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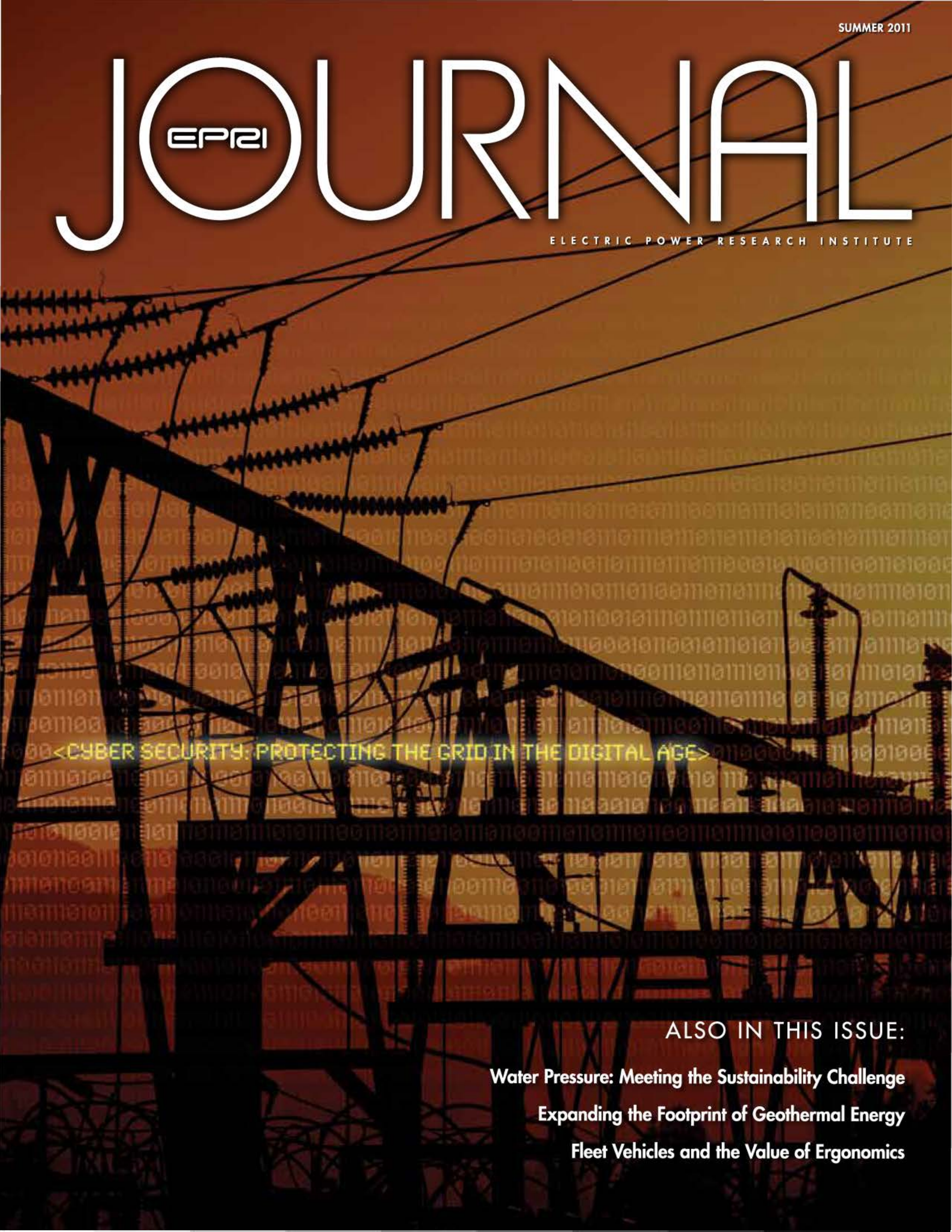

## <CYBER SECURITY: PROTECTING THE GRID IN THE DIGITAL AGE>

ALSO IN THIS ISSUE:

**Water Pressure: Meeting the Sustainability Challenge**

**Expanding the Footprint of Geothermal Energy**

**Fleet Vehicles and the Value of Ergonomics**

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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# In Search of Innovation

Here's an interesting Internet search I recommend you try. Go to your usual search engine and enter "greatest inventions." You will be rewarded with many different lists and perspectives on which inventions and innovations have contributed the most to humanity.

One list offering the "101 greatest inventions of all time" listed the abacus at No. 1 and the zipper at No. 101. Between those, I looked for electricity, and in particular I looked for those technologies that make up today's system of electricity production and delivery. Under "electric" I found only "electric razor." It seemed to me that something very important was missing.

Elsewhere on the list, I found "fire" keeping company with "fiber-optic cable" and "floppy disk" next to "flush toilet." Many of the list's top inventions use electricity, including the fax machine, refrigerator, laptop, light bulb, microchip, microwave oven, toaster, radio, television—and (of course) the Internet.

But where were Edison, Westinghouse, and Tesla?

To be fair, other lists I checked included "the use of electricity" or acknowledged Edison's important work in power generation and delivery. But I saw very little appreciation for the power plants, transformers, transmission and distribution lines, and other basic inventions and innovations that make possible life as we know it.

Today, we need innovation in the electricity sector more than ever. I would like to have seen in my brief Internet search a greater acknowledgment of the big breakthroughs in electric power generation, delivery, and the end use of electricity. We are seeing important innovations in lighting that will enable us to produce twice the lumens per watt. Although some consumers are resisting types of innovative lighting, I predict that they will soon become commonplace. They may not make the top

**“Many of the list’s top inventions use electricity, including the fax machine, refrigerator, laptop, light bulb, microchip, microwave oven, toaster, radio, television—and (of course) the Internet.**

**But where were Edison, Westinghouse, and Tesla?”**

100 list in 20 years, but their benefits will be significant.

Innovation in a variety of technologies moves us closer to grid-scale energy storage, which will fundamentally change the ways we produce and distribute electricity. Although hurdles remain, the payoffs could be huge. Yet even with big innovations in energy storage, it’s possible that in 30 years, average consumers will take little notice.

I don’t hold out much hope that innovations in basic materials will garner much attention. I’d like to think that some of the ultra-supercritical materials for power plants may someday make the same list of top inventions with fiber-optic cable, but it’s unlikely.

In the area of emissions, I did not see environmental control technologies on any of the lists, but we have markedly improved human health and environmental stewardship through these innovations, and we have a clear mandate to continue our progress.

Wind and solar technologies have come a long way because of innovative materials and power electronics, and I think that they have a reasonable chance of making some future lists. But regardless of that, we must continue to press hard to achieve every incremental gain in efficiency, reliability, and emissions in serving the grid and the consumer.

For the general public, the smart grid has emerged as a major area of innovation. We see interest in a more interactive grid, combined with worries about cyber security or radio transmission from smart meters. We see growing needs in every aspect of the new grid—from handling data proliferation to basic research into new sensors—and it’s my personal expectation that the smart, interactive grid makes someone’s top 10 innovations list within the next 20 years.

This brings me back to the search for innovation. We can’t always gauge the importance of an invention by the number of top 10 lists it makes. We can’t pick winners and losers at the front end, so we must press ahead in every aspect of the electricity sector, responding to every need, addressing every problem, and rising to every challenge. Necessity is the mother of invention—and of innovation.

At EPRI, we will continue the search for innovation in the generation, delivery, and use of electricity. Innovations usually arrive on our doorstep as problems and challenges. At EPRI, we like to address them with equal determination and objectivity, and when the work is done, we really don’t focus so much on the “ratings” as on the results.

As the theme of our 2011 Summer Seminar says, the future *will* be shaped through innovation.

Michael W. Howard
President and Chief Executive Officer

## Synchrophasors: Pushing the Envelope on Grid Stability

Ensuring grid stability has always been as much an art as a science. Operators in regional control centers monitor system stress by piecing together power flow data gathered from substations by a supervisory control and data acquisition (SCADA) system. This information is fed into a computer model, which then generates a rough estimate of the system's stability. If off-normal conditions start to eat into stability margins, the operators try to identify where the problem lies and take steps to remedy the situation by regulating voltages, rerouting power, or shedding load. Failure to do so can allow a minor localized disturbance to cascade into a regional blackout.

The "art" of stability management is in making effective decisions from an incomplete, inaccurate, or seconds-too-old data set. In the future, synchrophasors will provide a strong boost to the science side of the equation—a change that will be crucial to the successful development of the smart grid.

### Super Fast Data in Lockstep

Grid instability is signaled by changes in phase angle—the relationship between voltage and current in ac systems—and comparisons of phase angles at different substations can provide a strong indication of where the trouble lies. Unfortunately, conventional phase angle monitors sample data only every 2–4 seconds, and a lack of synchronization makes it difficult to determine which phase shifts occurred first and which were the slightly later effects of the early disturbances.

This uncertainty can be eliminated by synchrophasors—synchronized phase data taken by phasor measurement units (PMUs) installed at substations and other power delivery junctions. These units sample phase angle—as well as power flow, voltage, and frequency—30 times a second, synchronizing the data across the entire system via GPS time stamps. Such accuracy and coordination will not only clarify the sequence of events in outage postmortems, but will also open up the possibility for real-time stability analysis, increased situational awareness for control operators, and eventually, automated corrective actions.

In the near term, PMU data will allow operators to rely less on complicated stability models and calculated estimates of the state of the power system. As a result, they can safely reduce operating margins, making grid operation more efficient.

As EPRI senior vice president Arshad Mansoor observed, "The difference between conventional monitoring data and synchrophasors is like that between X-rays and MRIs: with synchrophasors you get an extremely detailed, real-time view of grid dynamics as they occur, rather than a snapshot that must be developed and studied in retrospect. The new technology will make a tremendous difference in managing tomorrow's electricity grid economically and with high reliability."

### A Must-Have for Renewables

Having a comprehensive, integrated view of grid dynamics will be especially important as the nation's power system moves from the current hub-and-spoke model to the more matrixed form of the smart grid, with distributed generation and storage units, more renewable power, and substantial new customer loads, such as electric car chargers.

Photovoltaic (PV) and wind generation pose particular problems because of the variability and uncertainty of their intermittent dispatch. And because of the specialized power-electronic controls currently used in their grid interface, many wind and PV generators do not have inherent inertial response, which can impact the dynamic performance of the power system in responding to disturbances. As a result, when large blocks of these new technologies replace conventional generation, the frequency response and modal behavior of the power system will change, requiring more of the close, real-time scrutiny that synchrophasors provide.

In this and many other ways, PMU measurements offer a capability that will be invaluable in the future—coordinated wide-area control that allows local protection devices to be activated in a centralized manner, in some cases automatically and without operator intervention. EPRI is currently forming a team of industry experts to accelerate the development and deployment of such advanced control room applications.

*For more information, contact Paul Myrda, pmyrda@epri.com, 708.479.5543.*





## EPRI Moves to Field Demonstration for the Solid-State Distribution Transformer

Distribution transformers are ubiquitous in the distribution system. Based on a technology developed over 100 years ago, they are extremely reliable in performing their primary function—reducing the electricity supply voltage to a level that can be used safely by customers. EPRI has developed a prototype for an "intelligent universal transformer" (IUT) that applies solid-state technology for voltage conversion and provides additional functionality expected to offer distinct advantages in a more complex delivery system, benefitting consumers and utilities.

Solid-state technology can improve consumer power quality, provide continuous voltage regulation and reactive power compensation, and facilitate distribution automation. Combined with communications technology, the solid-state transformer becomes a smart node within the smart grid that can help detect metering problems, track asset loading, and serve as a data source for real-time condition monitoring and load modeling. It will also help integrate distributed resources such as energy storage, photovoltaics, and plug-in electric vehicles.

### Clear Advantages

The IUT converts alternating current (ac) power at various distribution-level voltages to direct current (dc) and ac power ready for residential and commercial use. Unlike conventional copper-and-iron transformers, its solid-state high-frequency switching and fast-computing digital control technologies allow it to control and shape its output characteristics.

It can provide continuous, accurate control of the voltage levels at every customer location. Because it can regulate the customer-side voltage independently of the distribution voltage through active filtering and line voltage regulation, the IUT will improve ride-through capability for voltage sags and mitigate other power quality phenomena. When combined with energy storage that is connected to the dc tab, it can act as an uninterruptible power supply. Customer voltage control is also becoming increasingly important for utilities as an energy conservation and demand management technique.

For future smart grid applications, the IUT can be used to connect distributed renewable generation to the distribution system without the significant distribution voltage variations allowed by conventional transformers. Combining the power electronics required for electric vehicle (EV) charging with the distribution transformer is another promising application.

Unlike conventional units, the IUT retains its efficiency regardless of load—a characteristic that becomes more important with the addition of local generation, which reduces the overall load on the transformer. Other beneficial characteristics include:

- The IUT has no liquid dielectrics, eliminating spill risks.
- The solid-state transformer has the capability to convert a single-phase input to a three-phase output, which can be important in some rural areas.
- Solid-state transformers can be built from modules combined to achieve various transformer ratings for kilvolt-amperes (kVA) as well as voltage.

But some challenges remain, including matching the life expectancy and cost of traditional transformers.

*This 2.4-kV IUT prototype was tested in EPRI laboratories in 2011.*

### Prototype Development

EPRI is leading the development and demonstration of a fully integrated, production-grade 4-kV- and 15-kV-class solid-state transformer for integrating energy storage technologies and EV fast charging. The development team includes utilities, power electronics experts, and a transformer manufacturer to provide guidance on taking the technologies from concept to production.

EPRI has been working on the IUT's solid-state technology for a number of years and has completed proof of concept and various prototype designs that are ready to be included in field demonstrations and early deployment, leading to commercialization of the technology.

EPRI successfully demonstrated a working IUT in December 2010 at its laboratory in Knoxville, Tennessee, and a field prototype 2.4-kV, 25-kVA model with enclosure, packaging, and high- and low-voltage bushings was deployed earlier this year for evaluation. A fully functional EV fast-charger system was evaluated, along with a variety of communication and performance features. A number of field demonstration projects at multiple host sites are scheduled through 2012 to finalize IUT design, specifications, and manufacturing requirements.

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CYBER SECURITY:
PROTECTING THE
GRID IN THE
DIGITAL AGE

## The Story in Brief

Electric utilities are as vulnerable to cyber attacks as other businesses, but the critical importance of the nation's power infrastructure and the move to a highly interconnected smart grid make cyber security of particular concern for the power industry.

Cyber security isn't just a headache for information technology experts in a small part of a utility's operation anymore. Concerns about the security of the nation's critical infrastructure shot up after the September 11 terrorist attacks and raised awareness that many utility systems needed to increase their security controls.

Likewise, connectivity is not just a buzzword in the world of iPad and Facebook. It also describes a massive undertaking by utilities in the smart grid universe, where new technologies are digitizing the control of power generation and delivery and potentially linking this control to home networks of appliances. And just as all parts of the grid management are increasingly connected and increasingly digital, they need to address potential cyber security attacks.

Worries about cyber security for the grid have only deepened with the deployment of smart meters and other equipment that brings onto the grid a much wider array of technology, software, communications, and integration to make possible communication and control for utilities to manage power supply and demand. Companies are equally concerned about how to address cyber security for older legacy systems and equipment.

All this combines for a big challenge: how do you armor these emerging networks and their millions of components and systems to detect and mitigate security threats?

### A Primal Worry—Loss of Control

The emergence of Stuxnet, a very advanced program that can disrupt control systems while hiding its presence, highlighted the need for guidelines and tools to prevent service interruption of critical systems. Hackers have clearly demonstrated that Stuxnet can be used to reprogram equipment functions, with the best-known attack crippling a uranium enrichment operation in Iran.

"People used to think nobody would go after a control system, and Stuxnet woke up a lot of people," said Annabelle Lee, an EPRI technical executive for industry cyber security. "The policy of the United States is to support the modernization of electricity transmission and distribution, which means an increase in the use of digital controls. When it's digital, you have to worry about cyber security."

The control system isn't the only vulnerable spot in a utility's operation. Cyber security attacks can be launched against the electricity infrastructure at many points along the path, from power generation to substations to the final destination of the distribution—the homes. A weak link in the chain could invite security breaches that might impact the entire network.

"It's like having all of your house locked except for one window," said Neil Greenfield, senior cyber security architect and the cyber security technical team lead for gridSmart at American Electric Power. "If you forget to lock that window, then you open the whole house up to risks."

### From Legacy Systems to Smart New Technology

Keeping intruders away isn't the only goal for utilities. Power plant operators must demonstrate their compliance with the North American Electric Reliability Corporation's physical and cyber security standards for generation and transmission, said Galen Rasche, an EPRI technical executive for industry cyber security.

