FALL 2005

EPRI JOURNAL

ELECTRIC POWER RESEARCH INSTITUTE

THE PLUG-IN HYBRID VEHICLE: BEYOND GASOLINE

ALSO IN THIS ISSUE:

ELECTRIC POWER RESEARCH INSTITUTE

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

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Kevin Evans, *Senior Vice President and Chief Business Officer*

Contact Information
Editor-in-Chief
EPRI Journal
PO Box 10412
Palo Alto, CA 94303-0813

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COVER: Unlike conventional hybrids, the plug-in hybrid vehicle runs on electricity downloaded directly from the power grid, allowing personal transportation to draw on a broad variety of energy resources, including coal, nuclear, and renewables. (Art by Craig Diskowski/Edge Design)

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Editorial

Getting Oil Off the Streets

Electricity is undoubtedly the greatest tool for progress that the world has ever known. Even a cursory review of the last century shows that the unmatched efficiency, cleanliness, versatility, and controllability of electric power have enabled society's most important technological advances: from universal lighting to labor-saving household appliances to large-scale manufacturing to global communications to electronic commerce—the list seems endless. Electrification is so ubiquitous that it's become an almost unnoticed part of our lives while quietly powering our largest buildings and machines and our smallest personal handheld devices. Today there is but one major sector of energy use that has not benefited from the advantages of electricity: transportation. In this digital age, our "nation of drivers" gets around the same way it did in Henry Ford's day—by exploding gasoline in millions of internal combustion engines.

The recent emergence of the gasoline-electric hybrid as a commercially viable, high-mpg, low-emissions automobile is certainly an encouraging development. But while the hybrid has successfully capitalized on the efficiency of an electric motor–based drive train, virtually all the hybrids on the road today are still fueled entirely by gasoline. We can do much better. In a collaborative effort with DaimlerChrysler, EPRI is currently developing a plug-in hybrid vehicle that can operate for the first 20 miles of every day solely on electricity downloaded from the U.S. power grid via a standard 120- or 240-volt wall socket; if you need more range than that in a day, the vehicle automatically switches over to its gasoline engine, which then powers the car and recharges its battery like a conventional hybrid. Since about 40% of Americans drive 20 miles a day or less, millions of miles of daily travel could be powered entirely by electricity.

Many of the advantages of such a vehicle are clear. An automobile operating primarily on electricity is simply a cheaper ride, with electric "fuel" approaching the cost equivalent of 75¢-per-gallon gasoline. Air emissions may also be lower, depending on the specific electricity generation mix of the region. But the most important advantage of a plug-in hybrid is fuel flexibility. Today our only options are oil-derived gasoline and diesel fuel, whose prices and availability are largely dictated by overseas governments and cartels. The plug-in broadens the fuel mix to the nation's entire portfolio of electricity generation options: you can drive your car on coal, hydro, nuclear, wind, and biomass—energy resources that are plentiful and economical in this country.

Commercialization and widespread adoption of plug-in hybrid electric vehicles—a possibility that many experts see as a likely extension of the present hybrid boom—could go a long way toward breaking the stranglehold that oil dependence is having on our economic and energy security. Through support of this vision, the electric power industry has a terrific opportunity to extend the long history of electricity's value to society and to effect a permanent, substantial increase in this nation's energy self-sufficiency. I'm excited about the prospect of expanding the benefits of electricity by helping it achieve its full potential in transportation. Together we can lower the use of imported oil on our streets and plug into the promise of an extremely efficient, lower-cost alternative.

Steven Specker
President and Chief Executive Officer

Contributors

Driving the Solution: The Plug-in Hybrid Vehicle

(page 8) was written by science writer Lucy Sanna with technical assistance from Robert Graham and Mark Duvall.

Robert Graham is manager of EPRI's Electric Transportation Program. Before joining the Institute in March 1999, he worked for Northrop Grumman Corporation as director of its program on advanced-technology transit buses. Graham received a BS degree with an interscience major from Hampden-Sydney College in Virginia, and he also earned an MBA from Pepperdine University.

Mark Duvall is the manager of technology development for the Electric Transportation Program. He joined EPRI in 2001 after conducting R&D on prototype plug-in hybrid vehicles as a principal development engineer at the Hybrid Electric Vehicle Research Center at the University of California at Davis. Duvall has BS and MS degrees in mechanical engineering from UC Davis and a doctorate from Purdue University.

The Challenge of Nuclear Fuel Reliability

(page 18) was written by science writer Taylor Moore with technical information from Rosa Yang and Kurt Edsinger.

Rosa Yang is the technical executive for EPRI's Fuel Reliability Program. Before joining the Institute in 1987, she was with the Nuclear Fuel Engineering department at General Electric Company. Yang received a BS in nuclear engineering from National Tsing Hua University in Taiwan and holds MS and PhD degrees in the same field from the University of California at Berkeley.

Kurt Edsinger, senior project manager in the Fuel Reliability Program, is the technical leader for the Institute's nuclear fuel performance and reliability work. Before coming to EPRI in 2001, he worked for six years in General Electric Company's fuel group. Edsinger holds a BS from San Jose State University and a PhD from the University of California at Santa Barbara, both in chemical engineering.

IntelliGrid℠: A Smart Network of Power

(page 26) was written by science writer Paul Haase with guidance from Don Von Dollen.

Don Von Dollen, manager of the IntelliGrid Program, joined EPRI in 1991, focusing initially on underground transmission and superconductivity projects. Previously he spent three years at Pacific Gas and Electric Company as an engineer in the R&D and technical services programs. Von Dollen holds a BS in physics from California State University, Sacramento.

Innovation

Emerging technologies and cutting-edge engineering

The Innovator's Circle program was initiated in 2001 to provide seed funding for novel research ideas generated by EPRI staff members. The objectives of the program are to stimulate creative thinking, to incubate new technologies that are premature for consideration through EPRI's normal funding streams, and to enhance the Institute's overall culture of innovation. Eight to ten projects are chosen every year, each funded at a modest $100,000 or less. Three of the projects for 2005 are described below.

Distributed Computing for Real-Time Security Assessment

The growth of bulk power transfers in deregulated wholesale electricity markets is increasingly pushing the interconnected high-voltage utility grids of North America to their limits. Operating margins are further narrowed as a result of the relatively poor understanding of the dynamic stability constraints faced by power system operators. A new approach for assessing power system security—in real time using data on actual conditions as they develop—could help the electric power industry solve critical, longstanding problems with power system stability.

For years, system operators have compiled operating guidelines from non-dynamic, off-line stability studies. "When adjusted for actual generation patterns and transmission network conditions, the stability limits from off-line simulations tend to be conservative for normal conditions and inaccurate for unusual events," explains Pei Zhang, EPRI program manager for grid operations and planning. "A real-time security analysis tool is critical if system operators are to understand exactly where the stability boundaries are at any given time." The need for such a tool is underscored by lessons from the August 14, 2003, Northeast Blackout.

Assessing the real-time, dynamic security of a power system involves running complex simulations of hundreds of possible contingencies—continuously and virtually instantaneously. Such a formidable computing challenge has previously been beyond the capabilities of all but the largest, most costly supercomputers; an alternative approach has now emerged that may provide a far more economical solution. In recent years, the information technology industry has introduced increasingly affordable distributed computing technology as a means of more fully using all computing resources in large, interconnected networks of processors. Analogous to parallel processing in a supercomputer, distributed computing allows multiple tasks to be processed in parallel over a network, in substantially less time than was previously possible.

EPRI has launched a feasibility study of this distributed computing concept for real-time stability analysis in power system operations. The two-stage effort involves the adaptation of EPRI's Extended Transient Midterm Stability Program (ETMSP) and its integration with distributed computing technology. New software is being developed to prepare ETMSP contingency cases, and the simulation tasks for the cases will be distributed among many computers connected in a network. Additional software will be developed to gather and integrate the output results from all the computers performing simulations. Finally, the project will test the performance of the distributed computing approach to verify that it meets operators' requirements for real-time security analysis. By simulating hundreds of contingencies, researchers expect to determine how many computers would be needed to serve the needs of an actual utility transmission network.

