestration, generation and transmission efficiencies, and renewable technologies.

Tri-State completed the roadmap in June 2009 and submitted it to state policymakers, its member cooperatives, and external stakeholders. The analysis concluded that Tri-State's success in meeting emission reduction goals will depend heavily on developing cost-effective energy and environmental technologies and that this effort should be a major part of the company's resource planning. Tri-State intends to continue its analyses and make the roadmap a "living document" to help plan specific steps to implement technology options.

Con Edison is the primary electricity supplier to New York City.

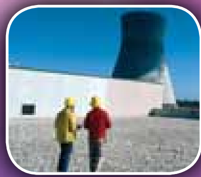
Con Edison Assesses Its Business Model

In contrast to Tri-State, Consolidated Edison is primarily an energy distribution company that owns relatively little generation capacity. As such, it will face particular challenges if the price of carbon begins to substantially affect wholesale and retail electricity prices. Con Edison needed to examine whether its existing business model would be sustainable if greenhouse gases were regulated, and it asked EPRI to adapt and apply an electricity sector market-modeling framework to analyze the effects of climate policy on all aspects of its business.

EPRI began by focusing on the region in which Con Edison purchases wholesale electricity, determining the potential impacts on costs and generation mix of CO_2 prices ranging from $10 to $80/ton. From these results, EPRI calculated how changes in wholesale electricity prices would affect Con Edison's retail prices. Finally, the assessment examined demand response to determine how customers would likely conserve power in response to higher prices. The analysis concluded that the utility's business model would remain viable even under scenarios of extreme carbon price and customer response.

The EPRI assessment will allow Con Edison to demonstrate to investment and environmental organizations that its business model, strategic planning, and ongoing commitment to environmental stewardship are solid, and the study can serve as a valuable base for reviewing the impact of future legislative proposals.

For more information, contact Tom Wilson, twilson@epri.com, 650.855.7928, or Victor Niemeyer, niemeyer@epri.com, 650.855.2262.


TVA Uses Evaluation Tools to Optimize Turbine-Generator Assets

Over its life, a steam turbine requires millions of dollars for maintenance, efficient operation, and routine repairs. As part of a cost-effective run/repair/replace strategy, operators must accurately assess the remaining life of a turbine's components and identify core weaknesses in parts likely to fail under normal operation. Tennessee Valley Authority recently used two EPRI tools to investigate such turbine issues in three of its steam power plants, enabling TVA to improve utilization of its turbine-generator assets and avoid the cost of replacement power.

Remaining Life of Rotor Disks

Cracking of low-pressure rotor disks has been a challenge for steam turbine operators for decades. Stress-corrosion cracking in a turbine's blade attachment area becomes more common as a turbine ages, due to local stresses, steam chemistry contaminants, temperature influences, operating conditions, and other factors. Cracking of the disk rim where the blades are attached can cause displacement of the blades and catastrophic failure of the entire rotor.

When the turbine manufacturer issued TVA a "duty-to-warn" letter regarding the health of its low-pressure rotor disks, TVA turned to EPRI to help assess the risk of continuing to operate a turbine at its Widow's Creek Unit 7 steam plant until replacement rotors could be procured. TVA engineers performed the analysis with LPRimLife, a computer program designed for this purpose. The code uses operating and design data, inpection results, and stress and fracture algorithms to determine a rotor disk's remaining life from both a deterministic and a probabilistic standpoint. The software also enables plant engineers to assess critical crack size and to more effectively plan maintenance and repair schedules.

Use of LPRimLife at Widow's Creek enabled TVA to more accurately estimate the rotor disks' remaining life and delay taking the turbine out of service, saving the company more than $500 million in replacement power costs.

Root Cause of Blade Failures

Blade failure represents the single greatest threat to the reliable operation of steam turbines, and given the high cost of unplanned outages and replacement power, operators can't afford to consider such a failure a random occurrence. Statistics and experience show that if the cause of a failure remains unresolved, problems are likely to recur following the initial repair. Accurate, timely diagnosis of root causes is fundamental to managing the immediate problem and building a long-term strategy to protect other units of the same design. But investigating causes of failure is a complex challenge, involving the coordination of multiple activities and specialized engineering disciplines.

TVA faced this problem when it experienced unexplained blade failures in low-pressure turbines at its Colbert Unit 5 and Johnsonville Unit 7. For assistance in formulating an effective course of action, TVA used EPRI's *Steam Turbine Failure Root Cause Analysis Guide* (1014137), a concise reference document designed to help operators plan and conduct such investigations.