Rasche and Lee joined EPRI this past year to spearhead cyber security research and development efforts across all segments of the utility industry. They launched the Cyber Security and Privacy Initiative earlier this year to identify key challenges and technology gaps and to develop guidance and tools to help utilities draft their own cyber security strategies and mitigate risks. The work will address challenges for managing legacy systems and incorporating smart grid technologies. Through collaborations with industry and government groups, EPRI plans to start a permanent research and development program for cyber security in 2012.

"We will be developing testing methodologies that utilities can use to look for vulnerabilities or to make sure equipment is configured properly before it is put in the field," Rasche said.

### From Consumers to Power—Providing for a Common Defense

In many people's minds, *cyber security* refers to the protection of information technology systems, such as utility data collection and billing operations. The rollout of smart meters and communication gateways is modernizing these portions of a utility's overall operation. Smart meters are also enabling utilities to detect service interruptions and troubleshoot other problems much more quickly than before. As the role of communications and information technology in managing supply and demand is evolving, so are the cyber security risks.

Smart meters contain communication chips for sending and receiving data. This bi-directional flow of communication and control increases the complexity of the

***The policy of the United States is to support the modernization of electricity transmission and distribution, which means an increase in the use of digital controls. When it's digital, you have to worry about cyber security.***

grid and could introduce vulnerabilities and increase the exposure to potential attackers and unintentional errors. Each smart meter is, in effect, an entry point for potential adversaries to exploit and must be protected.

Meanwhile, as smart meters and other communication equipment are developed, technology companies have embraced different communications protocols and jockeyed to set industry standards.

Several communications protocols, such as WiMAX and cellular, have emerged as popular choices, largely because equipment vendors are promoting hardware with open standards. Using standard protocols saves money, enables diverse pieces of equipment to "talk" to each other, and makes scale-up easier. This increased level of interconnectivity opens the door for security incidents, however, because it can introduce common vulnerabilities.

But the benefits of using open standards outweigh the disadvantages. Lee points out that a primary focus of information technology experts is protecting the confidentiality and integrity of the data. In this context, using standard protocols does have advantages. Widely used protocols invite more aggressive security monitoring and improvement by hardware and software vendors, which have a deep financial interest in keeping their broad customer base happy. A breach in one utility's network can lead to security fixes that immunize not only its own system but also other utilities' systems that use the same communications standards.

Using open communications technologies is crucial for creating a smarter grid, which is supposed to facilitate expedient communication about energy consumption, equipment failures, and power supply and demand management among various stakeholders, including utilities, grid operators, and consumers. If utility networks in the same regional grid speak different languages, not only will they have trouble communicating with each other, but they will also likely find it difficult to work together on building up a strong defense against cyber attacks.

"As we move forward with modernizing the grid, we want these systems to interconnect. If operators of a wind farm in Nevada want to transmit electricity to Southern California, the only way they can do that is by using a standard communications protocol," Lee said.

The push for smart grid deployment also leads to growing interconnectivity in the power generation and transmission systems. That could make key equipment such as supervisory control and data acquisition (SCADA) systems more vulnerable.

Crafting and deploying a cyber security strategy at a power plant will have to align with priorities that are different from those for information technology networks. Lee noted that for control systems, availability and integrity are the most important objectives, not confidentiality. In fact, the need to keep the power plant running with minimal interruptions often makes it difficult for utilities to update security measures.

## EPRI Launches Cyber Security Initiative

EPRI's cyber security initiative will address security challenges associated with both legacy systems and deployment of new technology, such as the smart grid. It is important that cyber security specifications be built into the smart grid and next-generation equipment and systems as they are developed, rather than added on after the fact. Legacy systems are largely analog technologies that were not designed with good—if any—security measures in place. Many of these legacy systems do not have a strong defense in place because they were built at a time when securing them against intrusion was not a priority. Large components—generators and transformers, in particular—are meant to run for several decades and are operated largely with proprietary communications protocols. Using proprietary protocols helps to shield the equipment from cyber attacks, because hackers cannot easily find the necessary

## Uncle Sam Brings Guidance and Support for Cyber Security

The U.S. Department of Homeland Security has developed guidelines for protecting critical infrastructures, including the energy sector. In addition, the National Institute of Standards and Technology last September issued Interagency Report 7628, Guidelines for Smart Grid Cyber Security.

In 2009, the U.S. Department of Energy announced the largest-ever single investment for electricity grid modernization by awarding grants totaling $3.4 billion to 100 smart grid projects. Many of the projects involved installing smart meters and building out communication networks for power transmission, distribution, and other electricity grid monitoring and control systems. Among the funding criteria were some that Lee and others helped DOE develop: requirements for cyber security. The importance that DOE places on this issue is reflected in the fact that it rejected one proposal that was good in every category except cyber security.

codes to create a virus and install it on the legacy equipment. The smart grid buildout will gradually connect these legacy systems to newer digital equipment that runs on open communications standards. These interconnections will expose legacy systems to cyber security threats. As a result, utilities need a road map to incorporate effective cyber security practices as they gradually upgrade various segments of their networks.

"Protecting legacy systems is a big issue for our members," Rasche said. "These systems typically don't have the computational capabilities or the bandwidth to support security updates."

Understanding the sources of potential threats is critical. Cyber incidents will not always be malicious or come from outside sources, Rasche said. Security breaches could result from employees who lack the training to handle sensitive data or who accidentally key in wrong commands. Disgruntled employees, because they may have ready access to proprietary information and control systems, pose a more serious threat than do hackers from the outside. One way to prevent internal missteps is to clearly delineate authentication procedures. And utilities must have processes in place to respond to security breaches that result not just from human actions but also from equipment failures or natural disasters.

"Once systems are interconnected, you could potentially have a failure that would impact more than a regional grid," Lee said. "The northeast blackout of 2003 is a good example."

EPRI's cyber security initiative will help assess security needs and risks and provide incident analyses and action plans for procuring and deploying solutions. The new set of tools will also allow utilities to quickly respond to cyber security threats. EPRI plans to provide a framework for installing an intrusion detection system for advanced metering infrastructure (AMI) networks. The framework will provide guidance on, among other things, where to place sensors on a communication network and how to set standards for alerts and alarms from different vendors. EPRI will also offer tools and techniques for testing the defense of a network that incorporates gadgets and smart appliances in homes. Nuclear power plant operators face unique safety challenges. EPRI is working on a system procurement guideline this year that will include cyber security requirements.

The new EPRI tools will help utilities tackle the daunting challenge of formulating a cyber security strategy, something that many utilities have not considered to be a priority. Changing this mind-set will be a crucial starting point. Another first step in crafting a cyber security strategy will be to take stock of what protective measures are already in place and what existing cyber security requirements and best practices from federal regulators and industry groups should be used. For example, the Advanced Security Acceleration Project for the Smart Grid (ASAP-SG), cosponsored by the Department of Energy, has been developing security profiles for various smart grid applications. The EPRI initiative is also supporting this effort and will build on these profiles.

"Security is like insurance. There is no return on your investment until something happens," Greenfield said. "But if you don't take into account the risks, then you might run into issues in the future."

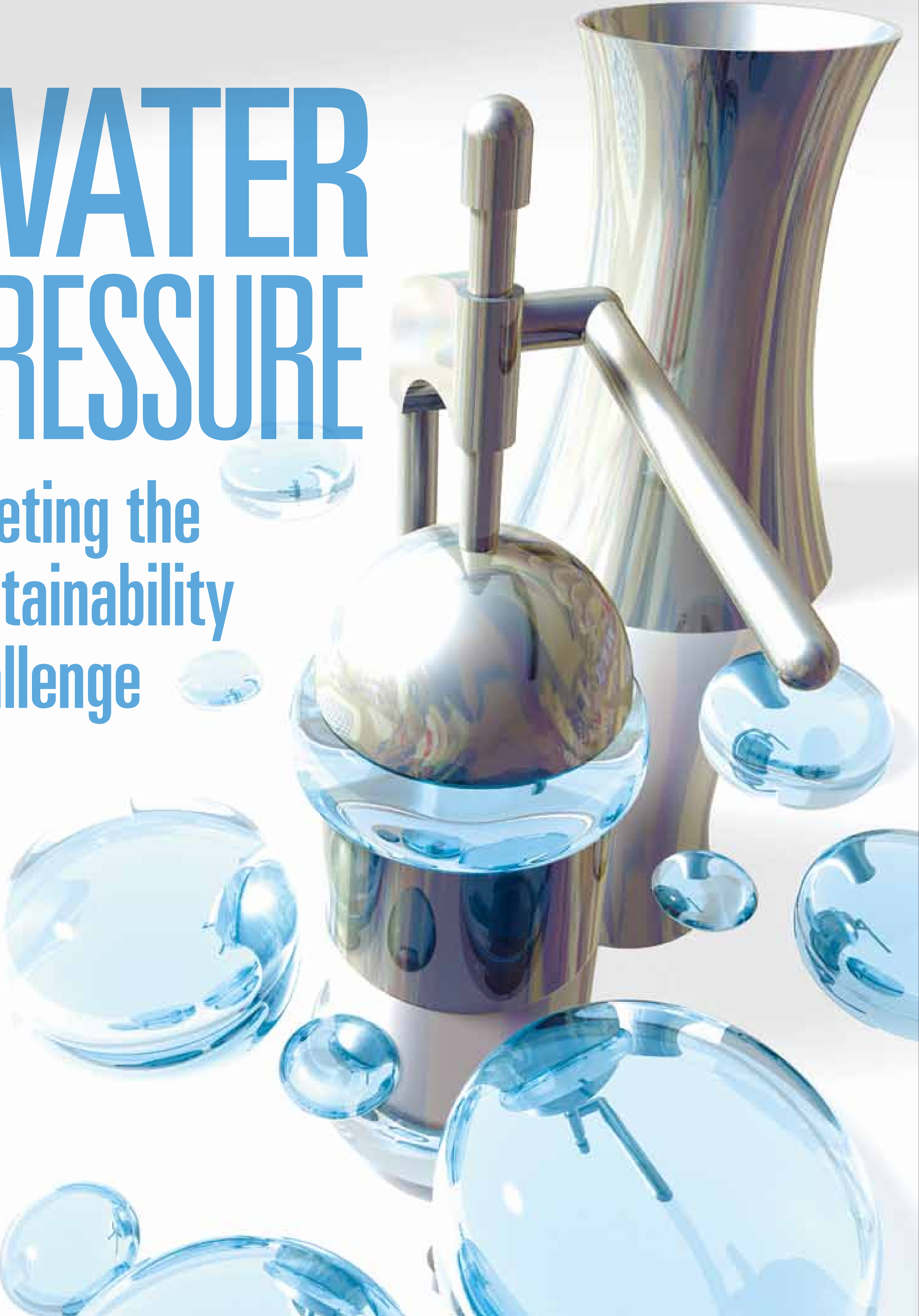
*This article was written by Ucilia Wang. Background information was provided by Galen Rasche, grasche@epri.com, 650.855.8779, and Annabelle Lee, alee@epri.com, 202.293.6345.*

**Galen Rasche,** a technical executive in the R&D Group's Senior VP Office, coordinates cyber security research across the Power Delivery and Utilization, Generation, and Nuclear sectors. Before joining EPRI in 2010, he worked at the Southwest Research Institute and at the Center for the Commercialization of Electric Technology. Rasche received B.S.E.E. and M.B.A. degrees from the University of Kentucky and an M.S. in electrical engineering from the University of Illinois at Urbana-Champaign.

**Annabelle Lee** is a technical executive in the Power Delivery and Utilization Sector. Before joining EPRI earlier this year, she spent 15 years as a senior cyber security strategist at the National Institute of Standards and Technology (NIST), where she established and led the Smart Grid Cyber Security Working Group. While at NIST, she was detailed to the Department of Homeland Security for four years to direct programs in its National Cyber Security Division. Lee holds a B.A. in psychology from Stanford University and an M.A. in educational psychology from Michigan State University.

# WATER PRESSURE

## Meeting the Sustainability Challenge



Economic development and technological progress depend on a complex, interdependent relationship between energy and water. Society's unprecedented dependence on abundant, reliable clean water supplies and economical energy faces equally unprecedented challenges. Population growth, regional population shifts, climate variation, stricter regulations, and other factors are putting pressure on all sectors of society to use less water and to develop long-term solutions to create a sustainable water future.

## THE STORY IN BRIEF

Competing demands for freshwater resources will compel power producers to use water more efficiently and prepare for a water-constrained future. R&D efforts are investigating how to do more with less, how to diversify water sources, and how to bring all stakeholders together to make forward-looking, informed decisions that recognize the growing demands for this finite resource.

### High Industry Priority

Electric power generation relies on large quantities of water. Fossil, nuclear, biomass, and solar-thermal power plants all require water for cooling and other plant processes, and hydroelectric plants need a steady supply of water to keep their turbines turning. The availability of water is also critical in siting new power plants and for long-term plant operations. For utility service areas, water availability affects economic development, industries, and communities. Prospects for future constraints on water supplies are becoming a major concern to plant operators and generation planners.

A recent EPRI survey gauged the concern among 89 electric utility executives. Results showed that water issues are a concern to all the executives interviewed, with 66% reporting "great" or "very great" concern about water. The survey found that the executives perceived the water-related challenges as "diverse and expected to grow" over the next decade because of stricter regulations and public attention to water scarcity.

"The power industry has a strong vested interest in water sustainability," said Robert Goldstein, EPRI senior technical executive for water and ecosystems. "Our water and energy infrastructures were designed to meet the needs of a future that has already come and gone. Business-as-usual practices that worked in the past won't work in the future unfolding before us. Achieving sustainability will require integrated approaches that involve all stakeholders and use innovative technologies that consume less water and use it more efficiently."

### Preparing for a New Future

For most of the twentieth century, power plants were built close to rivers, estuaries, oceans, or lakes to access a ready supply of cooling water. Many of these plants used a once-through cooling cycle that withdrew water to condense exhaust steam from the turbine and then returned the water, now warmer, to its source. Once-through cooling is still used by about 40% of thermoelectric power plants—a big reason that power generation accounts for some 40% of U.S. freshwater withdrawals. However, thermoelectric plants account for just 3.3% of freshwater *consumption*, much of which is a consequence of the heated effluent from once-through systems increasing the evaporation from the receiving water body. Still, those water withdrawals are as essential as fuel to the operation of once-through plants. The ability to meet withdrawal needs may become severe as agriculture, industry, and municipal users increasingly compete for limited water supplies. Newer plants employ wet recirculating cooling systems, which dissipate heat by directing heated water from the condenser through an evaporative cooling tower and then recycling the cooled water back to the condenser. Recirculating wet cooling is still water intensive. A typical 500-megawatt coal-fired power plant with wet cooling consumes about 5000–6000 gallons (18,927–22,712 liters) of water per minute through evaporation and blowdown. Although a wet recirculating cooling system withdraws only about 2% as much water as a once-through system, it consumes from two to five times as much, depending on site-specific conditions.

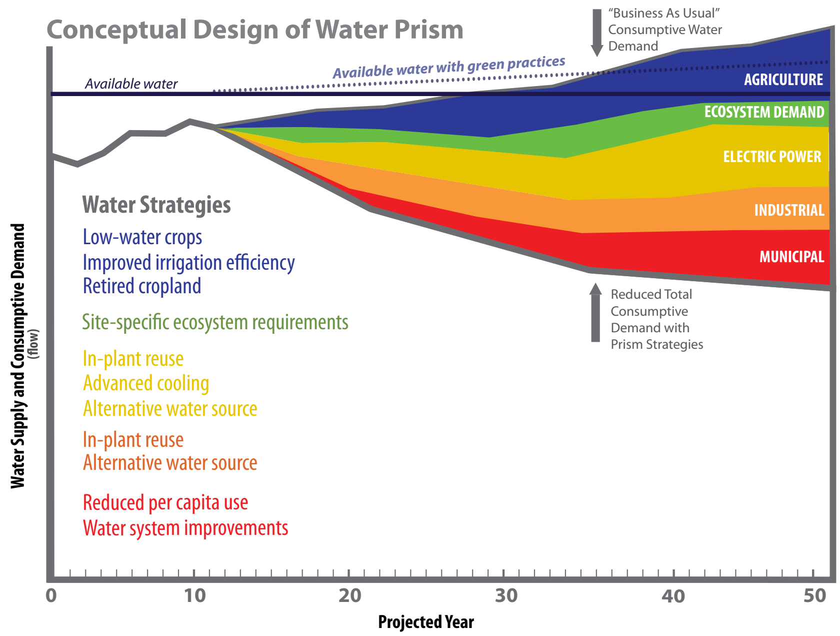
As competition for water intensifies and power plant water use attracts increasing public and regulatory scrutiny, power producers are considering advanced cooling technologies that reduce freshwater withdrawals and consumption. Dry (air) cooling, for example, is now used at some new plants. By using an air-cooled condenser to dissipate heat from steam leaving the turbine, dry cooling slashes water consumption and increases flexibility in plant siting, but it has higher capital and operating costs and requires more space than wet cooling. The dollar costs of dry cooling may, under certain circumstances, be offset by the reduction in dollar costs for water. Dry cooling also decreases plant energy production efficiency, which increases fuel consumption and emissions compared with plants that use conventional wet cooling. The efficiency penalty increases with ambient air temperature, and on extremely hot days, efficiency may plummet as much as 20%. Hybrid cooling systems employ the combination of a wet cooling tower with an air-cooled condenser. The wet cooling operates during hot spells to offset the efficiency penalty of the air-cooled system.