For more information, contact Pei Zhang, pzhang@epri.com.

Delivering Biocides Via Nanoporous Particles

Microbiologically induced corrosion (MIC) can be a problem in the service water systems of fossil-fuel and nuclear generating plants. With the buildup of tiny organisms in the closed loop of recirculating water, this type of corrosion results from the aggressive nature of the microbes' metabolic products or from the formation of crevices in the piping interiors that allow localized changes in water chemistry. Individual microorganisms (in the planktonic state) can be killed relatively easily, but their tendency to collectively form a persistent biofilm can make them quite difficult to eliminate.

The amount of biocide required to kill a biofilm can be as much as 1000 times the amount necessary to kill the same number of planktonic cells, for several reasons. First, the biofilm may be thick and composed partly of viscous slime that restricts mechanisms for transporting biocide from a bulk solution through the film. Second, once the biofilm's outer layer consumes biocides, whether they are of the oxidizing type (such as chlorine) or the nonoxidizing type (such as a poison), the outer layer dies. If this mechanism prevents a sufficient concentration of biocide from reaching the inner film region, the film survives and eventually recovers. Finally, the lower levels of oxygen in the film near its contact with the metal surface can induce a slower metabolic rate in the microorganisms; this makes nonoxidizing biocides less effective at a given concentration, even at the inner film region.

"Higher concentrations of biocide would be more effective, but using them in service water systems is not feasible because of environmental and cost concerns," explains Peter Chou, an EPRI project manager. "A method that delivers biocides into the interior of a biofilm without inducing high levels in the bulk solution is preferable." Encouraged by research reports from the emerging science of nanotechnology, Chou believes that particles with biocide embedded in nanoscale pores—on the order of 100 nanometers, or 25 millionths of an inch, in diameter—may be able to more deeply penetrate the outer layer of a biofilm, bypass it, and penetrate deeply enough to do their job on the inner layer.

In addition, incorporating biocides within particle nanopores would allow biocide to be concentrated locally over a small volume (that of the particles) rather than through the entire volume of the bulk flow circuit. So while the total amount of biocide needed is expected to be lower, the particles will act as local sources of concentrated biocide once they are implanted within the film. These advantages are predicated on the time-release nature of the nanopores, the surface interactions of which would introduce a time constant for the delayed release of biocide.

"Nanoporous particles infiltrated with biocide may be able to deliver high effective local concentrations of biocide to the biofilm without exceeding acceptable concentrations in the bulk solution," notes Chou. "This would allow a level of control over MIC that is not currently available. As a result of the lower concentration, less biocide would have to be removed from the water before discharge, which is both environmentally and economically advantageous."

Chou says it may be possible to infiltrate water-dispersible polymeric nanoporous particles with a marginally water-insoluble biocide that cannot otherwise be delivered effectively into solution. "This would broaden the treatment options for MIC," he adds.

For more information, contact Peter Chou, pchou@epri.com.

Controlled Reuse of Nuclear Material

Disposal of materials from retired nuclear power plants is an issue of concern to both the nuclear industry and the public. Just throwing away decontaminated metals is wasteful from the industry's point of view; and while it is possible to clean up many retired nuclear components to contamination levels below what is necessary for release into the public domain, there is public unease with the prospect of formerly contaminated materials passing into unrestricted use. A novel approach offers a way to keep these materials out of public contact and at the same time provide high-quality, recycled metal alloys at lower cost for reuse in the nuclear industry.

Known as "provenance tracking," the approach involves cleaning materials to contamination levels sufficiently low to allow their unrestricted release and then passing them to specialty alloy makers for melting and remanufacture into components and products for use solely in nuclear industry applications. The material is tracked through each step in the manufacturing chain to ensure compliance with its restricted end use.

Advantages of the approach include the ability to use existing manufacturing facilities and the flexibility to recycle a wide variety of cleaned materials into almost any of the products used in the nuclear industry: piping, valves, fasteners, waste containers, and other items. The economic benefits of the approach are greatest when the component or material in question has high intrinsic value—when it contains nickel, for example. The practice has already been established in the industry for certain products, such as shielding blocks.

"Decontamination of retired nuclear plants and components demands the proper management of the process, both for economic reasons and for retaining public confidence in the continued use of nuclear power for electricity generation," notes Chris Wood, program manager in EPRI's nuclear power group. "The industry will require large quantities of materials for various facilities in the future. The idea that these components should, where possible, be built out of recycled materials appears to command widespread support. The industry would also be likely to accept this practice if it permits a significant proportion of waste materials to be treated in an economical manner."

EPRI is pursuing an initiative to establish and demonstrate a complete provenance tracking process for actual radioactive material.

For more information, contact Chris Wood, cwood@epri.com.

Washington Report

Energy news and information from the nation's capital

The Energy Policy Act of 2005: Some Perspectives

On August 8, 2005, President Bush signed into law the Energy Policy Act of 2005, which he described as a bi-partisan energy bill that "will give America a comprehensive national energy strategy for the first time in a decade, [which] is critically important to our long-term national and economic security." Few would disagree as to the bill's scope or the critical need for national energy policy. While the energy bill of 1992 heralded deregulation and electric power markets, the 2005 act is largely focused on technology and the supply side of the energy equation. It promotes diversity of fuel options, with emphasis on low- and non-emitting technologies, and addresses critical infrastructure needs, such as reliability and transmission siting.

While the 2005 bill represents major advances in energy policy, it is not a silver bullet; it authorizes spending and incentives to move the industry forward but requires further White House and congressional action to turn those authorizations into appropriations. Given the bill's length—over 1700 pages organized under 18 separate sections—this article does not attempt a comprehensive overview. Instead, it offers some perspectives on the technology choices encouraged by the bill and their policy implications.

Consistent with the administration's general neutrality on the subject of climate change and carbon constraints, the energy bill devotes only two provisions explicitly to climate change. Those provisions direct the Department of Energy (DOE) to examine development of a national strategy to promote and commercialize technologies that will reduce greenhouse gas emissions intensity, and they recommend implementation of a strategy to export those technologies to developing countries. But underlying this modest agenda are a number of substantial and creative authorizations, incentives, and tax credits that support research, development, and deployment (RD&D) for low- and non-emitting energy sources and for technologies to address carbon. Nuclear and coal receive critical attention and support; aid to renewables is addressed to a lesser degree but certainly not ignored.

The Nuclear Option

President Bush observed when signing the bill that "of all our nation's energy sources, only nuclear power plants can generate massive amounts of electricity without emitting an ounce of air pollution or greenhouse gases." Setting aside the contentious issue of Yucca Mountain, the new law directs DOE to support R&D for the existing nuclear fleet, particularly with respect to reliability, availability, component aging, security, and safety. Near-term new-generation (Nuclear Power 2010) and advanced (Generation IV) nuclear energy systems with hydrogen-producing capacity are both supported by a $600 million authorization over three years. The bill also puts into place investment incentives for early deployers of new plants—including loan guarantees, an $18/MW production tax credit for certain early deployers, and $2 billion in risk coverage to mitigate delays in bringing new plants on line where the delays are not the owner's fault.

These incentives help address the fact, cited in a recent Harvard/Massachusetts Institute of Technology study, that deployment costs are far higher for new nuclear plants than for conventional fossil fuel plants. The Harvard/MIT study emphasized that despite the cost, the "nuclear option should be retained precisely because it is an important carbon-free source of power," (*The Future of Nuclear Power: An Interdisciplinary MIT Study,* http://web.mit.edu/nuclearpower). By addressing the deployment cost issues of new nuclear facilities, the energy bill supports technologies that can mitigate greenhouse gas emissions.