The guide provides a roadmap for a typical investigation, explaining when specialists should be involved, what they should contribute, and how the evidence can be used to establish corrective action. Providing both an overview and step-by-step procedures for identifying the damage mechanisms most common to blade failures, the guide clarifies how damage mechanisms relate to the unit's operating history and how to establish whether they constitute a principal (root) cause or merely contribute to the problem. The methodology is based on experience compiled from more than 350 failure investigations.

TVA used the guide to investigate the blade problems at Colbert and Johnsonville. Analysis results assisted investigators in understanding the factors and conditions that led to the failures, and equipped TVA to avoid future failures in these turbines and in sister units with the same blades.

For more information, contact Alan Grunsky, agrunsky@epri.com, 704.595.2556.

REPORTS & SOFTWARE

Key deliverables now available

The following is a small selection of items recently published by EPRI. To view complete lists of your company-funded research reports, updates, software, training announcements, and other program deliverables, log in at www.epri.com and look under My Research Areas.

Interim Guidance on Chemical Cleaning of Supercritical Units (1017476)

This report provides comprehensive interim guidance for assessing and chemically cleaning supercritical units for both feedwater corrosion product deposits and high-temperature oxides formed *in situ* on the low-alloy ferritic tubing of supercritical steam generators. The growth dynamics of *in situ*–grown oxides are also detailed, as well as methodologies for determining the most appropriate time to chemically clean supercritical units based on *in situ*–grown oxide thickness, deposit loading, tube operating temperatures, and tubing metallurgy. Further guidance is provided for proper selection of cleaning solvents and cleaning processes for the effective and efficient removal of deposits and *in situ*–grown oxides.

Concepts to Enable Advancement of Distributed Resources (1020432)

In managing the load response of distributed resources, replacement of the command-and-control approach with an inform-and-motivate approach allows the customer and the power grid to achieve fully transparent, extensible, and scalable interoperability. The emerging smart grid system offers key elements that can provide "smartness" in end-use devices as well as in the grid itself. This white paper offers an update to traditional control-based thinking to present an approach that facilitates the independent development and integration of intelligent end-use products. The concept enables a device manufacturer to design its product or system to be qualified as a virtual end node that is able to participate in any larger smart grid system without risk of obsolescence.

Fossil Maintenance Basis Optimization: Challenges and Strategies (1020505)

The maintenance basis optimization (MBO) process seeks to identify the preventive maintenance task strategies that are most effective at minimizing risk from premature failure of components or systems. EPRI staff recently assisted several member companies in developing a corporate MBO strategy to be implemented on a fleetwide basis at fossil generating stations. This report describes the process challenges that were encountered during the implementation of the MBO process and explains the strategies taken to overcome them. The report contains a significant collection of human performance information, including techniques and practices, related to an effective preventive maintenance program.

Aging Management Program Development Guidance for Power Cable Systems in Nuclear Power Plants (1020804 and 1020805)

Concern over the reliability of low- and medium-voltage power cable systems at nuclear plants has been increasing for the past 5–10 years as it has become clear that adverse environmental or service conditions could lead to degradation of cable insulation systems over time. The Nuclear Regulatory Commission and plant managers are concerned that multiple cable circuits could fail, causing adverse safety consequences and/or plant shutdowns. These guides provide a consistent methodology for the industry to follow in developing aging management programs for low-voltage (1020804) and medium-voltage (1020805) cable circuits, including cable condition assessment and implementation of corrective actions.

Welding and Repair Technology Center: Repair Welding Handbook (1021074)

During the life of a power plant, it often becomes necessary to perform weld repairs of various materials in order to continue safe operation. EPRI has done a great deal of work in this area, helping utilities choose appropriate repair techniques according to the materials involved and the damage mechanism that makes the repair necessary. Drawing from this previous work, the welding repair handbook offers weld repair techniques and documented lessons learned for a wide variety of repair methods that have been proven effective. By compiling this information in a single resource, the handbook provides utilities with a reference that can serve as a convenient and comprehensive decision-making tool.