EPRI is leading a collaborative effort with utilities and water industry experts to develop, test, and deploy efficient advanced cooling technologies. The project will also investigate and provide information on economics, performance optimization, risk management, improved decision making, and public acceptance. Current R&D activities include the following:

- Assess meteorological impacts on air-cooled condensers, and develop design changes to mitigate efficiency losses due to high winds and unit trips caused by gusty winds.
- Evaluate the performance and cost of indirect dry cooling systems using dry cooling towers in nuclear units with secondary cooling loops.
- Investigate new hybrid tower designs promising better performance and/or lower costs, and develop guidelines for hybrid system specification, design, construction, and operation.
- Explore water recovery options that capture water from cooling tower plumes and stack gases.

## Seeking Solutions at the Source

EPRI is investigating the potential for nontraditional (sometimes referred to as *degraded*) water supplies to take the place of freshwater sources. These include storm water, agricultural runoff, industrial and municipal wastewater, and water produced as a byproduct of oil, gas, and coal exploration. Several constraints are associated with such sources, including the volume and timing of available resources relative to demand, the water quality needed for use and discharge, and the location of the source relative to the point of use. As with the trade-offs associated with alternative cooling technologies, such constraints require an integrated evaluation that includes geographic, climatic, and plant-specific considerations; applicable regulations; environmental impacts; and interactions with other stakeholders.




*Water Prism will offer improved understanding of water availability, constraints, and management strategies for a broad range of stakeholders and policymakers.*

## Water Prism: Integrated Perspective

For more than a decade, EPRI has developed new approaches and tools to examine future water availability and to evaluate how different water management strategies can meet the needs of electric utilities and other stakeholders. Water availability issues and water management challenges differ greatly from watershed to watershed and involve a complex web of environmental, regulatory, reputational, and financial risks.

Building on the experience of using water budgets and dynamic watershed models, EPRI is developing a tool to support water management decisions. Called Water Prism and inspired by EPRI's $CO_2$ Prism methodology for examining options for curbing greenhouse gas emissions, it can be used for evaluating water-saving strategies across all economic or industrial sectors within a given watershed or region. Water Prism will have a richly visual output to support clear communication and understanding of water availability, constraints, and management options for stakeholders and policymakers.

"With this essential, shared, and finite resource, every sector of the economy and society has a stake in sustainable water resource management," said Goldstein. "Water management should be addressed not user by user, but in a holistic manner that considers all water uses across sectors, as well as environmental needs. Water Prism will do this. It provides visual road maps to navigate potential paths for accommodating future demands within the limits of available water and encourages collaborative water planning."

Water Prism calculates water balance and allocation among users and incorporates projected demands and possible water-saving approaches. Users can construct scenarios to explore how multiple options—reuse, advanced cooling technologies, increased irrigation efficiency, and more—affect water supply and demand. They can use the results to evaluate potential benefits of water-saving strategies and to support decisions regarding power plant siting and retrofits. Water Prism visualizes possible future reductions in demand for each sector in a spectrum of discrete color bands.

EPRI is applying Water Prism to the Muskingum River watershed in Ohio in a case study to explore alternative ways that water-saving technologies employed across multiple sectors could help meet sustainable water goals under projected future conditions. The 8000-square-mile (20,000 square-kilometers) watershed encompasses croplands, forests, industries, municipalities, and a mix of coal- and natural gas–fired power plants employing once-through and recirculating cooling. Water Prism is modeling how projected increases in water demand by electric power facilities and other sectors might be reduced over a 50-year time horizon as each sector implements water-saving measures.

"These measures might include efficient irrigation practices, low-water landscaping, gray-water recycling, water-efficient appliances, advanced cooling technologies, nontraditional water sources, and other approaches," said Goldstein. "Implemented in an integrated strategy that considers the needs of all sectors and the environment, these approaches over time can bring water use into balance with supply."

## Wanted: Innovative Technologies

EPRI's Technology Innovation program has initiated long-term research to expand water conservation options for new and existing generation. For example, hybrid cooling for plume abatement and water conservation is likely to be an option considered by new nuclear plants. Advances in hybrid cooling technologies are needed to reduce capital costs and operational challenges associated with balancing wet and dry cooling modes.

As pressures to save water intensify, EPRI is looking beyond the advanced cooling technologies currently in use or under consideration and is seeking fresh ideas from outside the power industry. The electronics, aerospace, and automobile industries have performed significant research and development in cooling technologies that might be applied to the power industry.

EPRI has issued a solicitation to identify high-potential water conservation concepts and has received more than 70 proposals related to cycle efficiency improvement, water resource expansion, and advanced cooling. Technologies under consideration include the following:

- Advanced cooling, including green chillers, thermosiphons, dew point cooling, and nanotechnology
- Cycle efficiency improvement utilizing advanced and integrated power cycles, including combined-cycle concepts and waste heat utilization
- Water resource expansion, via advancements in desalination and water treatment technologies, to allow for the use of degraded and nontraditional water sources for wet cooling

If successful, the program could lead to collaboration among power producers and suppliers for the development, demonstration, and deployment of technologies capable of reducing power plant freshwater use by 50% or more. By enabling continued cost-effective operation of existing thermoelectric plants and facilitating the siting of new capacity, individual innovations may have multibillion-dollar impacts across the industry while helping to balance competing needs for water resource and aquatic ecosystem protection.

"Water-saving options are emerging for all sectors and for all types of thermoelectric generation," said Goldstein. "There is no single optimal approach for conserving water, but rather an expanding toolbox of potential solutions that, along with analytical tools such as Water Prism, present opportunities to build bridges among water users to support collaborative and innovative strategies to ensure a sustainable water future."

*This article was written by David Boutacoff. Background information was provided by Robert Goldstein, rogoldst@epri.com, 650.855.2154; Kent Zammit, kezammit@epri.com, 805.481.7349; Sean Bushart, sbushart@epri.com, 650.855.8752; and Jessica Shi, jshi@epri.com, 650.855.8516.*

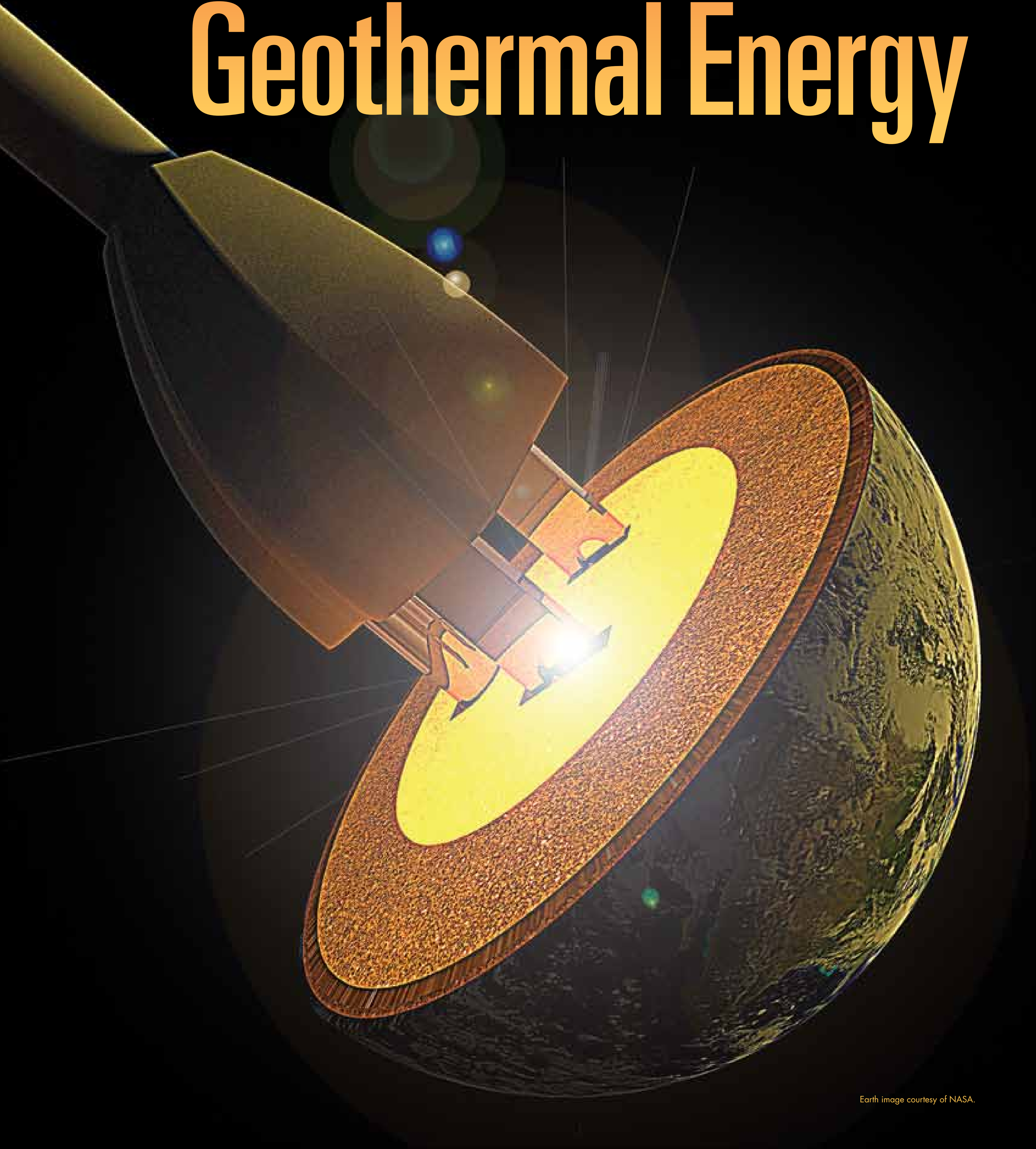
**Robert Goldstein** is a senior technical executive for EPRI's water and ecosystems research. His current activities include strategic planning for the Water and Ecosystems area and research management in the Fish Protection and the Watershed and Water Resource Strategic Issues programs. Before joining EPRI in 1975, he was a systems ecologist with the Oak Ridge National Laboratory. In addition to a B.A. from Queens College, he holds a B.S. in engineering and M.S. and Eng.Sc.D. degrees in nuclear science and engineering from Columbia University.

**Kent Zammit,** a senior program manager in the Environment Sector, has worked in a variety of areas in nearly 20 years at EPRI, including advanced cooling, fish protection, biofouling and corrosion control, selective catalytic reduction for NOx control, client relations, and technology transfer. Before joining EPRI in 1992, he worked at the Los Angeles Department of Water and Power for 12 years. Zammit received a B.S. in mechanical engineering from Louisiana State University.

**Sean Bushart** is program manager for the Low-Level Waste, Chemistry, and Radiation Protection area of the Nuclear Sector. His current activities focus on water quality improvement, waste minimization, environmental protection, and radiation worker safety. Prior to joining EPRI in 1999, Bushart worked as a laboratory director at CytoCulture Environmental Biotechnology. He holds a B.S. in biology and a Ph.D. in biology with specialization in contaminant degradation from Rensselaer Polytechnic Institute.

**Jessica Shi** is a senior project manager, working on water sustainability issues and development of innovative cooling technologies for thermal power plants. Before joining EPRI in 2010, she was a principal aero/thermal engineer at Northrop Grumann Electronic Systems and, earlier, a lead engineer in General Electric's aircraft engine division. Shi received a B.S. in thermal-fluid sciences from Tsinghua University in Beijing and an M.S. in environmental engineering and a Ph.D. in thermal-fluid sciences from the University of Illinois at Urbana-Champaign.

# Expanding the Footprint of Geothermal Energy



Earth image courtesy of NASA.

## THE STORY IN BRIEF

Geothermal power production has been constrained by a focus on the world's best, high-temperature resource fields. Now, innovative technologies for tapping intermediate- and low-temperature geothermal reservoirs promise to open up development in geographic areas not previously considered.

Over the long term, the potential for geothermal power production can hardly be overstated. The earth's crust serves as an insulating blanket over an otherwise hot planet. At differing depths, there is hot rock virtually everywhere, meaning that the thermal resource is as geographically dispersed as sunshine and is often available just a few hundred to a few thousand feet underground.

Yet access remains difficult and costly. Ideal conditions for power generation include a high-temperature permeable reservoir fed by groundwater; such resources are accessible in only a few, relatively small geographic areas of the world—typically in seismically active areas at the boundaries of the tectonic plates.

A few very high temperature reservoirs (>572°F [>300°C]) capable of venting large volumes of dry superheated steam have been tapped, but despite a half century of development, geothermal power production is still modest. The limitations are commonly land use constraints, restricted access, and long distances to existing transmission corridors. More than half of the U.S. capacity of 3100 megawatts (MW) is produced by the Geysers—the world's largest commercial geothermal field, about 80 miles (129 km) north of San Francisco. Worldwide capacity of more than 10,000 MW is concentrated around Iceland and along the "Ring of Fire" in Indonesia, Mexico, Japan, the United States, Latin America, New Zealand, and the Philippines.

Geothermal energy provides considerable advantages for power generation. Unlike wind and solar, it can generate baseload power with a capacity factor in the 80%–90% range and be readily dispatched to follow load. It requires very little surface land, is relatively free of emissions, requires no fuel supply, is amenable to dry-cooling technology in arid regions, and can be used to meet state renewable portfolio standard requirements. Thus, the incentives for wider, more robust development are substantial. "What is exciting to me is trying to make more of the geothermal resource available for use," said Travis Coleman, EPRI's geothermal energy project manager. "In fact, everything we are doing in our program is focused on expanding the geographic footprint of cost-effective geothermal energy."

### Two Domains of Technology

Expanding geothermal power will require advancing two very different domains of technology, one above the surface and one below. Above-surface technology includes the wellhead, gathering system, and steam turbine technologies for converting the energy of high, moderate, and low hydrothermal resources to electricity. High-temperature resources (>392°F [>200°C]) involve direct steam flow into the turbine. Moderate-temperature resources (>302°F–392°F [150°C–200°C]) are commonly accessed through flash technology, in which the hydrothermal fluids flash to steam as the pressure is reduced on the way to the surface. The separated steam is run through conventional steam turbines, and the brine is reinjected into the reservoir (or if hot enough, flashed a second time). All this technology is fairly mature, and improvements tend to be incremental. In contrast, recent advances in less mature binary-cycle technology are opening access to the far more abundant and widely dispersed low-temperature resources (212°F– 302°F [100°C–150°C]).

The more critical need is to improve technologies focused on the underground reservoir. These include the geoscience and methodologies for exploring geothermal resources. The primary risk for any geothermal project lies in accurately identifying, characterizing, and confirming the resource.

Also required is sophisticated resource management to sustain the flow of heat and water into and out of the reservoir during production. This can be a delicate balancing act, involving seasonal demands for electricity, the permeability of the rock, flow rates within the reservoir, and surface-level power plant cooling requirements during hot weather. In addition, efforts are growing to coproduce geothermal power with oil and gas and to find and utilize abandoned wells with sufficiently high thermal gradients.

For large-scale expansion, the greatest potential is in the development of technologies for enhanced geothermal systems, which will involve creating new permeable reservoirs thousands of feet below ground by controlled fracturing of crystalline rock. This approach is at the exploratory stage, but offers the potential of breaking the geographic barrier.

### The Promise of Low-Temperature Binary Systems

On a more modest scale, binary systems could open significant areas of the United States to low-temperature geothermal development. Low-temperature fluids are widely available at shallow to mid-range well depths in the western United States, as well as in some of the Plains and Gulf Coast states. However, prospecting for such fields is currently hit or miss. Given the marginal economics of power production from low-temperature geothermal resources, there is little exploration and development incentive. "Blind" reservoirs, for example, may give no indication of what lies beneath the surface, offering no visible geologic structures, hot springs, or trace emissions of telltale gases. Often these reservoirs are found accidentally while drilling for other reasons. Sinking shallow wells to find areas with higher-than-average temperature gradients is another way to locate viable resources close to the surface. Advanced exploration techniques are needed to attract investment capital and are most likely to be developed by the oil and gas industry.