Keeping Coal in the Fuel Portfolio

Coal—widely recognized as the country's most secure and plentiful fuel resource—also receives strong support in the energy bill; that support is focused on clean coal technologies and the potential for addressing carbon dioxide emissions from coal-burning plants. Again without taking on climate change, the President nonetheless emphasized when he signed the bill that it provides support for RD&D related to environmentally friendly coal technologies, driving toward "our goal of building the world's first zero-emission coal-fired power plant." To that end, the bill authorizes over $1 billion for coal-related RD&D and $200 million annually through 2014 for the Clean Coal Power Initiative. An additional

$90 million over three years is authorized to develop carbon capture for combustion-based systems. The bill creates the $3 billion Clean Air Coal Program to support reductions in sulfur dioxide, nitrogen oxides, and mercury, thereby improving the energy efficiency and environmental characteristics of existing plants.

Renewables

As noted above, renewables are not ignored in the energy bill, though many advocates are disappointed in the level of support they have received. While renewables do not see the budget authorizations that nuclear and coal receive, existing tax credits for wind, biomass, geothermal, and certain other renewables are extended; solar energy credits are increased, and new tax credits are authorized for fuel cells and distributed generation. For the first time, the bill creates a bond—the $800 million Clean Renewable Energy Bond—to provide interest-free loans to nontaxpaying builders of renewable energy facilities. The bond is scheduled to expire on December 31, 2007, simultaneously with the renewable energy production tax credit. These credits are not insignificant. They are available now and require no additional congressional or White House action.

Other Key Provisions

The new energy bill delineates changes and authorizes spending in a number of other areas of importance to the electric utility industry. Among these provisions are:

- A 20-year reauthorization of the Price Anderson Act, which indemnifies DOE contractors and NRC licensees
- Authorization ($40 million over four years) for DOE to improve power systems and other technologies for advanced vehicles, including plug-in hybrids and flexible-fuel vehicles
- Creation of mandatory electricity reliability standards, including provisions for cyber security
- Policy support for the deployment of advanced transmission technologies
- Federal Energy Regulatory Commission (FERC) transmission pricing incentives
- FERC backstop authority for interstate transmission siting
- Repeal of the Public Utility Holding Company Act (PUHCA)
- Modifications to the Public Utility Regulatory Policy Act (PURPA)

Next Steps: Appropriations and Tax Credits

Unlike tax credits, the authorizations contained in the energy bill require the White House to take action in the Fiscal Year 2007 budget and the Congress to appropriate funds. The difference between what is authorized and what is eventually appropriated is often significant. In the few months that have passed since the energy bill was signed into law, the budget landscape has changed dramatically. Hurricanes Katrina and Rita devastated the Gulf Coast, significantly diminishing the "art of the possible" when it comes to appropriations. For energy-related programs, the possibilities may be much more severely limited than it appeared on August 8. No predictions are offered on the outcomes here.

But while the government's ability to fund is uncertain, the industry should not overlook the potential benefits provided by tax credits offered in the energy bill or in the accompanying Energy Policy Tax Incentives Act. One provision that has not received a great deal of attention is the new energy research and development tax credit.

Several years ago, Congress approved an incremental tax credit to promote corporate research and development efforts. That credit (20%) applies only to amounts spent over the taxpayer's historic base R&D funding (an average of R&D funding over a period of years). In an era of generally declining R&D budgets, few in the energy industry qualified, as they did not spend over their base amounts. The energy bill offers an opportunity to promote energy R&D spending by expanding the corporate tax credit for such activities. The Energy Policy Tax Incentives Act includes language offering a credit for "20 percent of the amounts paid or incurred by the taxpayer…during the taxable year…to an energy research consortium," (Internal Revenue Code section 41(a)(3) as amended, August 8, 2005). *Energy research consortium* is defined in the act as an IRC section 501(c)(3) tax-exempt organization "organized and operated primarily to conduct energy research." As the credit applies to energy research broadly, it could presumably support a wide array of activities. The expanded research tax credit has been given the same expiration date as the existing corporate R&D tax credit: December 31, 2005. Efforts for its renewal are under way.

This credit, as well as the others provided in the bill, should help further the technology-driven goals of the act even while the more ambitious agenda of authorizations awaits further action.

Energy II

As Congress begins its second energy debate of 2005, dubbed Energy II, it is apparent that the Energy Policy Act of 2005 does not address all of the immediate energy challenges facing the nation. Hurricanes Katrina and Rita pointed up unrecognized weaknesses in the nation's infrastructure security. The aftermath of the storms offers an opportunity to explore once again how advanced energy technologies can improve the efficiency and resilience of our energy enterprise and, as a result, increase the value of electricity to society.

DRIVING THE SOLUTION
THE PLUG-IN HYBRID VEHICLE

by Lucy Sanna

The Story in Brief

As automakers gear up to satisfy a growing market for fuel-efficient hybrid electric vehicles, the next-generation hybrid is already cruising city streets, and it can literally run on empty. The plug-in hybrid charges directly from the electricity grid, but unlike its electric vehicle brethren, it sports a liquid fuel tank for unlimited driving range. The technology is here, the electricity infrastructure is in place, and the plug-in hybrid offers a key to replacing foreign oil with domestic resources for energy independence, reduced CO_2 emissions, and lower fuel costs.

In November 2005, the first few prototype plug-in hybrid electric vehicles (PHEVs) will roll onto the streets of New York City, Kansas City, and Los Angeles to demonstrate plug-in hybrid technology in varied environments. Like hybrid vehicles on the market today, the plug-in hybrid uses battery power to supplement the power of its internal combustion engine. But while the conventional hybrid derives all of its propulsion energy from gasoline, the PHEV gains much of its energy from the electricity grid.

What does this mean for the consumer? At current U.S. energy prices—that is, with the cost of gasoline at $3 per gallon and the national average cost of electricity at 8.5¢ per kilowatthour—a PHEV runs on an equivalent of 75¢ per gallon. And given that half the cars on U.S. roads are driven 25 miles a day or less, a plug-in with even a 20-mile-range battery could reduce petroleum fuel consumption by about 60%.

The PHEV combines the best of both electric vehicle and hybrid technologies. Like the electric vehicle, the PHEV is fueled by electricity generated from domestic resources: it reduces carbon dioxide (CO_2) and urban pollutants, provides utilities with a new, sustainable market for off-peak electricity, and offers consumers a clean, low-cost transportation fuel option. And like the hybrid, the PHEV can run on liquid fuel for unlimited driving range. This combination makes the PHEV more efficient in fuel and total energy use than any vehicle of comparable size and performance on the road today.

Dr. Fritz Kalhammer, who beginning in 1973 established and directed EPRI's programs for energy storage, fuel cells, and electric vehicles, has advocated a shift in focus to PHEVs for more than five years. "The PHEV is unique," he states. "It offers the optimal mix of power from the battery and the engine—of energy from the grid and the gas station—to consumers with varying transportation needs. Auto manufacturers can eventually provide a variety of battery options tailored to specific applications—vehicles that can run 20, 30, or even more electric miles."

Until recently, however, even those automakers engaged in conventional hybrid technology have been reluctant to embrace the PHEV, despite growing recognition of the vehicle's potential. A chief concern is the prospectively higher cost of the larger batteries required. Indeed, because the advanced batteries needed for PHEVs are currently produced on a limited scale, prototype PHEVs are costly, but once batteries go into mass production, costs are expected to come down.

According to Robert Graham, manager of EPRI's Electric Transportation Program, "We have the basic technology for the PHEV—the electric drive system and advanced batteries—and we have the infrastructure—home recharging. Our main challenge is to optimize the design of the batteries and the integrated battery-engine control systems that will allow us to take full advantage of the superior fuel savings and emissions reduction potential of this vehicle."

But is there a market? In a 2001 study, EPRI found that 30–50% of consumers surveyed would choose a PHEV even if it were priced up to 25% higher than a $19,000 conventionally powered vehicle. What's more, 63% of respondents preferred plugging in a vehicle at home to going to the gas station. At the time of that survey, the U.S. national average price of gasoline at the pump was projected to be $1.65. Since then, the price has nearly doubled. This ongoing trend makes all types of hybrids—and especially the PHEV—increasingly attractive. Today, in fact, the market for fuel-efficient vehicles has begun to escalate along with the price of oil.

Oil at a Boiling Point

Though the United States holds only 3% of global petroleum, Americans consume 25% of the world's oil supply. According to the U.S. Department of Energy, that was 20.5 million barrels of oil per day in 2004, more than half of which came from imports.