Engineering and Economic Evaluation of Central-Station Solar Photovoltaic Power Plants (1021320)

This report presents information gathered and analyzed by engineers and specialists on the design, materials, and recent advances in state-of-the-art solar photovoltaic components for utility-scale applications. The components of interest include the solar panels, mounting systems, inverters, and other electronic equipment required to interface with the electricity grid. An engineering and economic evaluation was performed of conceptual 10-MW central-station photovoltaic power plants for 22 combinations of technologies in four U.S. locations. The evaluation estimated annual energy capture, total capital requirements, operation and maintenance costs, and the cumulative probability distribution of the current-dollar levelized cost of electricity.

WIRED IN

Perspectives on electricity

Generations of Methane

Jesse Ausubel *is director, Program for the Human Environment, The Rockefeller University, and vice president (programs), Alfred P. Sloan Foundation. He served on EPRI's Advisory Council from 1998 to 2006 and on its Board of Directors from 2006 to 2010.*

Evolution is a series of replacements. Cars replaced horses around 1920, color TV replaced black-and-white about 1960, and digital downloads replaced CDs about 2000. In the energy system, decarbonization, proceeding for more than 200 years, has spanned the successive replacement of wood and hay by coal, then oil, and now natural gas—basically methane. A long, bumpy road sometimes obscures our capacity to see, but happily the USA and the world have crested a hill on the road of decarbonization that permits clear direction for managers, investors, regulators, politicians, and consumers.

This "hill" is the massive quantity of recently established unconventional natural gas deposits, most famously shale gas, and the technologies allowing their economical extraction. Heightening the prospect is experimental evidence that hydrocarbons may also be produced abiogenically in the high temperatures and pressures of the earth's upper mantle and then transported through deep faults to shallower regions in the crust, where they could also contribute to energy reserves. Indeed, abiogenic hydrocarbons are now documented to make significant contributions to commercial gas reservoirs in China's Songliao Basin.

As if anticipating the progress of the geologists and engineers, the capacity to generate electricity from natural gas recently surpassed coal for the first time in the USA. In 2010, natural gas will account for about 24% of USA electricity generation, up from about 9% in 1988. Coal this year will account for about 44%, down from a peak of about 56% in the retrograde year 1988. Many utilities have used natural gas confidently for peak generation but cautiously for baseload, because of worries about volatile and high gas prices. As recognition has spread of methane abundance, both in terrestrial shales and offshore, money worries lessen, and resistance to replacing coal with gas seems folly. Methane spares power generators risks and costs of sulfur, mercury, and mine collapses.

While halving coal's greenhouse gas emissions, methane still contains a worrisome carbon for each of its quartet of hydrogen atoms. Happily, zero-emission power plants, a nightmare with coal as the feedstock, become far less daunting when methane enters the plant. Development of carbon capture needs to shift from coal plants to methane plants. Impressive prototypes exist—for example, at the Kimberlina facility of Clean Energy Systems in Bakersfield, California.

Meanwhile, a deluded crowd believes in wind, as earlier crowds believed in witches and subprime mortgages. The costs of wind to the landscape, system reliability, and wallets will strand its believers and investors—and leave demand for methane to inherit.

Methane also provides the best raw material for pure hydrogen, until nuclear reactors begin to split water thermochemically at a commercial scale in another two to three decades. Steam-reforming the methane to provide the hydrogen for fuel cells creates carbon dioxide for capture and storage, just as a methane-based zero-emission power plant will. Fuel cells operating on hydrogen from methane will operate in favor of climate only when the total system efficiency is higher or the carbon dioxide is safely stored.

In any case, in the long run only hydrogen substitutes well for oil. Battery technology cannot. Basically cars will operate on hydrogen fuel cells with battery assistance to achieve a fulminating start and recover braking energy. The hydrogen tanks will probably initially be fiber-wound pressure bottles.

A further evolutionary advantage for methane is that the gas pipelines accommodating methane can also include up to about 20% hydrogen, carrying the hydrogen piggyback, so to say. Separating the two for final distribution is not difficult with membranes or absorption.

Fuel cells will matter not only for mobility. Fuel cells are also coming to the fore as standby generators because of their capacity for instant intervention, valued for systems managing information, such as phones and computers.

Broadly, researchers and practitioners need to multiply the cleanliness, reliability, and safety of an energy system relying predominantly on natural gas. Total problems must shrink even as the scale of the gas system doubles and triples in the USA and globally during the next couple of generations.

While creationists may favor coal and renewables, evolution favors methane. So should the spectrum of enterprises and stakeholders involved in the generation, transmission, and distribution of electric power.

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