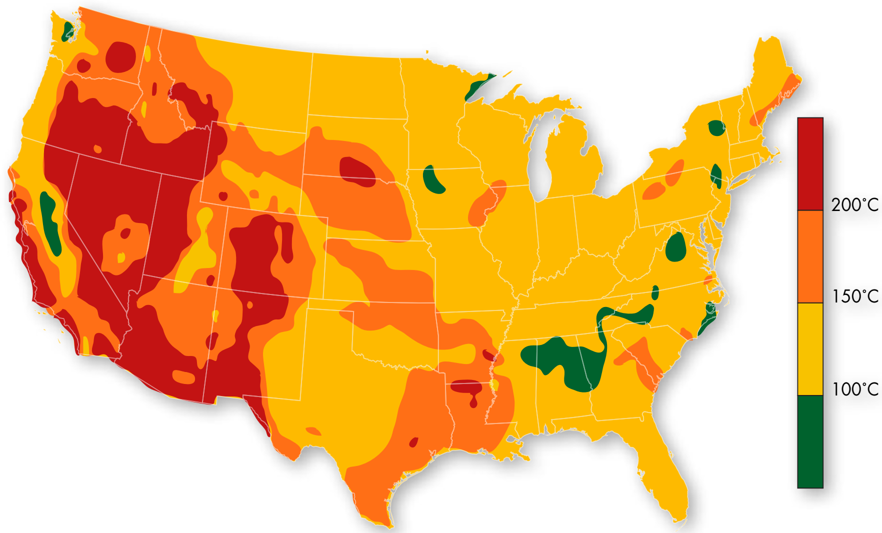
In a binary system, geothermal fluid (geofluid) is pumped out of the ground, collected from multiple wells into a header, and run through a heat exchanger. On the other side of the heat exchanger is an organic fluid, such as isopentane or isobutane, that is vaporized, expanded through a turbine, and condensed in a closed-loop system. Never exposed to the atmosphere, the geofluid is pumped back into the ground in a separate closed-loop system. In recent years, many binary geothermal projects have been successfully placed online in the United States, while many others are in development. In the near term, they are projected to produce 2000–3000 MW of new capacity.

EPRI recently completed economic studies of the likely costs of low-temperature binary systems (EPRI report 1019775). The results suggest that they will be able compete with other forms of renewable energy, with capital costs of $4300–$7300 per kilowatt.

## Exploring Novel Approaches

EPRI is studying a variety of novel approaches that could improve the economics and expand the reach of geothermal energy. One is a hybrid solar-thermal and binary geothermal plant, which could be particularly useful in the arid West, where plants rely on dry cooling. With rising summer temperatures, the performance of the cooling system—and consequently the plant—degrades. For good year-round performance, heat exchangers must be oversized, requiring additional capital. Using solar technology to increase the temperature of the fluid could reduce capital costs, and more turbine capacity would become available. Coleman and his colleagues intend to do conceptual studies of which solar-thermal technologies are well matched to the binary-cycle conditions and where and how to administer the thermal boost to get optimal plant performance.

Another approach is to harvest energy from a closed-loop, single-well system where the heat exchanger is located down in the reservoir itself, rather than on the surface. The advantage is that the exchanger is designed to work in a single borehole, such as an existing or abandoned oil well, pulling the heat out of the ground without extracting the geofluids. One idea being developed involves modifying or developing a heat exchanger to be installed downhole that does not rely on injection fluids except those contained in the closed heat exchanger loop. Dartmouth College modeled the potential for such a system, and the results have been covered in a recent EPRI report (1021607).

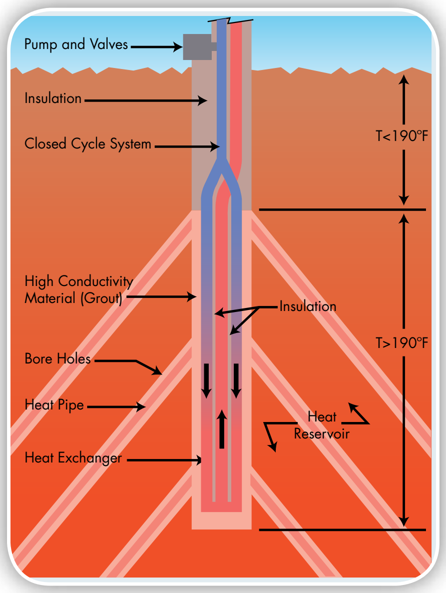



*The U.S. geothermal resource base suitable for electricity production using existing and emerging technologies appears to span almost the entire country. Temperatures are based on a depth of 3.7 miles (6 kilometers). (Source: DOE Geothermal Technologies Program)*

## Ensuring Careful Resource Management

A critical aspect of managing geothermal resources is balancing water and energy to protect the resource and optimize electricity generation. "You can't extract water or heat faster than it can be recharged," said Coleman. "If your water declines, your production suffers, and you might be tempted to pump faster, exacerbating the situation. Similarly, if your heat declines, your plant performance goes down, and your means of compensation is to pump more water, degrading your reservoir."

Geothermal fields are green but not necessarily sustainable, as the producers at the Geysers painfully learned. The Geysers is a football-shaped reservoir about 7 miles (11.3 km) long and 5 miles (8.1 km) wide, located a mile or two below the surface; it can yield prodigious amounts of dry steam, the ultimate geothermal resource. The water in the reservoir was trapped at least 10,000 years ago, however, and has no natural groundwater recharge. Before the




*Development of a closed-loop system that employs a single well to bring heat rather than geothermal fluid to the surface could provide cost-effective access to the massive hot dry rock resource base.*

reservoir's characteristics were fully understood, numerous developers, operating hundreds of production wells and venting the steam to the atmosphere, watched as steam and electrical output declined steadily through the 1980s, turning some of their investments sour. A source of water to recharge the Geysers was desperately needed, and several owners contracted with local municipalities to pump treated wastewater to the site for down-hole injection. With years of careful management, they have nearly stabilized output. Similarly, at the Coso field in southeastern California, natural water recharge from the Sierra Nevada could not keep pace with the extraction, forcing operators to seek new sources of water for injection—a difficult proposition in an arid region. Developers are currently building a water storage system to provide makeup water during seasonal or sustained droughts.

## Enhanced Geothermal Systems: The Grand Prize

In street parlance, development of enhanced geothermal systems is "the big enchilada." If successful, it could increase geothermal power production to unprecedented levels and expand its footprint to regions well beyond seismically active zones. Experimental work is under way in the United States, France, Germany, Australia, and other countries. A Massachusetts Institute of Technology study in 2007 indicated that as much as 50 gigawatts of new U.S. geothermal capacity is feasible by 2050 with accelerated research and development. In the United States, both public funding and private venture capital are aggressively pursuing this option. Such a renewable energy source, with the scale and firm-power equivalent of hydro, could help reshape the power-planning horizon, and long-term economics appear compelling. For example, the Northern California Power Agency, which invested in the Geysers in the 1980s and just paid off the debt on its investment, has begun offering its members geothermal power at $20 per megawatt-hour.

Several developers believe they will be able to create a self-contained, highly permeable reservoir thousands of feet underground by carefully fracturing rock through "stimulation" and monitoring progress with fluid tracers, seismic monitors, and other devices to help them see what they are doing. The trick is to produce a highly fractured, permeable void in the middle of solid hot rock that will hold water in place while producers extract the heat. Significant fracturing is the key to increasing the surface area of the exposed rock, and effective water containment can minimize the need for recharging.

"Enhanced geothermal systems are a big part of the future," said Coleman. "The technology is conceptually very simple, but how you apply it in different rock formations is incredibly complex." In theory, two boreholes are drilled, and the solid rock between them is fractured to allow the passage of fluid. Water is injected into one hole, and steam or hot water extracted from the second hole. This is easier said than done. It is not the idea, but the art and science of fracturing and increasing fluid conductivity between holes, that poses the greatest challenges. Part of EPRI's work is to outline any real or perceived risks that might be involved in the process.

One possibility is to use supercritical carbon dioxide ($CO_2$) rather than water for hydraulic stimulation and fracturing. Supercritical fluids have the unique ability to diffuse through solids like a gas while retaining the properties of a liquid. Studies suggest that injecting supercritical $CO_2$ to create an artificial reservoir and serve as a hydrothermal fluid might yield heat extraction rates 50% greater than those achievable with water. In addition to reducing costs and improving productivity, this approach could afford an option for sequestering $CO_2$ captured from fossil power plants.

EPRI's program in geothermal energy is working to enhance the effectiveness of proven technology; to bring emerging technology, such as low-temperature binary geothermal, into mainstream use while lowering costs; and to assist the pioneering efforts in enhanced geothermal systems—all of which could reshape the entire landscape of geothermal energy over the next 20–30 years. All three avenues of development have a single objective: to expand the geographic footprint of cost-effective geothermal power generation, making these resources more widely accessible to power producers and consumers.

*This article was written by Brent Barker. Background information was provided by Travis Coleman, tcoleman@epri.com, 650.855.2009.*

**Travis Coleman** manages geothermal energy projects in EPRI's renewable generation group. Prior to joining EPRI in 2009, he spent eight years at the Public Service Company of New Mexico on projects involving system modeling, resource planning, renewable energy resource assessment, and renewable energy generation development. Coleman holds a B.S. in mechanical engineering from the University of New Mexico and also completed graduate work in computational fluid mechanics.

# DATELINE EPRI

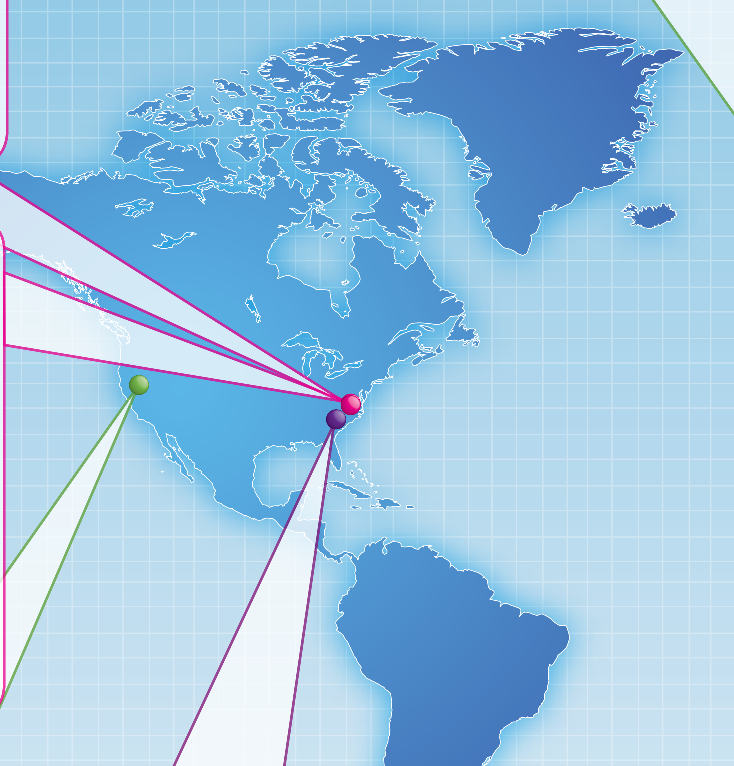
*News and events update*

## Electric Cars, Natural Gas, EPA, Policy, and More: Climate Seminar Casts a Wide Net

WASHINGTON, D.C. — EPRI in May held its 16th annual Global Climate Change Research Seminar. The seminar communicates the latest global climate research findings of interest to the electricity industry and other organizations concerned with energy and environmental issues. Seminar topics included U.S. and international climate policy and Environmental Protection Agency regulations, the Massachusetts Institute of Technology's Future of Natural Gas study, the McKinsey cost-curve methodology, electric vehicles, the economics of energy storage, market vs. non-market approaches to regulation, a regional examination of biomass supply, a California climate technology strategy, and an in-depth examination of greenhouse gas emissions in China.

## EPRI Sector Hosts International Council Meeting

LONDON — EPRI's Power Delivery and Utilization Secto
Council meeting in June to discuss a smarter transmission
technologies, and applications. Perspectives on the fu
were offered from the European Network of Transmission
Electricity, the U.S. Federal Energy Regulatory Commiss
tional Grid. European, North American, and Australia
cussed challenges and technology gaps for grid operati



## Organizations Drive for Integrated Response to Fukushima Daiichi

WASHINGTON, D.C. — EPRI, the Institute of Nuclear Power Operations, the Nuclear Energy Institute, and several senior nuclear utility executives in June launched an effort to integrate the U.S. nuclear industry's response to events at the Fukushima Daiichi nuclear energy facility. The goal is to ensure that lessons learned are well understood and that responses are effectively coordinated and implemented throughout the industry. The effort will address seven areas called *building blocks*. EPRI has the lead or shares the lead for two: *Provide Technical Support and R&D Coordination* and *Anticipate and Coordinate with International Organizations*.

## EPRI Presents Results at Hydrovision International Conference

SACRAMENTO, Calif. — EPRI research leaders chaired and moderated several sessions and provided key presentations on EPRI water power research at the July Hydrovision International Conference. Paul Jacobson, Tom Key, and Doug Dixon discussed the results, status, and priorities of EPRI research in water power, the Hydro Grid Project Industry Review. Jacobson chaired the conference track on hydrokinetic energy (ocean, tidal, and stream), moderating the session on siting and environmental considerations.

## Workshop Looks at Nanotechnology in Key Areas

CHARLOTTE, N.C. — EPRI's Technology Innovation program and the Oregon Nanoscience and Microtechnologies Institute hosted a June workshop titled Advancements in Nanotechnology. It highlighted nanomaterial advances, recent developments, and research opportunities in areas such as power transmission, nanoscale sensor applications, and nanotechnology in water treatment and reduction/reuse.

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ons and development.

## International Panel Plans Guidance for Accelerating Innovation

PARIS — Representatives of EPRI's Energy Technology Assessment Center participated on a panel reviewing an International Energy Agency draft report on accelerating energy technology innovation. The report will provide perspectives on best practices in guiding government energy research and development, with delivery expected in early 2012.

## Korean Workshops Focus on a Variety of Nuclear Issues

DAEJEON, South Korea — Korea Hydro & Nuclear Power Company (KHNP) hosted technical workshops on nuclear plant technology and on materials in May and June addressing life-cycle management, risk and safety, plant engineering, plant maintenance, buried piping, digital technologies, and instrumentation and control. A key area of interest was the lessons learned from the Fukushima Daiichi accident and the potential impacts on the EPRI research portfolio. The four days of materials workshops addressed ongoing EPRI research related to materials reliability in pressurized water reactors and in steam generators.

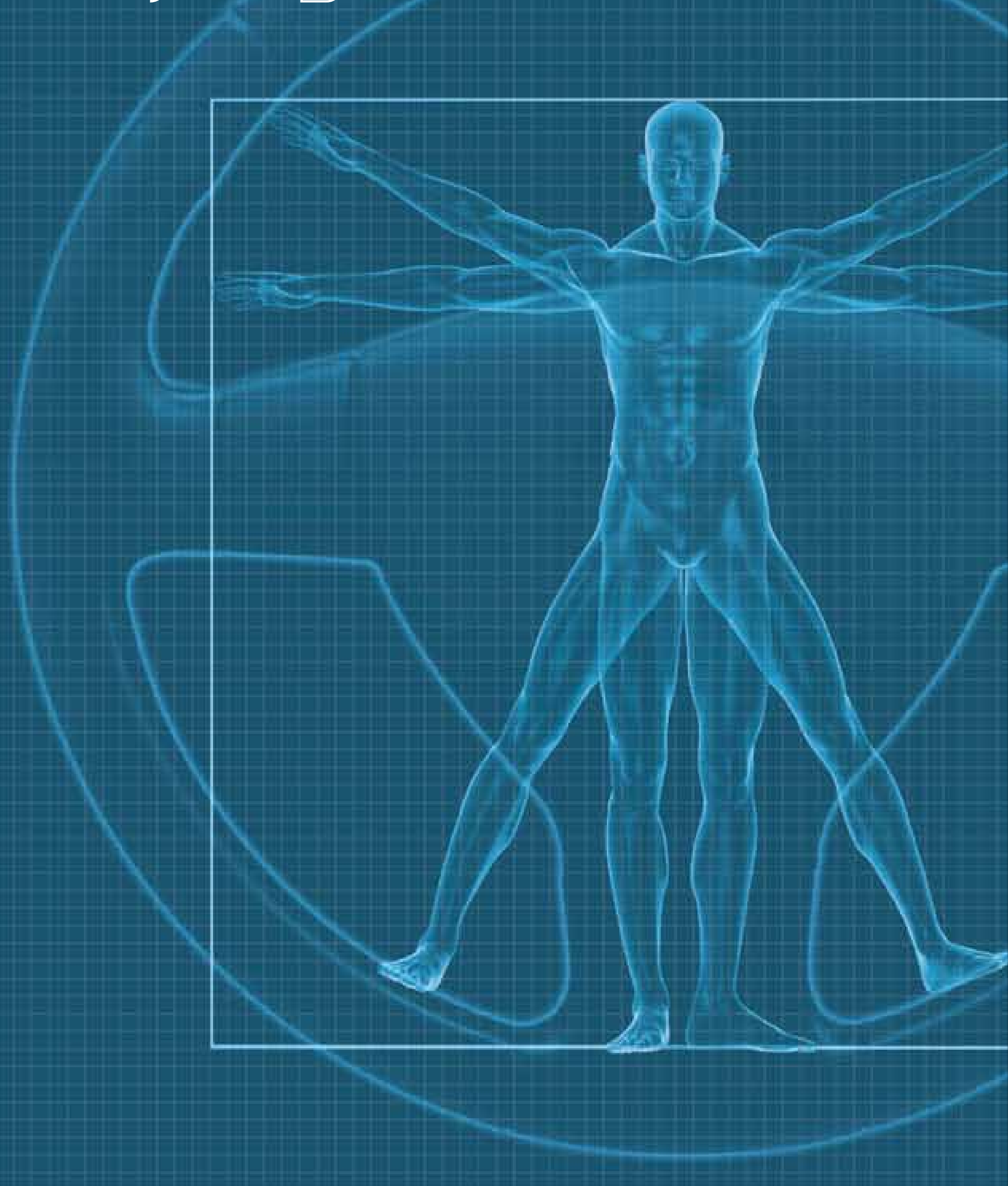
## International Congress Hears Results on Combustion By-Products

HANGZHOU, China — In June, EPRI senior technical executive Ron Wyzga chaired the health sessions at the 12th International Congress on Combustion By-Products and Their Health Effects: Combustion Engineering and Global Health in the 21st Century—Issues and Challenges. Wyzga presented two papers: one on the health effects of organics and the other on the toxicological evaluation of realistic emissions of source aerosols study, which evaluates the toxicity of particulate matter. The latest results from the Atlanta and St. Louis aerosol research and inhalation epidemiological studies were also presented.