With growing global demand, particularly from China and India, the price of a barrel of oil is climbing at an unprecedented rate. The added cost and vulnerability of relying on a strategic energy resource from an unstable part of the world continues to threaten national security. Add to that the environmental concerns surrounding global warming: petroleum combustion accounts for about 40% of all U.S. CO_2 emissions. Taken together, these three significant issues—fuel cost, national security, and the environment—gained momentum in September 2004 when an unusual alliance of U.S. environmentalists and security hawks, the Set America Free coalition, called on the Bush administration to cut U.S. oil consumption in half over the next four years.

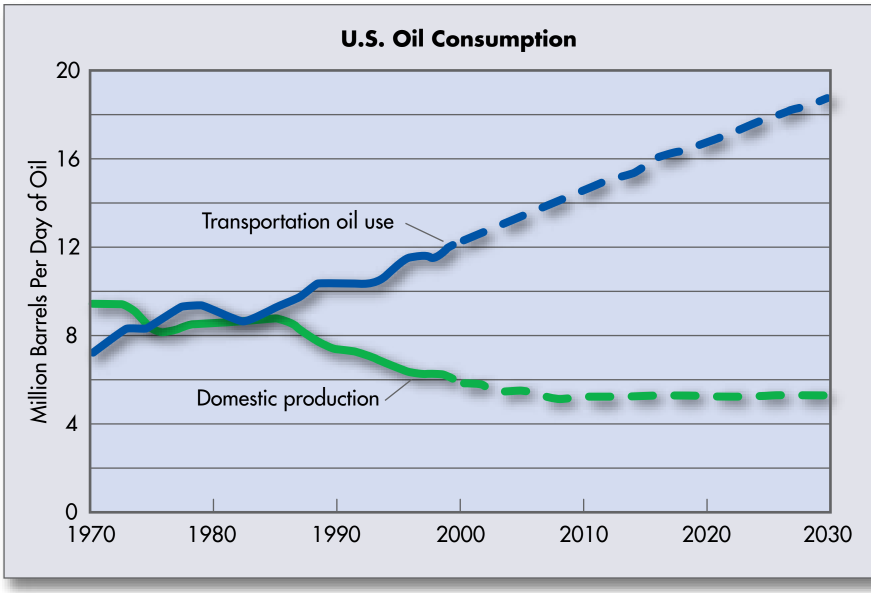
The concern is not new. Anyone over the age of 35 today will remember the so-called Arab Oil Embargo of 1973, which created a worldwide oil shortage. Six years later, the Iranian revolution underscored global energy vulnerability. Before the decade was out, world leaders and energy experts alike sought ways to reduce oil consumption. Energy conservation became the watchword, and efficiency played a major role in reducing overall energy use. Auto manufacturers developed smaller, more-efficient vehicles, appliance manufacturers developed energy-efficient products, and utilities reduced the use of oil for generating electricity; in the United States alone, oil used for electricity decreased from nearly 17% in 1973 to less than 3% today.

In recent years, however, auto manufacturers have increased the power and size of cars and sports utility vehicles, thereby increasing oil dependence. Today because two-thirds of all U.S. oil consumed goes into cars, trucks, and buses, the focus in energy conservation is on transportation.

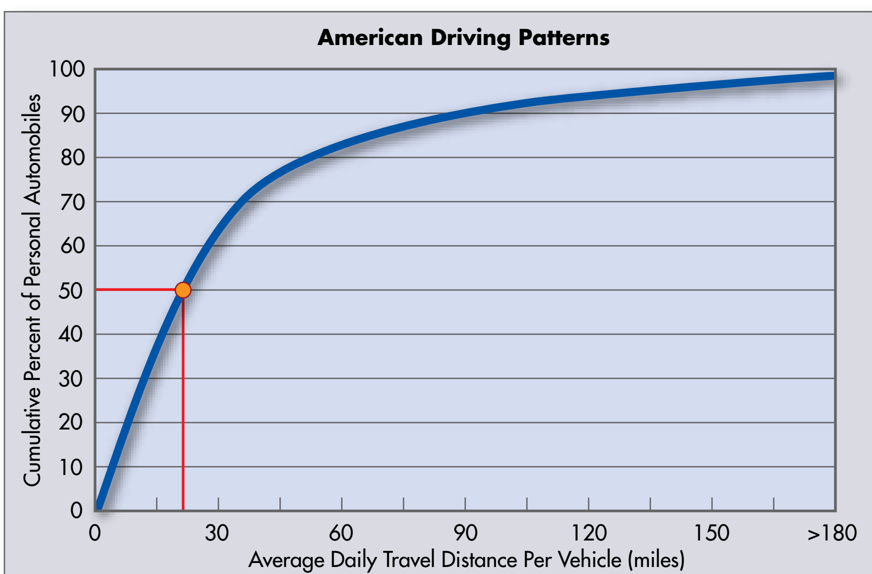
What's Driving the Market?

The internal combustion engine (ICE) is designed to start quickly and provide power as soon as the driver demands it. But until the engine warms up, it runs quite inefficiently. It also idles at every stop, and according to Mark Duvall, manager of technology development for EPRI's Electric Transportation Program, "in urban driving, that idling translates to about 10–15% of total vehicle carbon emissions."

One clean solution is the electric vehicle. In 1996, GM boldly entered the electric vehicle marketplace with its EV1. The EV1 served as a benchmark for electric vehicle technology development, but because of its limited utility and driving range, it met with limited acceptance. Early adopters—mostly environmentalists ready to trade urban pollutants for a clean and quiet if limited ride—were generally enthusiastic about their EV1 experience, but they didn't constitute a large enough consumer base to make the vehicle profitable within the few years that it was available.



While U.S. domestic production of oil has decreased 44% since the 1970s, the use of oil for transportation has increased 83%, and the gap is widening. Given a continuation of this pattern, U.S. oil consumption is expected to grow 60% over the next 25 years, with consequential increases in transportation fuel costs, carbon emissions, and security vulnerability. (Source: Energy Information Administration)



Because half the cars on U.S. roads are driven 25 miles a day or less, a plug-in electric hybrid vehicle with even a 20-mile-range battery could reduce petroleum consumption by about 60%.

This being said, hundreds of electric vehicles such as the Toyota RAV4, manufactured for several years under California's zero-emission mandate, continue to operate in communities such as Los Angeles; and a variety of electric vehicles of limited range and performance are now successfully serving such niche markets as airports, retirement communities, city governments, and golf courses. These limited applications, however, cannot solve the problems of strategic vulnerability and trade imbalance caused by dependence on imported oil.

The hybrid electric vehicle is a move in the right direction. Its battery/electric motor combination provides the quick starts, so when the vehicle is standing still, the gas engine can be shut off automatically to prevent idling and conserve fuel. In fact, the hybrid can achieve an increase in fuel efficiency of roughly 30%. The battery also boosts the performance of the ICE at takeoff and for passing.

The hybrid's ICE uses fuel available from any gas station, and the battery charges whenever the ICE is running. The battery also charges when the driver brakes to stop; in a process called regenerative braking, the electric motor becomes a generator and converts otherwise wasted kinetic energy into electricity. Hybrids are not designed to operate on electricity alone, but if they run out of gas, most can go a short distance with extremely limited performance.

In 1997, Toyota introduced the world's first mass-produced hybrid to the Japanese market, and two years later Honda brought its own hybrid design to the United States. Since that time, improvements in battery and system control technologies have increased hybrid power and drivability, and today designs by U.S. and European manufacturers have also emerged on the marketplace.

Because hybrids can cut carbon emissions up to 30% and also reduce urban particulates, early adopters purchased them primarily for the sake of the environment. More recently, however, hybrids have attracted consumers concerned with the price of gas at the pump. In 2003, the Public Policy Institute of California found that 47% of those surveyed would consider buying a hybrid in spite of the higher sticker price. In fact, hybrid sales rose 81% in the United States last year and are expected to double in 2005.