## Workshop Sets Research Goals on Australian Brown Coal

MELBOURNE — The State of Victoria invited Jeff Phillips, EPRI senior program manager for advanced generation and $CO_2$ capture, to participate in the Victorian Brown Coal Roadmap Workshop, which worked this past June to identify research goals needed if the state's brown coal resources are going to be used in a $CO_2$-constrained future.

# Fleet Vehicles and the Value of Ergonomics



## THE STORY IN BRIEF

From running boards to laptops, good design can drive safety, satisfaction, and savings.

When we think of occupational injuries within the electric power industry, our mental image is often of linemen working high up on utility poles and towers. But a surprising number of injuries originate on the ground, in and around company vehicles. In fact, 6% of all injuries to electric utility workers are related to fleet vehicles and problems with their design and use. In many cases, the issue is ergonomics—design that can improve the usability of vehicles and equipment by fitting them to the form and function of the users.

Good ergonomics allows workers to do their jobs more efficiently while limiting body movements that can cause muscular aches and pains as well as more serious physical injuries. For example, if handholds mounted above doorframes are not within easy reach, workers may be tempted to ignore them when entering or exiting a vehicle or to grab the steering wheel instead, increasing the risk of slipping or losing their balance. If a running board or bottom step is situated too high on a truck, shorter people may be forced into awkward positions, increasing the risk of injury. If a heavy piece of equipment is stored behind other objects, a worker may be tempted to reach over and strain to lift it, instead of shifting items to get better access.

Ergonomic design reduces the risk of musculoskeletal disorders from injury or overuse, decreasing absenteeism and improving worker satisfaction. Well-designed vehicles that the workers themselves help choose can infuse a sense of ownership that inspires workers to take better care of the vehicles so that they last longer and need fewer repairs.

EPRI research indicates that including worker input can make a difference in safety and in the economics of fleet vehicle purchases. Conventional buying decisions are typically made solely by fleet or supply chain departments and are driven primarily by volume discounts. EPRI studies show that a team approach would be better, incorporating input from the workers who use the vehicles, the maintenance people who repair them, supervisors, health and safety personnel, and others who can advise on work groups' specific needs. The up-front price advantage provided by a volume discount can be more than offset by the substantially higher costs of incorporating ergonomic and safety modifications. It is often more cost-effective to buy vehicles designed to meet specific work group needs than it is to buy identical standard vehicles at a discount and then upfit them for efficient use.

### Developing the Data

EPRI has been collecting data on workplace injuries in the electric utility industry since 1999 and publishes annual updates detailing injuries that occur and their causes. These have served as the starting points for a series of EPRI studies to identify ergonomic principles for transmission and distribution workers, power plant operators, and power plant electricians. The work on fleet vehicles started in 2008 with a review of existing literature, followed by site visits to member companies, vehicle manufacturers, upfitters, and vendors; researchers also gleaned information from conferences and trade shows where vehicles were exhibited for sale.

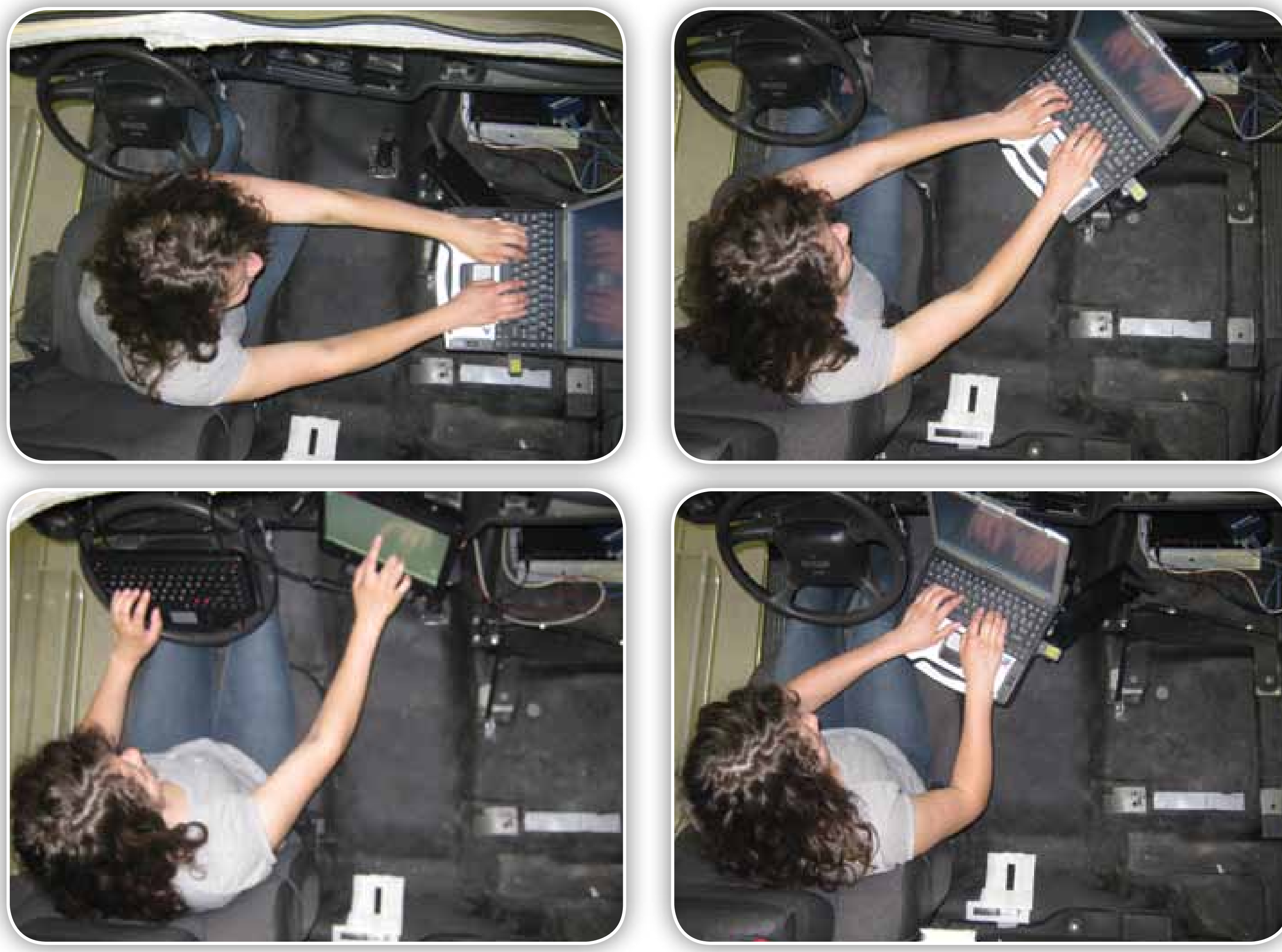
Detailed measurements were taken of vehicle and cab dimensions. The team interviewed supervisors, workers, and maintenance personnel and observed how vehicles were used. Anthropometric measurements of workers were used in computer 3-D models of the vehicles and human occupants to identify ergonomic issues and needs. In collaboration with Marquette University, the research team addressed gaps in data by conducting laboratory experiments focusing, for example, on ergonomics for in-cab computers and other electronic devices. A second experiment is being considered that would focus on entering and exiting the bucket on aerial trucks, which is a common site for slips and falls (see "Aerial Bucket Safety," p. 23).

### Accommodating the Mobile Office

Computers and other electronic devices—mobile data terminals, printers, cell phones, two-way radios, GPS units, rear-view camera systems—are becoming more and more common in fleet vehicles, and the trend appears to be for even more electronics in the future. Most vehicles are not designed to accommodate these devices, leaving it to the end users to find ways to mount them.

In-cab computers are perhaps the most problematic of the devices. It is common practice to install computers on or directly in front of the passenger seat, requiring users to twist and reach. Because field workers typically use computers for short times, most people assume that there are no long-term risks of developing musculoskeletal disorders. Workers have complained of discomfort and fatigue, however, and anecdotal evidence suggests that some long-term effects are possible. To evaluate the risks, EPRI collaborated with the Marquette researchers to take measurements on how workers use their computers.

They studied four popular mounting methods. One places the computer at the center of the passenger seat, either on a mobile office/desk or on the back of a fold-down passenger seat. A second places the computer on a fixed pedestal in front of and to the left of the passenger seat. The third arrangement, popular in police and emergency vehicles, places the monitor in a fixed position just to the right of the steering wheel; a separate keyboard is either clipped temporarily to the steering wheel or located on a platform attached to the monitor. The fourth design uses a platform mounted on an articulating arm, which allows the driver



*Studies showed that a computer mounted on an articulating arm just to the right of the steering wheel (bottom right) causes the least twisting, stretching, and discomfort.*

to position a laptop computer just to the right of the steering wheel.

To evaluate the comfort of test subjects in each position, researchers measured angles of elbows and wrists by using electronic devices called *goniometers*. They used electromyography to monitor the electrical activity of major trunk muscles and recorded posture from the left and above with video cameras. For each position, they measured the time that subjects required to perform certain computer tasks and their accuracy in performing them. Finally, the researchers asked each participant to fill out a questionnaire rating the comfort for each position.

The study concluded that the two configurations with the monitor just to the right of the steering wheel were far better than the ones with the monitor on or in front of the passenger seat. Users gave the highest rating to the articulating arm, which allows the most freedom in positioning the computer and requires the least reaching and virtually no twisting. The second-best choice is to mount the monitor on a fixed pedestal to the right of the steering wheel.

The other positions, on or near the passenger seat, required users to hold their arms horizontally and nearly straight at shoulder level and to extend their left lower back muscles. Measures of muscle activity showed that physiologic fatigue would begin to develop in as little as 10 minutes in the lower back (10–15 minutes in the arms). Workers with a history of back problems or other musculoskeletal disorders could experience difficulties even more quickly, especially if muscles have inadequate time to recover between uses.

## Designing for Safety

Two years of study have produced interim conclusions and practical guidance that utilities can apply to improve vehicle fleet ergonomics.

***Handholds.*** Vehicles' handholds should be positioned so that workers can at all times maintain three-point contact—both feet and one hand, or both hands and one foot—when getting in and out. That usually means two handholds within easy reach.

***Steps.*** Step treads need to prevent slipping in mud, snow, or icy conditions. Steps should have uniform spacing, depth, and angle of inclination and be wide enough

*Goniometers attached to the test subject's wrists and elbows were used to measure joint angles for biomechanical analysis.*

## Aerial Bucket Safety

Line mechanics and troubleshooters are among the electric power company employees most at risk for occupational injuries. The EPRI fleet project team has identified a number of ergonomic issues with aerial trucks that contribute to those risks. Some of these factors are as follows:

- Controls that can be difficult to use
- Inadequate handrails on the catwalk to the bucket
- Steps to the catwalk that are too high
- Tool storage areas that are hard to reach or inadequate for the equipment needed
- The wrong type of boom, mount, or materials-handling package for the work crew, its tasks, or the work environment
- The wrong type of bucket for the number of workers involved

Falls and slips while entering or leaving the bucket are especially common causes of injuries, and difficulty getting in and out can exacerbate cumulative injuries. A separate lab study is under way at Marquette University to determine the safest locations for bucket steps and handles.

that workers can find the next step easily without looking. Step position should not be too high for workers who have limited range of motion or short stature; a relatively high step-up of 24 inches (61 cm) was not unusual in vehicles surveyed by EPRI.

***Containment.*** Many vehicles use a board placed across the bottom of a truck bed to prevent equipment from sliding out during driving. Although the board is easily removed, workers almost always choose to step over it instead, risking a stumble while moving or unloading equipment. A preferred containment device found on some newer vehicles is a cargo net that hooks over the bed entry. Because the nets are too high to step over, workers have no choice but to remove them.

***Storage and Access.*** Storage areas should be designed on the principle of "a place for everything and everything in its place"—with dividers, hooks, and shelves to separate items. Safety equipment such as rubber gloves, wheel chocks, safety cones, signs, grounding equipment, and outrigger controls need to be stored for quick access. Heavy, awkward, and frequently used equipment needs to be at optimal height and reach for lifting. All available space should be used, including undercarriage, doors, and ceiling. To the extent possible, storage spaces should be designed to accommodate future needs and technologies.

***Information Technology.*** Beyond computers, items such as two-way radios, GPS units, rear-vision camera displays, mobile phones, and any future technologies need to be positioned within easy reach, where they do not block vision or add to clutter. Design and placement should discourage their use while driving or minimize distraction if the devices must be used.

***Maintenance.*** Vehicle design should not restrict important maintenance. Good design can reduce injuries to maintenance workers, reduce the cost and turnaround time for maintenance, and help ensure that proper maintenance is completed. Currently, aerial buckets are particularly expensive and time consuming to maintain.

***Other Considerations.*** Effective lighting is needed for the cab and work areas. Outrigger controls need to be positioned where workers are out of traffic and are not in danger of having the outrigger come down on a foot. Vehicles should be suitable for safe driving in adverse weather. Seat and steering wheel adjustments need to be adequate for both shorter and taller workers, and pedal clearances need to be suitable for work boots and snow boots.

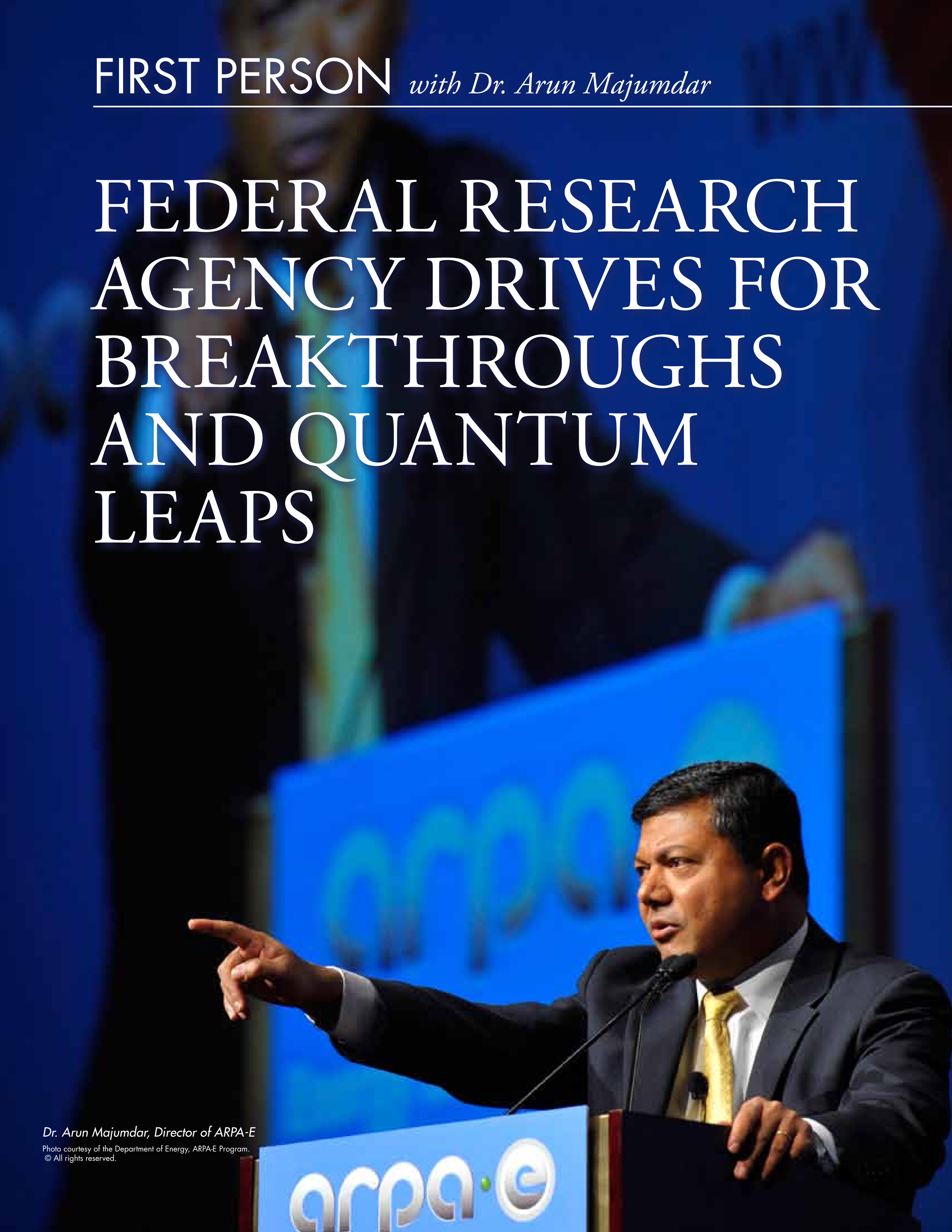
The final findings of the ergonomic studies, along with detailed recommendations for vehicle design and purchasing, will be published in two EPRI handbooks. The first, *Ergonomic Design of Original and Upfitted Fleet Vehicles*, is scheduled for release at the end of this year. The second manual, *Ergonomics Guidelines for Vehicle Specification, Purchase Process, and Maintenance*, will be published in 2012.

*This article was written by Cliff Lewis. Background information was provided by Gabor Mezei, gmezei@epri.com, 650.855.8908.*

**Gabor Mezei** is program manager of both the Occupational Health and Safety program and the EMF and RF Health and Safety Assessment program. Prior to joining EPRI in 1999, he worked as a physician and epidemiologist at the National Institute of Dermatology in Budapest, Hungary, and at the Toronto Hospital, University of Toronto, Canada. Mezei received a M.D. degree from the Semmelweis Medical University in Budapest and a Ph.D. in epidemiology from the School of Public Health at the University of California, Los Angeles.

FIRST PERSON *with Dr. Arun Majumdar*

# FEDERAL RESEARCH AGENCY DRIVES FOR BREAKTHROUGHS AND QUANTUM LEAPS




*Dr. Arun Majumdar, Director of ARPA-E*

Photo courtesy of the Department of Energy, ARPA-E Program.

In 2007 the U.S. Congress passed the America Competes Act, which authorized the creation of the Advanced Research Projects Agency—Energy, modeled after a long-standing counterpart agency in the defense sector. ARPA-E is charged with focusing on transformational energy research to bridge the gap between basic research and development and industrial innovation. Dr. Arun Majumdar is director of ARPA-E and also serves as senior advisor to U.S. Energy Secretary Steven Chu. *EPRI Journal* interviewed Dr. Majumdar to get his perspective on the agency and its work.

***EJ: People are interested in understanding what ARPA-E brings to energy R&D, as well as your insights and thoughts on that.***

**Dr. Majumdar:** Fundamentally, what ARPA-E does is to translate science into technologies that are breakthroughs—quantum leaps—technologies that do not exist in the market today, but that would make today's technologies obsolete.

***EJ: So you're looking beyond incremental progress?***

**Dr. Majumdar:** That's right. Looking for quantum leaps, looking at propositions too risky for the private sector to invest in. Today's technologies are on certain paths, which are, in economic terms, called *learning curves*. For example, in manufacturing as you increase production, the cost comes down over time, and performance goes up. That's a learning curve. The lithium-ion battery is on a learning curve today. What ARPA-E does is to create new learning curves, new technologies, and try to make today's learning curves obsolete—to reduce the cost substantially or increase the performance substantially.

***EJ: So you're really trying to rev up innovation on a number of fronts.***

**Dr. Majumdar:** Absolutely. At ARPA-E we are right in the middle of what is called a technology push and a market pull. By statute we have a mission, and we are a very mission-focused agency, centered on energy security and economic security, and the U.S. technological lead.

**"From the beginning, ARPA-E has had a commercialization team to provide the connections between breakthrough technologies and the commercial world, to make them aware of what's coming down the pipeline."** *~ Dr. Arun Majumdar*

***EJ: Looking at it from EPRI's perspective and its collaborative model, do you see that this creates new opportunities for collaboration in R&D?***

**Dr. Majumdar:** Absolutely. EPRI's connection to the utility sector is critical. ARPA-E invests in technologies that are very risky, but should they succeed, then we may need to look at a number of connections—how could they be integrated onto the grid, what are the costs, what are the metrics that they should be going for. That's the partnership I see between ARPA-E and EPRI and the utilities.

From the beginning, ARPA-E has had a commercialization team to provide the connections between breakthrough technologies and the commercial world, to make them aware of what's coming down the pipeline. And for our teams, we need to know what really matters in the market.

***EJ: So that focus on ultimate commercialization helps impose the goal-oriented discipline of the marketplace.***

**Dr. Majumdar:** We are focused on developing those technologies that will actually matter in the real world—not on exploratory research.

***EJ: Although if you're focusing on, as you say, some of the riskier technologies, your R&D will have certain attributes of that exploratory research.***

**Dr. Majumdar:** Absolutely. If you go back in history, AT&T Bell labs got a Nobel Prize for the transistor—big science. But what they were seeing was the end of vacuum tubes. They realized that they could not make large banks of switches or telephone circuits based on vacuum tubes, even though they were improving the performance 5%–6% per year. They saw the end coming and said, "Why don't you try something different?" And that's why the transistor was invented and integrated circuits came out of that. That's the kind of innovation that we're looking for. Yes, we go back to science, but it is not exploring for the sake of exploration. It is for a very defined goal.

> “I hope we see a very close partnership for ARPA-E to learn from EPRI and the utilities about the real challenges, so that we can get the scientific community together and design programs to address those challenges.” ~ *Dr. Arun Majumdar*

***EJ: One of ARPA-E’s major research areas is energy storage. How would you characterize your focus in this area?***

**Dr. Majumdar:** Well, for the grid, there are different time scales for storage. One is a very short scale for frequency regulation, etc. For the second time scale, an example is that you want to store 700 megawatts for an hour because there’s a wind ramp that’s coming, and there’s a mismatch between supply and demand—and you want to store excess energy. So it’s a gigawatt-hour kind of energy storage problem. The third scale is more seasonal or long term.

The short-term scale is being addressed today by various batteries.

The big challenge is how you store a gigawatt for an hour. So what technology should we be focusing on that will bring down the cost? If it does not bring down the cost, then it is not relevant in the real world. There are additional factors. How many times you can cycle. What is the round trip efficiency? Storage will have to compete at the end of the day with fast-ramping gas turbines, combined-cycle natural-gas turbines, which are really efficient and low cost.

In terms of long-term, seasonal storage, we have created a program on thermal storage and things that are scalable to gigawatt-hour-level storage, but even longer, even bigger than that. I think that thermal storage can be really important for this, and so we are looking at that as well. We want to do high-temperature solar. It is much more, much higher efficiency, which brings down the cost, but you need thermal storage at high temperature. So that’s the kind of thing that we’re looking at also.

***EJ: What was the genesis of your electrofuels program, and where do you see it going?***

**Dr. Majumdar:** If you look at biofuels today, it’s converting sunlight into fuels, using photosynthesis to take carbon dioxide and make carbon bonds. But there are many biological approaches for making carbon bonds without photosynthesis, and they’ve never been tried to make fuels. Dr. Eric Toone (ARPA-E Deputy Director for Technology) held a workshop of biologists, chemists, etc., who had not talked to each other. And out of that workshop came a suggestion for a non-photosynthetic way of making fuels, and the source of energy could be electricity directly. It could be the hydrogen sulfide waste product from natural gas and oil. We want to try this approach because no one has tried this. And this could be 10 times—at least 10 times—more efficient than a photosynthetic way. It could be a great way to convert carbon dioxide into fuel using electricity that we generate locally. That’s how it came to be called *electrofuels*.

And this is ARPA-E: let’s try a different route. Maybe we’ll fail, but if it succeeds, it could be much, much better.

***EJ: ARPA-E is looking at heating and cooling technologies, an area perhaps where people—businesses and electricity consumers as a whole—sort of expect incremental progress. They’re used to seeing incremental gains in the efficiency. What is your take on the potential for significant gains in efficiency?***

**Dr. Majumdar:** The potential is huge. We recruited Ravi Prasher (program director for Building Energy Efficiency Through Thermodevices Innovation) who was tackling the huge problem of cooling microchips—a brilliant guy, very creative, connected to science, but still doing technology development for a chip manufacturer. I said, “Here’s a problem. I want you to go after it in a different way.”

Let’s see what the theoretical limit is for air conditioning and how far we are from that. And we asked, “What is the limit of what we can do, practically?” What we determined is that we are short of the theoretical limit of efficiency by a factor of 10 and short of the practical limit by a factor of 5.

In April 2011, ARPA-E, Duke Energy, and EPRI announced a memorandum of understanding to identify opportunities for testing and deploying projects funded by ARPA-E that have the potential to drive technological development in smart grid, energy-efficient cooling technology, grid-scale energy storage, and power electronics. The umbrella agreement will allow for similar partnerships with other utilities. For more information about the agency and its areas of research, visit the home page at www.arpa-e.energy.gov.

We determined that the main opportunity is to separate humidity control from temperature control. Right now what we do is we cool the heck out of the air to remove the moisture, and then we heat it again, which is crazy. If we could remove the humidity and make the air dry in a really energy-efficient way, then we cool the dry air, and we've saved a lot of energy. That's one approach.

Then we said that maybe there are other ways of doing refrigeration that do not include refrigerants that contribute to global warming. We think a lot of innovation is coming out of magnetic refrigeration, from electric refrigeration, all kinds of refrigeration and air conditioning based on that. So that's the way we approach the problem. A target like that is a sign to the research community. When you bring chemists together with engineers and physicists, when you bring scientists and engineers together and give them a target and give them some money, you will see innovation. We can create a competition and energize the scientific community to innovate.

***EJ: So you deliberately get people to face a question or a challenge from a nontraditional perspective?***

**Dr. Majumdar:** Right. And be fearless about doing it. Sometimes, it doesn't work. That's okay. But you know, that's the risk that we take, letting people spread their wings. So I can tell you that none of the people in ARPA-E are actually doing or funding research that they have worked on in the past. They have gone in new directions.

***EJ: Let's tie that fact to this question: Which recent events do you think will most profoundly shape the direction and focus of energy R&D?***

**Dr. Majumdar:** That's hard to predict. Going back in history, there are a few events that changed the course of American technology innovation. Sputnik in 1957 was a wakeup call that the Soviets were ahead. And out of that came DARPA, the Apollo program, and research on information and defense technology, space technology.

Our technological leadership is being challenged right now. If we do nothing, we'll fall behind. I think the Sputnik moment is today. President Obama has said it, Secretary Chu has said it, I've said it. But it's a different kind of a Sputnik moment. The United States thrives on competition. This is part of the American ethos. If you think about it, you find that Google, Yahoo, and all are competing like crazy. And that competition has led to a number one and a number two. ARPA-E is part of the America Competes Act, to make the United States more competitive, which is part of our culture.

***EJ: And you're working to instill this in ARPA-E?***

**Dr. Majumdar:** Absolutely.

***EJ: In a collaborative vein, ARPA-E, Duke Energy, and EPRI signed a memorandum of understanding earlier this year. What is your perspective on this?***

**Dr. Majumdar:** I hope we see a very close partnership for ARPA-E to learn from EPRI and the utilities about the real challenges, so that we can get the scientific community together and design programs to address those challenges in the way that ARPA-E does—in its characteristic way. That's number one. Number two is I hope the technologies that we develop will make an impact in the real world. That engagement is absolutely critical for us, and I hope ARPA-E can provide some value in this whole landscape.

## Carbon Nanotubes for Water Filtration

Carbon nanotubes—tiny cylinders of rolled-up graphite sheets with diameters in the range of 1–3 nanometers—have been enjoying an iconic status among nanoscience researchers for a long time. However, despite their spectacular properties, carbon nanotubes have had few commercial applications. Now a new technology is exploiting one of the most remarkable properties of this high-tech molecule: the ability of the tiny carbon nanotube pore to transport water at an extremely fast rate, using almost frictionless flow. Carbon nanotube membranes promise drastic improvements in membrane fluxes that could enable many new applications and improve existing purification systems. EPRI is working with Porifera, Inc., to develop nanotube-based filtration membranes that will be cost competitive with conventional reverse osmosis membranes, but will deliver far better performance.

### Exciting Properties

The most consequential properties of carbon nanotubes for water treatment applications originate in the nanotube structure. Carbon atoms in the nanotube wall form a densely packed lattice that presents an exceptionally smooth surface. These hexagonally packed carbon atoms are also hydrophobic, essentially eliminating the interaction of water molecules with the walls. As a result, water molecules moving through the nanotube inner pore do not experience wall friction. Computer simulations also show that water molecules in this environment have an increased propensity to form hydrogen bonds with one another. This hydrogen bonding arranges the water molecules (at least in these simulations) into tight water plugs, or columns, that can move through the nanotube pore as a "train," rather than as individual molecules. This unique pore structure leads to the extremely fast water transport through the carbon nanotubes.

Ion rejection is the key property of the reverse osmosis membrane that determines its usability in water treatment applications. The rejection properties of the bare nanotube pores are determined by the interactions of the charged carboxylic acid groups at the end of the nanotube with the ions in solution—these charged groups repel ions and prevent them from entering the carbon nanotube. Maintaining the membrane selectivity requires a set of (typically proprietary) membrane modifications or architecture changes that bring about some necessary tradeoffs between flux and selectivity.

Currently, the rejection properties of the nanotube membranes are competitive with those of modern-generation polymeric membranes, with sodium chloride rejection reaching 99.5% at seawater concentrations. An interesting property of the carbon nanotube membranes is that their rejection properties can be tuned to some extent without changing the structure of the membrane, which potentially could provide a lot more flexibility in tailoring membrane performance for specific applications.

### Production Challenges

Carbon nanotube membrane technology promises revolutionary improvements in membrane permeability that can harness the nanotube's capability for frictionless water transport. Yet in order to become a viable technological solution, the membranes would need to be manufactured in a reliable, cheap, and practical way. Recent improvements in carbon nanotube manufacturing methods, better understanding of the growth process mechanisms, and better catalyst designs have all contributed to high-quality, low-defect nanotube production at a substantial reduction in price. Still, the nanotubes have to be made in the right configuration. For example, aligned carbon nanotube membrane fabrication generally requires aligned carbon nanotube starting material. This issue may be the most important obstacle to the industrialization of the advanced membrane technology, but Porifera is well on its way to demonstrating the feasibility of the process.

Porifera projects that its first-generation nanotube membranes will be cost competitive with the current generation of reverse osmosis membranes, delivering better performance to the end user at comparable costs. The next generation of the nanotube membrane, based on straight-pore-aligned carbon nanotube technology, will utilize a proprietary manufacturing technology. While these fully scaled-up second-generation membranes are likely to carry a small cost premium over commercial polymeric membranes, they will provide significantly superior performance.

Porifera projects that the pilot-scale testing of the first generation of carbon nanotube filters will be completed within 24 months, with full-scale commercial applications about 36–48 months away.

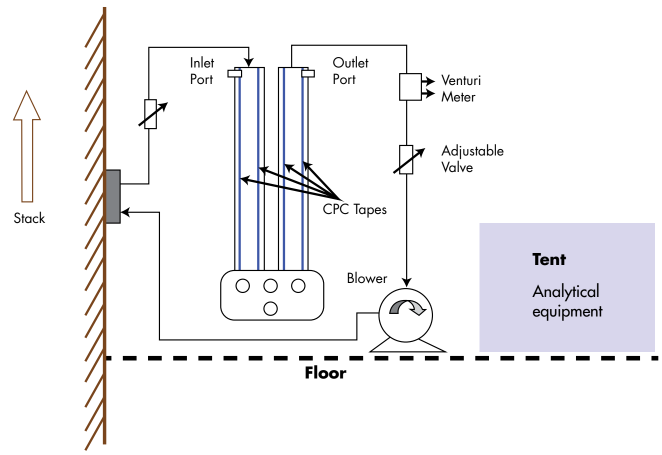
*For more information, contact James Mathews, jmathews@epri.com, 704.595.2544.*

## Mercury Removal Using Carbon-Polymer Composites

New, more stringent rules issued in March by the Environmental Protection Agency for removing mercury from flue gas are expected to substantially raise the bar for coal-fired utility boilers. For many plants, beefing up their conventional sorbent-based capture systems—injection of activated carbon particles or use of stationary carbon beds—will be the most economic option for achieving compliance.