Electricity in the Driver's Seat

Although such hybrid electric vehicles offer substantial fuel efficiencies, they depend entirely on petroleum to charge their electric batteries. If electricity is the end game, why not design a vehicle that will plug directly into the electricity grid—a vehicle that offers high performance and fuel efficiency in both electric and hybrid mode, with a battery pack that would draw a charge directly through a standard home outlet?

"When we saw the results of the 2001 plug-in hybrid design and comparison study," states Graham, "we were encouraged about the potential benefits and market. If these vehicles look so attractive on paper, we reasoned, we ought to build some of them to see if they behave as predicted, and get customer responses."

Aa a result, EPRI has been collaborating with DaimlerChrysler AG of Stuttgart, Germany, to design and build the PHEV prototypes that are now rolling into demonstration in U.S. cities. Based on the DaimlerChrysler Sprinter van, the PHEV Sprinter uses a parallel hybrid configuration with five-speed automatic transmission. The prototypes are testing two different advanced battery chemistries: nickel–metal hydride (NiMH) and lithium ion (Li-Ion). They're also testing hybrid performance for two different liquid fuels: diesel and gasoline. Lessons learned in the demonstration of these initial PHEV commercial vehicles can be applied to mass consumer vehicles in the near future.

"DaimlerChrysler recognizes the potential market for zero-emission PHEVs in sensitive environmental areas, including cities that are becoming closed to polluting vehicles," says Graham. "Once we have results from this demonstration phase, we'll work with DaimlerChrysler to refine the technology, with a drive toward mass production."

How is a PHEV battery charged? "A PHEV sedan could be charged through a 120-V outlet in three to four hours," says Graham, "and a commercial delivery van charges in about four to five hours on the 240-V connection typically found in commercial garages." The PHEV will either have an onboard charger that plugs into an electric outlet, or it will plug into a charger installed in a service garage. "In the future," Graham notes, "auto manufacturers could make PHEVs even more convenient by offering a docking station: when the vehicle arrives in the garage, it rides onto the docking station and charges automatically, without a plug."

Regarding the cost of this electricity to the consumer, Duvall states, "If a van like the Sprinter PHEVs now being demonstrated is driven about 20 miles on batteries five days a week for 50 weeks a year, it will use about 2000–2500 kWh to cover its 5000 annual all-electric miles. In the United States, this electricity will cost about $170–$215 annually. Compare this with the annual fuel cost of about $750–$825 for a gasoline van driving the same 5000 miles at an average fuel efficiency of 18 miles per gallon and today's gasoline prices."

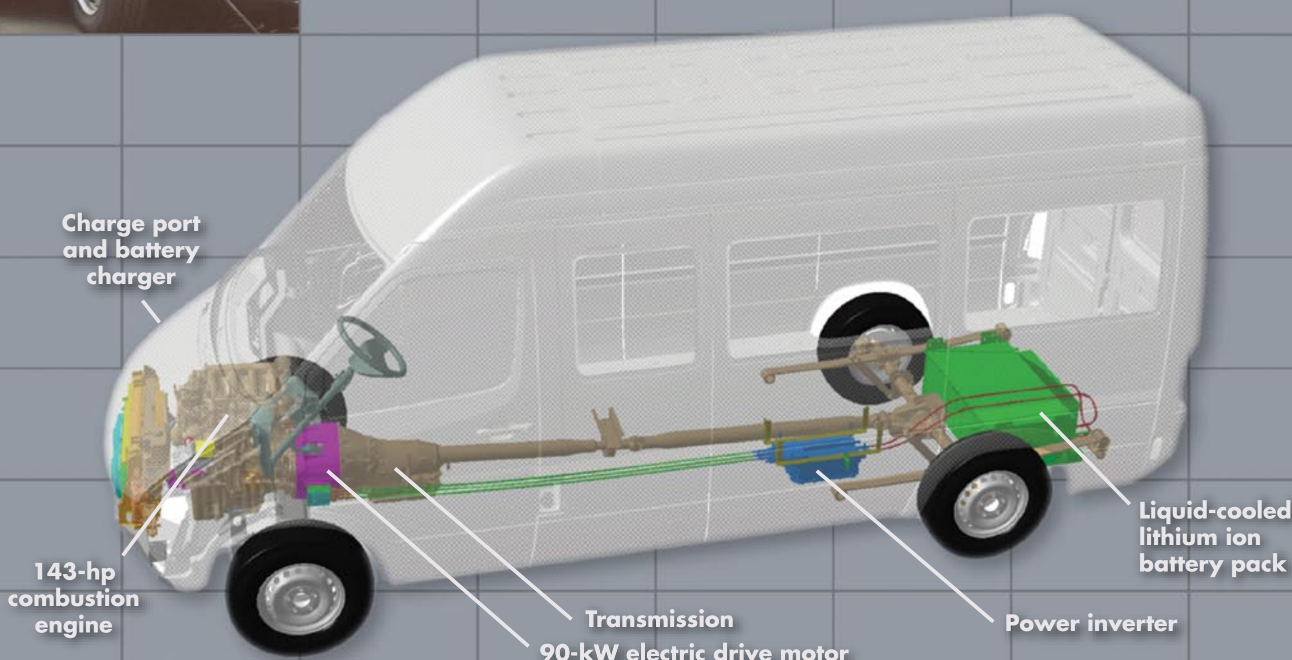
Where will the electricity come from to charge PHEV batteries? Consumer demand for electricity peaks during the day, but more than 40% of the generating capacity in the United States sits idle or operates at reduced load overnight. It is during these off-peak hours that most PHEVs would be recharged. According to Roger Duncan, deputy general manager, Austin Energy, "Our national power system could charge tens of millions of PHEVs without requiring new plants. What's more, we produce a lot of wind-generated electricity, mostly at night, which provides a perfect fit for environmentally friendly PHEVs."

Putting PHEVs on the Road

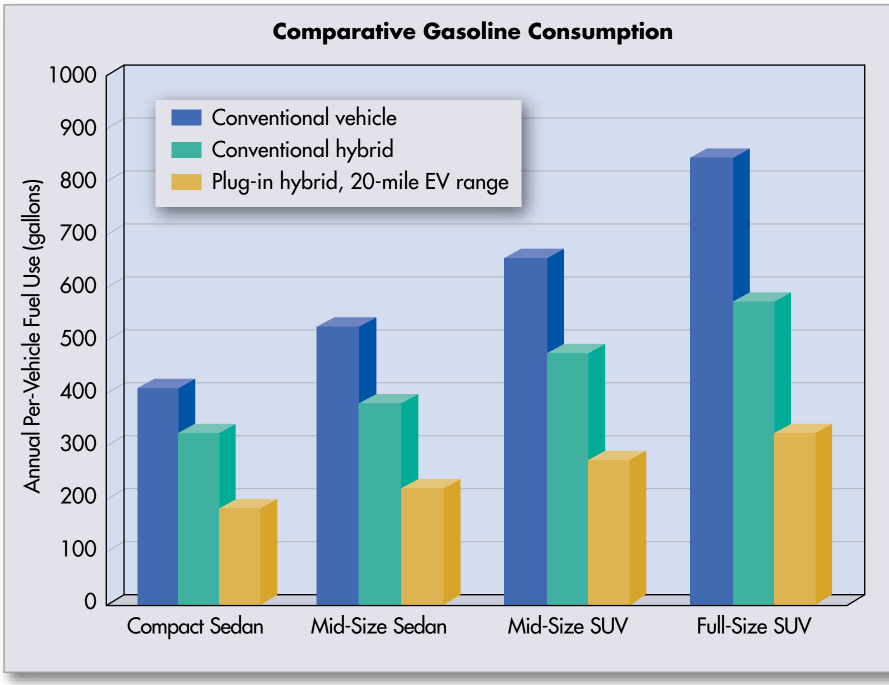
"EPRI is leading the charge on the technology side of this issue," says Duncan, "and political groups such as Set America Free are working on the regulatory and policy side. What's needed now is a market for PHEVs, and we're starting at the grassroots level." With that goal, Austin Energy has taken the lead in forming a national coalition of local and state governments, electric utilities, nonprofits, and the business community to initiate grassroots campaigns in 50 to 75 cities to demonstrate that a market exists today for the mass production of PHEVs.