But high sorbent injection rates can affect electrostatic precipitator (ESP) performance and contaminate fly ash, making it difficult to sell or otherwise dispose of. Stationary carbon beds have their own problems, becoming quickly saturated by $SO_2$ and other acid gases and requiring frequent bed regeneration. And some boilers—especially those that fire bituminous coal—have relied on existing selective catalytic reduction, ESP, and wet scrubber units to remove mercury as a co-benefit to their primary functions. These plants may now need dedicated mercury removal equipment to meet the tougher requirements.

EPRI worked with a team from industrial materials manufacturer W. L. Gore & Associates to develop an innovative new option: a carbon-polymer composite structure placed in the flue gas stream that promises high mercury removal without many of the drawbacks of conventional approaches.




*The mercury capture capability of carbon-polymer composite tape was demonstrated at Southern Company's Plant Yates power station. (Source: W. L. Gore & Associates)*

## Trapped in the Matrix

To optimize capture and practicality, W. L. Gore developed a method for embedding small activated carbon granules in a polytetrafluoroethylene (PTFE) polymer matrix, which can be processed into carbon composite sheets. The matrix stabilizes the carbon while allowing the flue gas ready access to the granules. The PTFE, a hydrophobic polymer, keeps water away from the activated carbon surface.

The composite sorbent sheets, attached to plastic backing plates for stability, can be arranged vertically in parallel and incorporated into the mist eliminator at the top of the wet scrubber or added as stand-alone modules downstream, just before the stack. The carbon composite sheets carry several advantages over conventional capture systems: Because the sorbent remains embedded in the polymer matrix, it does not have to be collected by an ESP and will not contaminate fly ash. Because the matrix is hydrophobic, it can be operated even in wet flue gas. And because the unit can be operated downstream of the scrubber, it capitalizes on the better activated carbon utilization that comes with lower temperatures (<210°F [<99°C]); as a result, it has a potential carbon life of a year or longer.

In addition to adsorbing mercury, the matrix's activated carbon can convert $SO_2$ that was not removed by the scrubber into $SO_3$, which then reacts with water in the humid environment to form sulfuric acid. The sulfuric acid drips from the vertical composite surface and can be collected below. Thus, a carbon composite unit may allow both mercury and residual $SO_2$ to be captured from flue gas downstream of a wet scrubber at a low flue gas temperature and a moisture level of up to 100% relative humidity.

## Field Demonstrations

W. L. Gore, EPRI, URS Corporation, and Southern Company have been carrying out proof-of-concept testing and small-scale module demonstrations at Southern Company's Plant Yates power station since March of 2010. Flue gas was removed from a slipstream at the stack (just downstream from the plant's limestone wet scrubber) and fed through a series of 6-inch- (15.2-cm-) deep cylindrical carbon-polymer composite modules. At a linear gas velocity of 5.0 feet/second (1.5 m/second), a stack of eight modules was able to remove over 90% of the mercury in the slipstream sample. $SO_2$ removal showed promise as well, and the system was able to operate for over four months without requiring sorbent regeneration or maintenance.

The next step is a 1-MWe pilot-scale evaluation planned for later this year at Alabama Power's Gorgas Steam Plant. This effort will include short-duration parametric testing to evaluate mercury and $SO_2$ capture over a range of flue gas velocities, plate spacings, and module configurations, followed by a three- to six-month continuous run to assess longer-term performance. Results from this study will then be used to develop full-scale design options and costs and to assess engineering economic feasibility.

*For more information, contact Ramsay Chang, rchang@epri.com, 650.855.2082.*

## Automated System to Protect Bats from Wind Turbine Blades

Bat species are especially important to ecosystem function, providing pollination, seed dispersal, and insect control. Some species are already listed as threatened or endangered, while populations of more common species are collapsing because of white-nose syndrome. These circumstances have elevated concern about the significant bat kills observed at wind facilities along forested ridgetops in the eastern United States and in other U.S., Canadian, and European locations. Such concerns have put some wind projects on hold, while seasonal curtailment of operations to mitigate the problem has threatened the economic viability of others. Combining ecological understanding of bat behavior with the need for a low-cost solution, EPRI's Technology Innovation program is developing an automated curtailment system for individual turbines that kicks in only when bats are present.

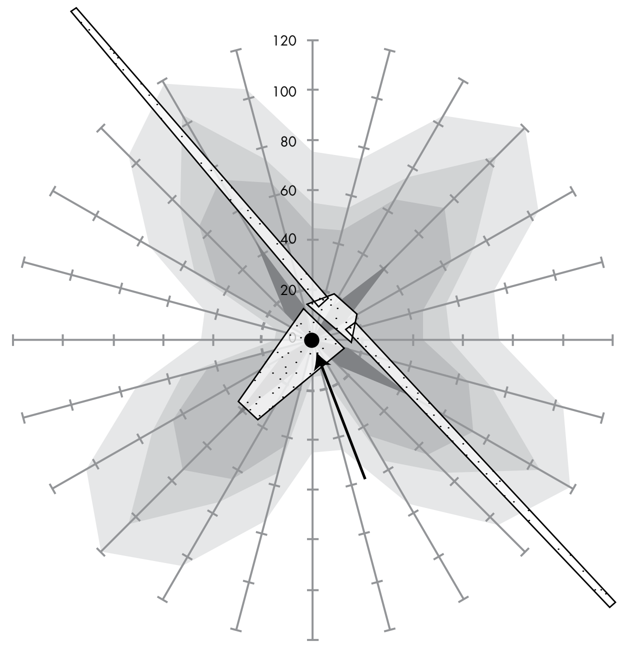
### Fine-Tuning Curtailment

The majority of fatalities have been observed in late summer and early autumn, when migratory bat species are on the move. Preliminary testing indicates that bat mortality during fall migration could be reduced by 50% or more by increasing the turbine cut-in speed—the wind speed at which the turbine blades are allowed to start rotating. However, this higher start speed means that the turbine is producing power less of the time, and curtailing turbine operations over a several-week period can result in significant productivity losses. Recent research indicates that high-mortality events tend to be clustered at particular locations and times and likely are preventable through more targeted curtailment strategies.

Through a Polaris Initiative project initiated in 2010, EPRI is collaborating with EDM International, wind plant owners, and the National Renewable Energy Laboratory (NREL) to establish proof of concept for a bat detection and turbine shutdown system. The "bat protector" will integrate inexpensive, nacelle-mounted ultrasonic microphones with the computer control system of a turbine to automatically slow or stop blade rotation when bat echolocation calls are detected within the area of the rotor's sweep.

### Feasibility Testing

In 2010, EPRI used recorded calls from big brown bats and small-footed bats—species widespread throughout North America—to evaluate existing echolocation detection hardware and software under turbines at the Cedar Creek Wind Resource Area, a 200-megawatt wind farm in Colorado. These tests were conducted using a ground-mounted transmitter and receiver. With results averaged across species, broadcast calls were detected about 90% of the time when the transmitter and receiver were on the same axis and separated by distances of less than 15 feet (4.6 m), 75% of the time at 45 feet (13.7 m), 50% at 75 feet (22.9 m), 25% at 105 feet (32 m), and 10% at 120 feet (36.6 m). Tests were also conducted when the call source and detector were located at various angles to one another. The findings demonstrated the potential viability of this detection method and are informing the design of microphone arrays capable of providing the best coverage of the three-dimensional space surrounding a wind turbine from a location on its nacelle.




*An inexpensive microphone array (arrow) on the wind turbine's nacelle triggers an automated control system to stop blade ratation when bat calls are detected.*

In consultation with bat ecology and wind energy experts, EPRI will deploy a prototype bat detection system in 2011 on a functioning turbine at NREL's Wind Technology Test Center in Colorado. Mounting the system on the nacelle will challenge hardware and software components to distinguish bat calls from rotor noise, as would be required in actual deployment. Proof-of-concept tests will be conducted by broadcasting ultrasonic calls from a nacelle-mounted transmitter placed on-axis and off-axis relative to the receiver. Recordings of silver-haired bats, hoary bats, and eastern red bats will be used, as wind turbines appear to pose particular risk to these species in North America.

Assuming field tests prove successful, EPRI plans to collaborate with a turbine manufacturer to incorporate bat detection as a control system input. Additional field evaluation would be conducted at a utility wind turbine site to demonstrate the system's ability to slow or stop blade rotation in the presence of migrating bats and to quantify impacts on energy production.

Successful demonstration of an inexpensive, off-the-shelf solution for minimizing bat mortality is expected to help facilitate widespread wind deployment, as concerns about bat species represent an obstacle to development in some areas and increase predevelopment costs and postconstruction monitoring requirements in others.

*For more information, contact John W. Goodrich-Mahoney, jmahoney@epri.com, 202.293.7516.*

## Study on Circuit Card Reliability Helps Prolong Nuclear Equipment Life

Nuclear power plants in the United States were built in the days when analog instruments and controls were the norm. Now, 30 to 40 years later, this equipment is approaching the end of its useful life and is becoming responsible for increasing numbers of incidents, such as forced shutdowns, power reductions, and potential unnecessary activation of safety systems.

The cost to replace all of this equipment at once would be overwhelming. In addition, the need for replacements to be tested, documented, and qualified—and, in some cases, subjected to regulatory approval—means that at least some of the older equipment is going to stay in service for the foreseeable future.

Several studies by EPRI have been conducted with the goal of helping nuclear utilities keep their analog equipment in use for as long as possible, while minimizing the risk of failures that can affect safety, performance, reliability, or availability. These studies have been concerned with the integrity of individual circuit cards (printed circuit boards with attached electronic components, such as transistors, diodes, relays, resistors, and connectors). The studies aim to develop guidance for increasing the usable life of circuit cards and identifying cards that cannot be trusted to continue operating from one scheduled shutdown until the next, and to define methods for testing or replacing those parts.

In many cases, failures are random and unpredictable, and the age of the card is not a good predictor of its reliability. Not only does an unnecessary replacement add costs, but an untested new card may have a higher risk of failure than the one it is replacing. Even removing an old card for testing can be a stressor that will accelerate its failure.

### Gold Card—Guidelines and Techniques

The current study, dubbed the Gold Card project, aims to provide a complete outline of practices that utilities can follow in order to get the maximum usable life out of existing circuit cards and to make informed decisions about repair and replacement. These procedures include guidelines for identifying and reducing or eliminating stressors that might shorten the life of the card, such as excessive temperatures, voltage spikes, vibration, and electromagnetic interference. The report, to be published by the end of 2011, will provide information on identifying vulnerable components that are susceptible to failure, recognizing precursors to failure, and assessing the aging of components.

The Gold Card project also addresses training needs for engineers and technicians to enable them to follow suitable maintenance and troubleshooting practices, including precautions for handling cards to minimize the risk of damage.

Procurement is an often-overlooked but important part of the picture. A section in the Gold Card report will detail the procedures for specifying critical features of replacement cards to obtain high-quality components that meet the demands of the application. Guidelines in the report cover storage, handling, and off-line burn-in of new cards to help ensure that they will not fail when placed into service.

In cases where a card depends on a particularly unreliable component, the best solution might be to replace the entire card with one based on an updated design. The redesign can incorporate more reliable technologies, such as field-programmable gate arrays, to obtain the same operating characteristics as the analog card. The redesign can also remove single points of vulnerability to increase reliability.

A future goal is to develop improved techniques for preparing a highly reliable estimate of the remaining useful life and failure risk of components. One approach being considered is to create computer models of the cards, components, connectors, power sources, cabinets, and operating conditions, simulating not just individual components, but also how they interact with their surroundings. Remaining-life analysis, a statistical method used by the military, aerospace, and automotive industries, can also provide insights. Finally, new card designs with on-board monitoring capabilities could allow real-time detection of failure risks.

*For more information, contact James Heishman, jheishman@epri.com, 704.595.2768, or Joseph Naser, jnaser@epri.com, 650.855.2107.*

## Reactive Cap Shows Potential to Remediate Coal Tar

From the mid-1800s to the mid-1900s—before the nation's extensive network of natural gas pipelines had been established—thousands of local manufactured gas plants (MGPs) produced synthetic natural gas from coal for heating, cooking, and lighting in many parts of the United States. Most of the sites closed during the 1960s, but many of the closures did not address an environmental hazard left behind by the plants—the presence of large amounts of coal tar. Coal tar is composed of hundreds of compounds, some of which are toxic to humans, animals, and plants. Many MGP facilities were located adjacent to rivers and streams, and because coal tar is denser than water, it is often present in river sediments and is challenging to clean up.

A limited number of remediations are available to reduce the exposure potential for humans as well as the risks to the environment. Sediment removal—dredging—has been a commonly used remedy, but it has had mixed results in achieving cleanup goals. One option that has shown promise as an alternative to sediment removal is reactive capping—covering the tainted river bed with a permeable mat of chemically reactive material that can adsorb coal tar residues.

### Field Testing

In 2006, EPRI began planning a field-scale demonstration of three types of reactive caps to control and/or contain coal tar–impacted sediments at a former MGP site adjacent to the Hudson River in New York state. Field work began in 2009, and the test was concluded in January 2011. The project was sponsored by nine EPRI members and hosted by Central Hudson Gas & Electric Corporation at their Poughkeepsie site.

The caps were assembled using Tensar International's Triton® marine mattresses filled with three different types of material:

- Type 1—mattresses filled with 6 inches (15.2 cm) of armor stone, underlain by an organoclay-filled CETCO Reactive Core Mat® (RCM) and geogrid
- Type 2—mattresses filled with 3 inches (7.6 cm) of armor stone and 3 inches (7.6 cm) of sand (wrapped in geotextile)
- Type 3—mattresses filled with 3 inches (7.6 cm) of armor stone and 3 inches (7.6 cm) of bulk organoclay/sand (wrapped in geotextile), underlain by an organoclay-filled RCM and geogrid

Organoclay is a manufactured product in which clay material is mixed with other chemicals to enhance its adsorptive capacity. Laboratory testing using site-specific coal tar was conducted to identify the organoclay best suited for the site. For each cap type,

*Sorbent-filled marine mattresses are lowered into the Hudson River to test their effectiveness in cleaning up coal tar residues.*

25 mattresses measuring 6.5 feet (2 m) by 20 feet (6.1 m) were ganged together and lowered to the river bottom by crane. Site characteristics considered during the study design included strong river currents, relatively deep sediments (approximately 50–60 feet [15.2–18.3 m] below the water surface), and the presence of underwater infrastructure, such as natural gas pipelines and high-voltage electric transmission lines. The caps were left in place for 18 months.

### Positive Results

Divers performed physical inspections throughout the testing period and extracted samples, which were periodically analyzed. At the end of the testing period, the caps were removed and further analyzed for effectiveness. Following is a summary of study conclusions:

- The Type 1 caps had the highest level of success. These mats had approximately twice the adsorption capacity of a 5:1 mixture of sand and bulk organoclay and approximately three times the adsorption capacity of sand.
- Organoclay-filled RCMs retained significant adsorption capacity and permeability 18 months after initial placement—performance comparable to that of unused sorbents
- The effective life of organoclay-filled RCMs depends on the mass of coal tar in the sediments and the mechanisms and rate of transport from the sediments to the overlying water.

The results of this study demonstrate that a reactive capping system may provide utility site managers a viable alternative to sediment dredging, which may not be feasible in locations where contamination is at great depths and strong water currents are present. The choice of material to fill the caps will depend on the characteristics of each site. Detailed findings are presented in the final technical update report (EPRI report 1022757).

*For more information, contact Jeff Clock, jclock@epri.com, 845.608.0642.*

## Powder Metallurgy Improves Fabrication of Large, Complex Components

Valve bodies, pump housings, piping elbows, and many other large and complex power plant components are commonly fabricated using metal casting processes similar to those first applied more than 50 years ago. After casting, extensive machining is typically required to prepare components for service duty, and once installed, components are often difficult to inspect because of a complex cast microstructure.

EPRI's Technology Innovation program is leading collaborative development of powder metallurgy fabrication as an alternative to casting. This breakthrough technology promises to significantly decrease rework and improve inspectability, reducing both costs and risks for nuclear power producers. It could also lead to components with characteristics such as enhanced erosion resistance that today can be achieved only by using coatings or other post-manufacturing treatments.

Powder metallurgy fabrication methods were initially developed for aerospace and other specialty components, which are commonly much smaller than those used in power plants. The process begins with component design, alloy specification, and mold construction. A mold is loaded with metallic powder of the desired composition, degassed under vacuum, and sealed. High temperatures and high pressures consolidate the powder into a solid with homogeneous microstructure.

### Scaling Up for Power Plants

In 2009, EPRI initiated exploratory research to apply powder metallurgy methods in fabricating large, complex power plant components. Working with Carpenter Technology and two valve manufacturers, EPRI demonstrated the feasibility of using an austenitic (316L) stainless steel powder to produce a 12-inch-(30.5-cm-) diameter valve body in "near net shape." The component incorporated intricate features, required no finish machining, and offered exceptional toughness, a 15% improvement in mechanical performance, and superior inspectability relative to conventional cast stainless steel components.

Valve bodies have now been produced from a broad cross section of materials used in nuclear, conventional coal, and ultra-supercritical coal plant applications, including 316L stainless steel, a creep-strength-enhanced ferritic steel (Grade 91), and a nickel-based alloy (Inconel 625). Detailed testing is under way to verify inspectability and weldability, and to generate data required to support an American Society of Mechanical Engineers (ASME) code case permitting these processes to be used for fabricating large pressure-retaining components.

EPRI expects a code package for 316L stainless steel to be submitted to ASME in 2011, with other alloys to follow in 2012. Pending process qualification, an in-plant testing and demonstration program for large-scale powder metallurgy valves is scheduled for 2013, and commercial manufacturing could begin that same year. For both nuclear and fossil plants, the technology has true breakthrough potential for replacement components and new construction. Primary advantages include:

- ***Efficiency.*** "Near-net-shape" components reduce materials waste and minimize machining and cleanup. Improved production efficiency reduces manufacturing and delivery lead times and costs.
- ***Inspectability and weldability.*** Cast components may contain microstructural irregularities that make nondestructive inspection difficult. Powder metallurgy produces a very uniform, homogeneous microstructure that is much more amenable to inspection for both defects and sizing. The microstructural properties also enhance weldability.
- ***Optimization.*** Powder metallurgy allows materials' composition to be specified and optimized component by component, reducing waste and facilitating the use of new alloys.

### Follow-On Research

EPRI is exploring powder metallurgy's advantages for precisely controlling materials composition during fabrication to achieve desired functional characteristics, such as increased erosion resistance at the surface of a valve, fan blade, or turbine blade. A feasibility demonstration is focusing on valves made with 316L stainless steel that incorporate materials to reduce erosion, wear, and galling at the surface, along the seat/hardfacing region.

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# TECHNOLOGY AT WORK

*Member applications of EPRI science and technology*

## Con Edison Collaborates on Manhole Arc Detector

Cable deterioration in underground vaults is more than a routine maintenance concern. Damage to cable insulation or splices caused by rodents, chemicals, or simple aging can produce electrical arcing and high temperatures that cause the insulation to smolder and produce toxic or combustible gases. Continued arcing may ignite the gases, leading to vault fires or even explosions. Thus, a potential reliability issue becomes a worker safety issue.

EPRI and Consolidated Edison of New York are collaborating to develop technology that will alert workers to the presence of low-voltage system cable faults in underground structures. This work has resulted in a prototype safety device that warns workers of electrical arcing before they enter a structure and monitors for arcing as crews work. The prototype unit is fully functional and detects arcing events with very high sensitivity.

*Lowered into a manhole, the detector's sensor pod can signal the presence of arcing before workers enter underground structures.*

### Easy to Use, Accurate Results

Using this technology is straightforward. The briefcase-size measurement system is connected to a sensor pod that is lowered into a manhole before workers enter. The sensor pod samples the electromagnetic spectrum within the manhole. If the system senses a certain combination of cable arcing signatures, the unit sounds an alarm and initiates a flashing light, alerting workers to the potential arcing concern. If workers determine that the manhole is safe to enter, they keep the sensor with them as a warning indicator in case a nearby arcing event should begin while they are inside the manhole.

The new device offers a significant advantage over existing technology, as most arc detection systems require the user to clamp a sensor around the cables to be measured, which is not feasible if the objective is to scan the structure before entering. The only currently available noncontact device suitable would be an AM radio receiver, but such a receiver is not capable of distinguishing between real arcing and the many other spectrum emissions that might cause false alarms. The EPRI prototype is the first device to accurately accomplish arc detection and alarm objectives with the operator safely outside the underground structure.

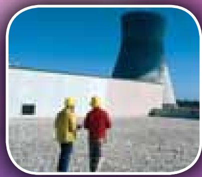
### Past Work Leads to New Technology

The ability to recognize specific electromagnetic signatures that appear during arcing events is central to the detector's function. Two decades of EPRI research have led to important developments in arc fault recognition and location within power systems, and the industry now has a better understanding of the nature of the arc itself. Having sharp rise times and erratic states with various periods, arcs generate a broad spectrum of frequency emissions that range from interharmonics around the 60-hertz power frequency to radio frequencies extending to hundreds of megahertz. This broad spectrum of emissions has allowed several key signatures to be extracted, and through digital signal processing, an arc may be detected in its early stages with a high level of confidence.

Development of the arc detector built on earlier proof-of-concept testing by EPRI, which suggested that even small, low-current arcs emit discernable signatures that can be picked up by properly configured off-the-shelf hardware. This led EPRI and Con Edison to collaborate in testing various hardware devices and filtering algorithms under both laboratory and field conditions. Much of this work was performed at the Con Edison Cable and Splice Center for Excellence, an advanced laboratory environment well suited for such an effort. The overall objective was to develop a system that detects arc faults with very high sensitivity and a minimum of false alarms.

The prototype arc detection system is now being field-tested to confirm its capabilities and its reliability and sensitivity objectives. "Initial results have been promising," said Neil Weisenfeld, department manager for distribution cable systems and team leader for this project at Con Edison. "Worker and public safety is a top priority for Con Edison, and if this system can be optimized and then commercialized, there is a significant potential to improve safety for our employees and advance the state of the art in detection of low-voltage arcing."

*For more information, contact Doug Dorr, ddorr@epri.com, 407.968.3010.*


## A Software Solution for Dry Cask Storage Strategies

In the absence of centralized storage facilities or licensed disposal facilities, used fuel assemblies discharged from U.S. nuclear reactors must be stored at the reactor sites in dry storage systems, consisting of either all-metal casks or metal canisters in concrete overpacks, located outside the reactor buildings on sturdy concrete pads. Using such dry cask storage presents substantial logistical and data-management challenges, including the matching of fuel assembly characteristics with specific cask/canister designs.

Entergy, Exelon, and other nuclear utilities are now applying EPRI's Cask Loader software to plan and execute the transfer of used fuel assemblies into dry storage systems. The software, along with collaboration and information sharing among members of the Cask Loader Users Group, is helping utilities optimize cask loading costs and scheduling, ease crowding in spent fuel pools, analyze cask loading scenarios to plan future used-fuel management strategies, and standardize dry cask storage procedures across multiple sites.

### End-of-Life Logistics

When fuel assemblies reach the end of their useful lives, they are removed from the reactor core and stored in steel-lined, water-filled pools at the reactor site. As these fuel pools eventually fill up, they lose their ability to accommodate a full-core offload that may be required to support inspection, maintenance, or repair of the reactor internals. To prevent such occurrences, some of the used fuel assemblies must, on a regular basis, be transferred from the wet pools into dry casks.

A plant's spent fuel pools can contain several thousand fuel assemblies—each about 15 feet (4.6 m) long and weighing approximately 700 pounds (317.5 kg) for a boiling water reactor (BWR) assembly and about twice that for a pressurized water reactor (PWR) assembly. Each assembly has different physical properties, such as fuel composition, radioactivity, decay heat, and burnup. Cask manufacturers customize each cask's internal structure to store specific types of assemblies with particular physical properties. Unfortunately, the various types of data associated with an individual fuel assembly and dry cask are often in different locations, and some are not in electronic form. Manually sorting and prioritizing assemblies for cask loading is thus complex, time-consuming, and costly, given that a single cask can hold up to 40 PWR assemblies or 68 or more BWR assemblies.

### Matching Up Specs

EPRI's Cask Loader software helps users select the appropriate used fuel assemblies for each cask and then prints utility move sheets and other required forms. This enables plant personnel to minimize fuel movement and significantly reduce documentation errors. Inputs to Cask Loader include fuel assembly as-built data, burnup, core location, and failure status; core data, including cycle dates and exposures; and cask as-built data. Cask Loader populates the chosen casks according to each cask's technical specifications and the available fuel assemblies that match these specifications. Users can print reports and export data to spreadsheets or other proprietary report formats.

Cask Loader also enables users to calculate the decay heat of a fuel assembly, one of the key factors influencing cask loading decisions because of regulatory limits that specify the thermal performance criteria that must be met by dry storage systems. These calculations are based on the U.S. Nuclear Regulatory Commission's (NRC's) Regulatory Guide 3.54 procedure or the NRC Branch Technical Position ASB 9-2.

Some utilities input their spent fuel assembly data into Cask Loader and run the program themselves, while others may engage a vendor to use the program to develop loading plans. In either case, the software offers an integrated, comprehensive solution to both near- and long-term decisions.

"Using standardized loading procedures across multiple sites is much more cost effective than having each site use a different approach," said John Weiss, senior lead engineer, Entergy. "Moreover, the software enables us to run many loading scenarios, making it a powerful tool for planning how to unload spent fuel pools over time in the most efficient and cost-effective manner without running into problems in the future."

*For more information, contact Mary McKenna, mmckenna@epri.com, 650.855.7931.*

# 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 go to Program Cockpits.*

### Nuclear Maintenance Applications Center: Guideline for Cooling Tower Inspection and Maintenance (1021060)

This report identifies failure mechanisms and provides inspection and maintenance guidance on mechanical and natural-draft cooling towers used in nuclear plants. In addition to basic information on cooling tower construction and principles for operation, the report offers guidance on identifying degradation, assessing damage severity, and effecting mitigation or repair.

### Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects: Volume 1, Measuring Impacts (1021423)

This guidebook presents a step-by-step framework and standardized approach for estimating the benefits and costs of smart grid demonstration projects. Included are detailed discussions of the first 17 steps, from initial project definition to establishing measurement and verification protocols. The guidebook can help utilities produce evaluations that meet reporting requirements for DOE-funded smart grid projects as well as provide the types of information that regulatory commissions are likely to require for approving cost recovery through regulated rates.

### Permitting Guidance for Biomass Power Plants (1022577)

This report was developed to assist power plant owners and project developers in preparing permit applications for direct-fired biomass power plants. Technology and permitting considerations applicable to four specific scenarios are highlighted: (1) new 100% biomass power plants, (2) repowering or replacement of fossil fuel–fired units with biomass-fired units at existing power plants, (3) conversion or modification of fossil fuel–fired units at existing power plants to biomass firing, and (4) modification of existing coal-fired units to allow for biomass co-firing.

### Evaluation of Waterwall Corrosion Fatigue, Volumes 1 and 2 (1022707 and 1022708)

Research has shown that although corrosion fatigue damage may look the same in multiple units, the actual root cause may be different in each instance. Volume 1 provides a step-by-step process for understanding and mitigating boiler damage, including a methodical way to determine root causes. Volume 2 presents a case study of corrosion fatigue at American Electric Power's Big Sandy Unit 1, delineating operational, design, and maintenance aspects that have allowed damage to develop.

### Control Relay Aging-Management Guideline: Auxiliary, Control, and Timing Relays (1022972)

Recent data show that many nuclear plant control relays have been in service for an extended period of time without an effective aging-management program in place and that relays are one of the leading component types causing scrams. This report provides an evaluation of maintenance and replacement strategies for auxiliary, control, and timing relays and includes guidance on maintenance frequencies, a decision-making flowchart, programmatic recommendations, and a collection of best practices.

### Key Institutional Design Considerations and Resources Required to Develop a Federal Greenhouse Gas Offsets Program in the United States (1023122)

This report evaluates the government requirements and resources needed to develop a large-scale national domestic greenhouse gas emissions offset program. It also describes potential institutional barriers that might limit the ability of the evolving carbon market to generate significant offset supplies in the United States, in both the near and the long term. Proposed alternative approaches to addressing these institutional barriers also are discussed.

### Communication Modularity: A Practical Approach to Enabling Residential Demand Response (1023245)

An important part of the smart grid vision is enabling communication connections with residential devices so that ratepayers can be involved in demand response activities. This white paper describes an EPRI project through which industry participants developed and demonstrated a modular interface specification that enables product compatibility with any demand response system through standardized plug-in communication modules.

### Plausibility of Toxicological Interaction Between Lead and Methylmercury (E235282)

Improved quantification of the joint risk for concurrent exposures to lead and methylmercury will require integration of the underlying toxicological mechanisms for these developmental neurotoxins. This work summarizes the available evidence for a biological interaction of lead and mercury, the relevance to neurological and developmental effects, and the implications for future human health risk assessments.

## Preparing for the Unthinkable

Maria Korsnick, *Chief Nuclear Officer, Constellation Energy Nuclear Group (CENG)*

Since March 11, 2011, we have witnessed the devastation brought upon Japan by an immense earthquake and the corresponding tsunami. The natural disaster also severely damaged the Fukushima Daiichi Nuclear Power Station, prompting important and valid questions about the nuclear power industry's safety, security, and ability to respond to a myriad of "what if" scenarios.

One fact is clear: nuclear plant operators go to great lengths to produce electricity safely, reliably, and economically. Multiple layers of physical security and high levels of operational performance protect the public, plant workers, and the environment. In the United States, the Nuclear Regulatory Commission's (NRC) independent oversight helps ensure that American nuclear plants are well designed, properly operated, secure against attack, and prepared in the event of an emergency.

Operators are rigorously trained and hold federal licenses to operate each facility. Emergency response plans, tailored to each nuclear site, are regularly tested during exercises with federal, state, and local emergency response organizations.

Despite our ingrained emphasis on safety, security, and continued learning, this tragic accident is a stark reminder that we must rededicate our efforts so that we can meet a crisis of similar magnitude. The industry is taking the same aggressive approach we used after the September 11, 2001 terrorist attacks, when we invested millions of dollars to drastically enhance our security capabilities. This effort encompasses detailed technical analysis, identification of possible physical and procedural modifications, regulatory interactions, and research to drive continuous improvement. Simply put, preparing for the unthinkable will strengthen the nuclear industry and increase safety at all nuclear power plant sites.

At my company, which operates five nuclear units in New York and Maryland, we are initially focusing on lessons related to four aspects of the Fukushima Daiichi accident: probabilistic risk assessment (PRA) of external events, station blackout planning, used/spent fuel storage, and specialized disaster-response equipment. Each aspect provides opportunities to respond effectively to any incident.

- The cumulative effect of two natural disasters inspired a reevaluation of PRAs that model natural and manmade disasters. Such models help identify where events pose the greatest risks to safe plant operations, enabling owners to focus resources in those areas. Current evaluations that consider solo events may need to review multiple-event scenarios, such as tornadoes and massive flooding. Additionally, PRAs that estimate injury to the public and environmental damage may need to be considered.
- An immediate lesson learned is the need to increase our versatility and defense in depth by using portable equipment. We will examine severe accident time lines and logistic capabilities to determine the amount of portable equipment (pumps, compressors, diesel generators) each site requires to supplement safety equipment procured after the 9/11 terrorist attacks and the appropriate location to store the equipment.
- The Fukushima Daiichi accident has raised important questions about the handling and storage of used/spent fuel. We are reviewing the methodology employed to determine the length of time that used/spent fuel is stored on site before transferal to dry storage. It may be feasible to move used fuel assemblies from wet storage pools to dry storage facilities more quickly, but we need to evaluate the range of factors involved in such a decision, including worker radiation exposure, manufacturing capacity for dry casks, and economics.
- The Fukushima Daiichi accident also demonstrated the need for specialized equipment, such as robotics, if radiation levels restrict plant access. Regional staging of key equipment could be established to provide a centralized, rapid-response capability that would be available to all nuclear power plants.

In the wake of the Fukushima accident, EPRI, the Nuclear Energy Institute, the Institute of Nuclear Power Operations, the World Association of Nuclear Operators, and senior utility executives formed the Industry Response Team to integrate and coordinate our response to this incident. We recently published "The Way Forward," which describes our objective to learn and apply lessons from the accident and our strategic goals. The industry also is ready to engage the NRC in discussing actions that may be needed to address the findings from its 90-day Japan Task Force report.

The nuclear power industry's passion remains fixed on safety: public safety, worker safety, and environmental safety. Through global collaboration, communication, and a renewed commitment to excellence, we are committed to learning from this tragedy so that we can become an even safer industry.

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