According to Will Wynn, mayor of Austin, "We believe that the 50 largest cities in this country, united in purpose, can build a groundswell of demand sufficient to entice carmakers to mass produce what is the logical near-term step toward the critical goal of energy independence. And we intend to set the example right here."

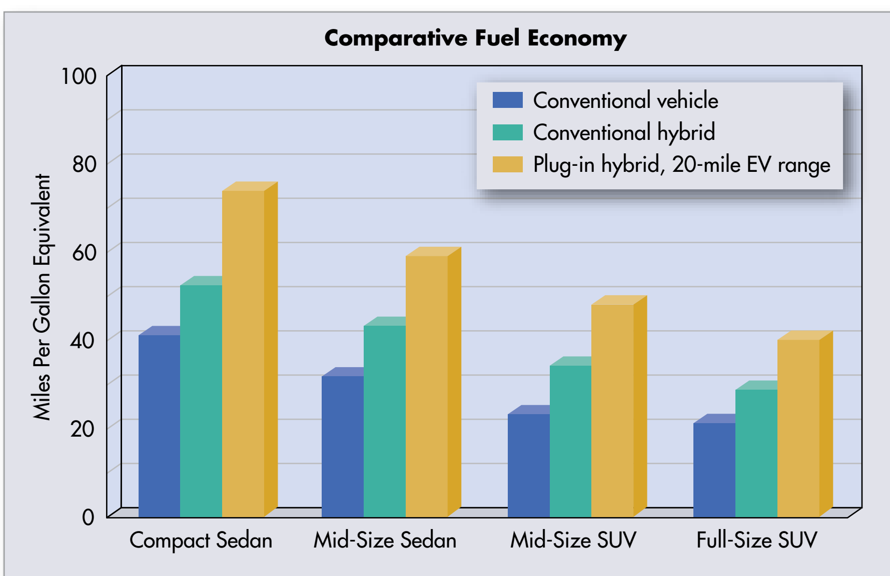
For starters, the city of Austin will set aside a million dollars for rebates to help local governments, businesses, and citizens acquire PHEVs once they become available for purchase. The campaign is also asking local governments and businesses to make "soft" commitments to add PHEVs to their fleets. In addition, Austin will be one of some 10 cities that will sponsor testing of a plug-in hybrid DaimlerChrysler Sprinter van. The city is circulating petitions whereby signees can express to automakers their desire to purchase PHEVs. The national coalition's plan is to replicate this package of rebates, fleet orders, and consumer



Designed and built in a collaboration between EPRI and DaimlerChrysler AG of Stuttgart, Germany, the PHEV Sprinter van incorporates a parallel hybrid configuration with five-speed automatic transmission and an electric energy battery that can be charged from a 240-V AC outlet in four to five hours. The vehicle is designed to use either a nickel–metal hydride (NiMH) or a lithium ion (Li-Ion) battery pack, and is available with the option of either a gasoline or a diesel engine. Sprinters are likely to find their first uses as fleet vehicles, such as delivery vans and shuttle buses, that can run cleanly and noiselessly in stop-and-go driving on city streets throughout the day and then plug into the electricity grid at night to take advantage of off-peak power.



Nearly 70% of all oil consumed in the United States fuels cars, trucks, and buses, and as auto manufacturers increase the power and size of passenger vehicles, the amount of petroleum needed for personal transportation increases as well. The hybrid was a step forward in reducing petroleum consumption, and now the PHEV takes the next step, doubling that improvement—the PHEV is to the hybrid as the hybrid is to the conventional vehicle. (Source: Energy Information Administration)



The equivalent fuel economy of the plug-in hybrid vehicle with a 20-mile-range battery is more than double that of a conventional vehicle and 30–50% higher than that of a conventional hybrid. Because of the amount of petroleum it displaces, for example, the PHEV version of the full-size SUV has a fuel economy equivalent to that of a mid-size hybrid. (Source: Bureau of Transportation Statistics)

endorsements in municipal governments across the country.

While a plug-in hybrid can be a vehicle of any size, the earliest market targets are fleet vehicles—delivery vans, shuttle buses, and maintenance vehicles, for example. For many local service and government organizations, fleet vehicles can run cleanly and noiselessly on city streets throughout the day and then plug in at night to take advantage of off-peak power. Some of these vehicles may almost never need to visit a gas station because of their short routes. But in cases where the vehicle drives beyond that range and depletes the battery charge to a preset minimum level, the PHEV will automatically switch to its ICE/battery combination and operate as a typical hybrid. In that mode, the electric motor supplements the PHEV's ICE for highly efficient acceleration and passing performance with minimal emissions.

The Environmental Equation

Cutting back on imported oil may be good for the U.S. economy and national security, but what about the environment? After all, 55% of the nation's electricity is generated by coal. If we transition from gasoline to electricity, aren't we just trading one set of pollutants for another?

Not so, according to the California Air Resources Board. A CARB study looked at the so-called well-to-wheel emissions of electric vehicles—that is, emissions along the entire supply chain, from extraction of the fuel source all the way to the tailpipe and the wheel. Using today's national grid, a battery-powered electric vehicle generates only a third of the greenhouse gases produced by an equivalent gasoline vehicle. The differential will only improve as old plants are modified with pollution controls or retired and as new generation comes to rely increasingly on clean coal technology, renewable energy, and in the longer term, advanced nuclear power. What's more, pollution is easier to manage at a large, central electric generating plant than at the tailpipes of millions of gas-guzzling vehicles.

Advanced Battery Technology

The battery is the heart of any electrically powered vehicle. The performance and practicality of the vehicle depend on the weight of the battery in relation to the amount of energy it can store and the power it can produce. The lighter and more compact the battery, the more efficient and practical the vehicle; and the more energy the battery stores, the longer the vehicle's driving range.

Electric vehicles of the past used mostly lead-acid batteries and had very limited range. The considerable battery weight compromised vehicle performance and efficiency. And lead-acid batteries had a relatively short life, which meant several replacements over the life of a vehicle.

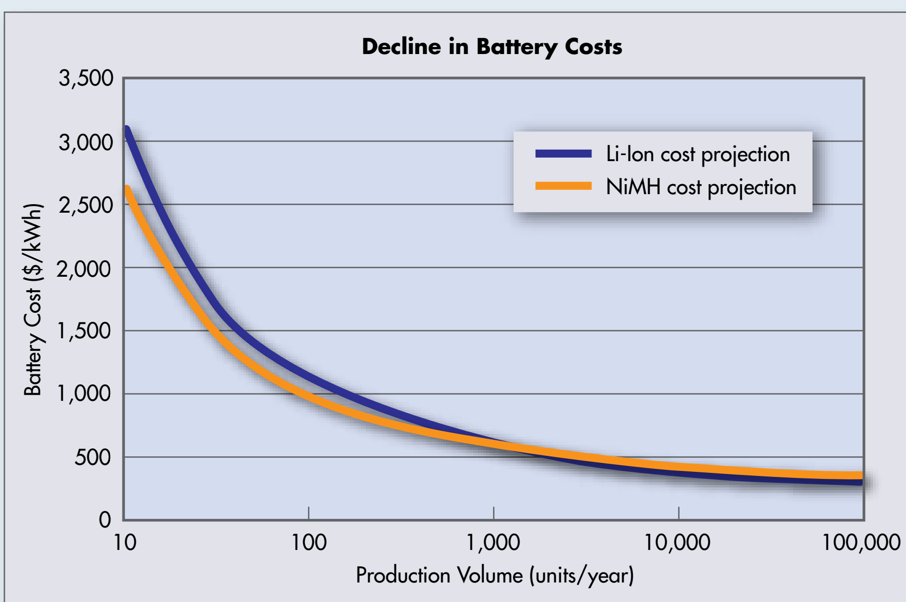
Today's advanced batteries, principally the nickel–metal hydride (NiMH) and the lithium ion (Li-Ion), have demonstrated not only much-higher energy storage and power delivery capabilities but also far longer life in the deep-discharge cycling required for electric vehicle and PHEV propulsion. Specifically, for a given amount of energy storage, the NiMH battery weighs half as much as a lead-acid battery and produces two to four times the power. The Li-Ion battery weighs half as much as a NiMH battery and provides up to 100% more power than NiMH. Being the lightest and most powerful, the Li-Ion battery has a fundamental advantage. For example, a state-of-the-art NiMH battery that weighs around 250 kg can give a Sprinter a range of 20 to 30 miles on electricity alone, which is perfectly adequate for PHEVs that can perform a substantial fraction of their daily operations within that range. The lighter Li-Ion battery, on the other hand, would be the choice for PHEVs that need a greater electric range—say, 40 to 60 miles—and for purely electric vehicles.

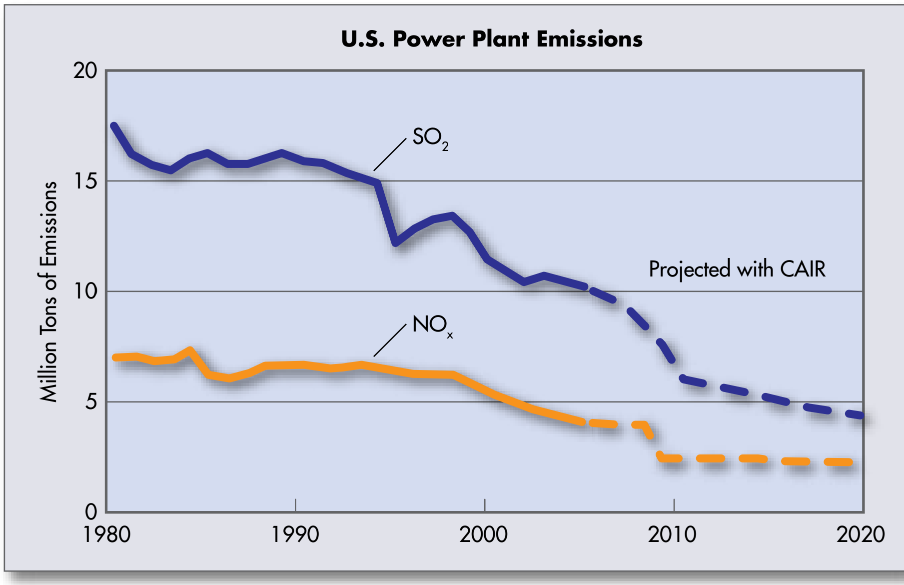
Unlike the lead-acid battery, both NiMH and Li-Ion batteries have the potential for very long life. The NiMH battery has demonstrated more than 2000 deep-discharge cycles—that is, cycles that nearly deplete the battery of its stored energy. The Li-Ion battery has shown more than 3000 deep-discharge cycles. These numbers correspond with the number of cycles a PHEV battery is expected to deliver over the vehicle's 10- to 15-year life. In the lab, a lead-acid battery can live through just 1000 such cycles at best, and in practice, not more than 300 or 400. What's more, NiMH and Li-Ion batteries can be recycled to recover and reuse their valuable metal content, and unlike lead-acid batteries, they don't use any toxic materials.

A major disadvantage of advanced batteries is their high cost. Both NiMH and Li-Ion are more expensive to produce today than lead-acid batteries: the materials themselves are more expensive, and the manufacturing methods are substantially more sophisticated. But just as the cost of the small NiMH and Li-Ion batteries used in cell phones and other hand-held devices has dropped dramatically, the cost of PHEV batteries is expected to drop as they go into mass production and as worldwide competition for that market develops.

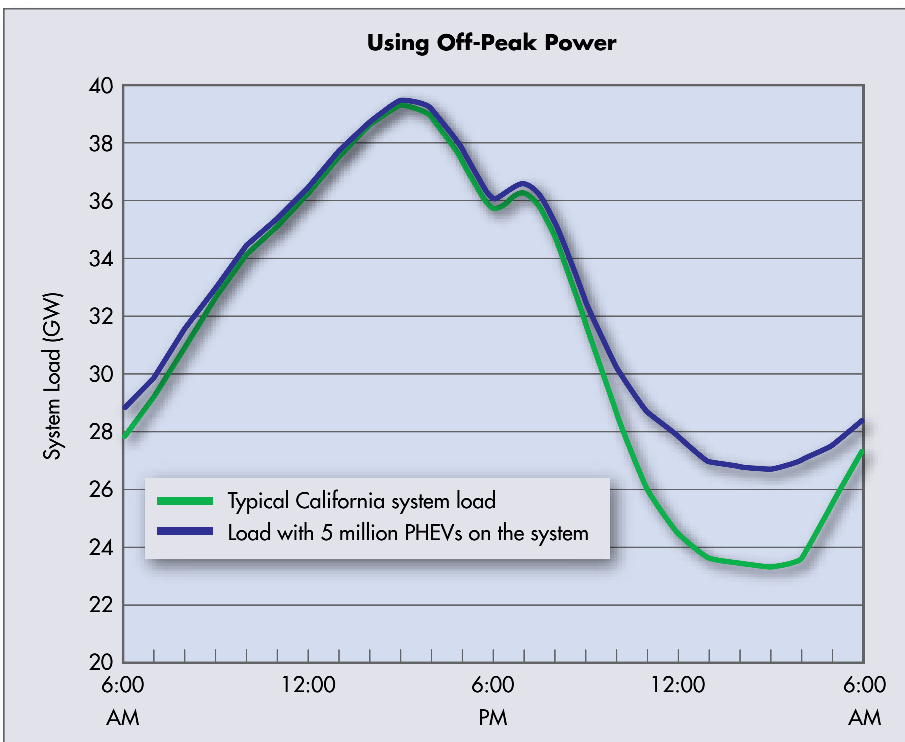
The ultimately achievable cost is likely to determine which applications develop first and to what degree PHEVs of extended electric range will penetrate markets. The PHEV DaimlerChrysler Sprinters in demonstration today are testing both NiMH and Li-Ion batteries to establish optimal weight, range, performance, and operation in a variety of climates and real-life applications.

The production cost of NiMH and Li-Ion batteries presents a key challenge to the marketability of PHEVs. As production volume increases, however, costs will come down with the introduction of automated manufacturing lines and economies of scale. The cost-effective tipping point is at about 100,000 battery packs annually. With roughly 16 million new cars sold in the United States every year, once auto manufacturers commit to the PHEV, that tipping point should be easily reached.





Over the past 25 years, electric utilities have reduced power plant emissions by retiring older plants and incorporating advanced, clean generation technologies. Since 1980, power plant emissions of SO_2 have decreased by 40%, and of NO_x by 36%. Projections based on the new Clean Air Interstate Rule (CAIR) show continued emissions reductions into the future, which means that the PHEV—which draws electricity directly from the grid—will actually get cleaner with age. (Source: U.S. Environmental Protection Agency)



Because PHEVs would be charged mainly at night—when electricity is readily available—generating plants would run much closer to steady load. Electric utilities could capitalize on expensive assets that now sit idle during off-peak hours, allowing for more-efficient operation. The PHEV also provides utilities with a new major electricity market without the need to build additional power plants.

The bottom line is this: because electricity generation is getting cleaner over time, electric vehicles and PHEVs will actually get cleaner with age. The PHEV offers the most promising approach to reducing CO_2 emissions in transportation.

Sustainable Transportation

"We are currently in the PHEV feasibility phase, with the objective of testing and demonstrating the concept in multiple applications," says Graham. "Beginning in 2006, we plan to promote interest across the country in order to lower vehicle production costs and demonstrate a business case to additional auto manufacturers, particularly those who would like to partner with us in developing PHEVs for consumer markets. We expect PHEVs to be available for commercial van application by 2008 and to be in the mass consumer marketplace by 2010."

In the future, the PHEV can become a key part of the long-term transition to a carbon-free energy economy, where petroleum will be replaced by clean energy sources through the energy vector electricity. All renewable and carbon-free primary energy sources—hydropower, solar energy, wind energy, biofuels, and uranium materials—are readily and efficiently converted to electricity, and the PHEV offers the best prospects for widespread use of electricity as a transportation fuel.

What about hydrogen? Derived primarily from water, hydrogen is not a new idea as a fuel source. In 1874, in fact, Jules Verne saw water as "the coal of the future." While the current U.S. administration views the fuel cell hydrogen vehicle as the solution for reducing foreign oil imports and greenhouse gases, energy experts predict that the hydrogen economy may be at least fifty years in the future.

But if we do see that day, will there be a role for the PHEV? According to Graham, most definitely. "It would make enormous sense for a fuel cell vehicle to have a battery of sufficient storage capacity to provide battery-only range for the vehicle.

For one thing, the cost of a battery capable of delivering a given amount of power will very likely always be lower than that of a fuel cell with the same power rating. Batteries are inherently simpler to manufacture and operate than fuel cells. Just as important, electricity will be much less expensive as a transportation fuel than hydrogen, in part because we already have the required electricity production and distribution infrastructures, and in part because the well-to-wheel efficiency is much higher for electricity from the grid. So any fuel cell capacity and hydrogen fuel you can replace with a battery and grid electricity will lower both the first and the operating costs of transportation. Instead of being a competitor, the PHEV actually might help effect a long-term transition to fuel cell vehicles because of the PHEV's potential to lower the high capital and fuel cost barriers faced by fuel cell electric vehicles."

Today the plug-in hybrid is attracting the attention of U.S. municipalities concerned about reducing both fuel costs and urban pollutants. It's attracting the attention of political organizations on both the left and the right that are concerned with global warming on the one hand and energy security on the other. The future of the PHEV depends on the willingness of market leaders to grab hold of this solution and drive it to commercialization.

"Municipal governments benefit from lower urban emissions and lower-cost transportation," says Duncan. "And utilities gain a new market for off-peak power. EPRI is paving the road to sustainable transportation, but it can't achieve that goal alone. Electric utilities and municipalities must make it both attractive and convenient for consumers to plug in hybrid electric vehicles."

Background information for this article was provided by Robert Graham (rgraham@epri.com), Mark Duvall (mduvall@epri.com), Fritz Kalhammer, and Roger Duncan.

The Impact of Collaboration

EPRI's Electric Vehicle Program began as an effort to understand the benefits and challenges of introducing a new electricity-based technology to the U.S. marketplace. According to Dr. Fritz Kalhammer, who initiated the program in 1976, "We saw the potential of electric vehicles, but we knew that the utility industry alone couldn't design, test, and demonstrate them and take them to market. We needed the backing of major auto manufacturers." Over the ensuing years, EPRI collaborated with a number of partners that included government organizations, auto manufacturers, and electric utilities in the development, testing, and demonstration of electric vehicle technologies.

Because the success of the electric vehicle depends on the batteries that power it, EPRI collaborated with GM, Ford, Chrysler, and DOE in 1991 to found the U.S. Advanced Battery Consortium—the USABC. It has been largely responsible for bringing the NiMH and Li-Ion electric and hybrid vehicle battery technologies to where they are today.

Perceiving the potential of hybrid electric technology, EPRI in 1999 formed the Hybrid Electric Vehicle Working Group (HEVWG), which brings together representatives from the utility and automotive industries, government and regulatory agencies, and university research organizations. From its inception, the HEVWG has led the energy and auto industries in studies and analyses of PHEV technology and market acceptance.

In 2001, the HEVWG completed the first public domain multivariate study comparing benefits and impacts of conventional vehicles and PHEVs; the study provided evidence that grid-connected hybrid electric vehicles would be technologically feasible and could offer significant benefits. The report also presented results of a customer survey indicating that people preferred plugging in a vehicle to going to the gas station. With the encouraging results of that study as support, EPRI was able to develop its partnership with DaimlerChrysler to design, develop, test, and demonstrate the PHEV prototypes that are on the road today. Other funders and participants include Southern California Edison Company, New York Power Authority, the Federal Transit Administration, the Metropolitan Energy Center of Kansas, Long Island Power Authority, and the South Coast Air Quality Management District.

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THE CHALLENGE OF NUCLEAR FUEL RELIABILITY

by Taylor Moore

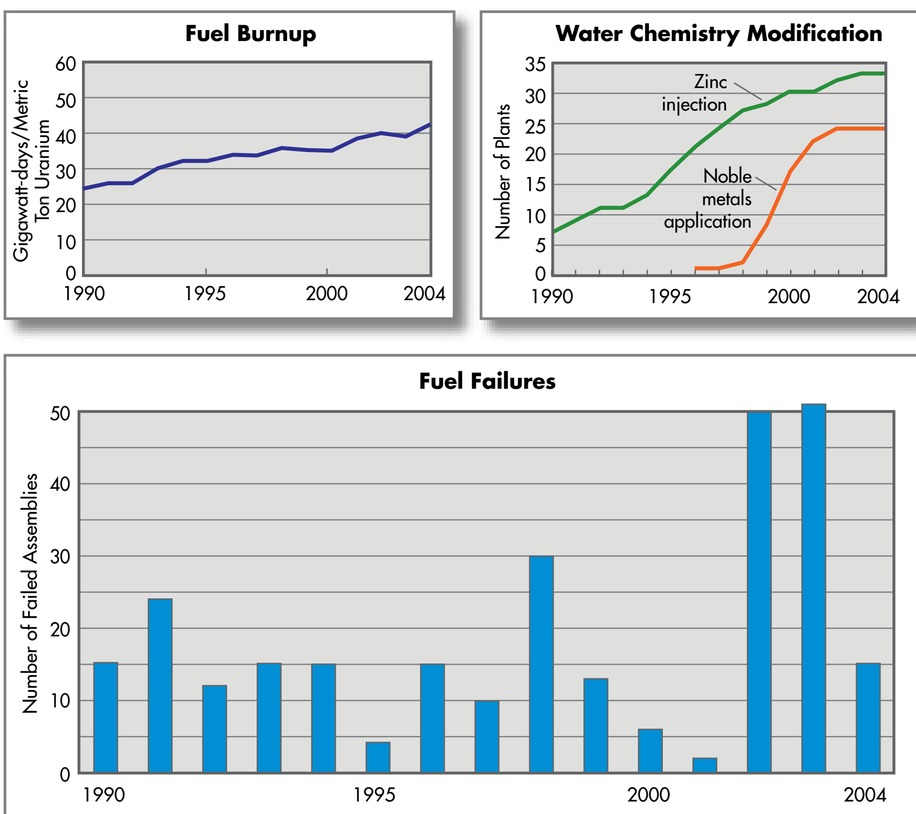
The Story in Brief

The current fleet of U.S. nuclear power plants produces some of the country's most economical electric power, largely because of the relatively low cost of nuclear fuel. But new operating strategies aimed at enhancing plant and fuel performance have also led to increased fuel failures in recent years—a problem that threatens nuclear's cost competitiveness. In response, EPRI has restructured its nuclear fuel reliability activities to more effectively pursue mitigation techniques and identify root causes for the industry's toughest fuel problems. The collaborative, international effort—involving nuclear plant operators, fuel manufacturers, and fuel service providers—seeks to better quantify operating margins, provide insights leading to advanced fuel designs, and eliminate fuel failures. The ultimate goal is zero fuel defects.

The relatively low and stable cost of uranium is one of the key factors that make the nation's current fleet of 103 operating nuclear power plants economically competitive with other sources of electricity. The cost of fuel as a percentage of total production cost is about 25% for nuclear, while ranging from 70% to 90% for coal- and gas-fired generation.

Throughout the history of commercial nuclear power, fuel-cycle economics have continually improved as fuel manufacturers have introduced advanced, more highly enriched and higher-burnup fuel and as nuclear plant operators have come to use increasingly longer fuel cycles. Since the 1990s, both burnup and cycle length have increased by more than 50%. These increases have allowed nuclear plants to operate more efficiently and produce more electricity. The gains have saved nuclear plant operators—and consumers of the electricity—more than $1 billion a year through increased power production and reduced costs for spent fuel storage and eventual disposal. The operating changes have also resulted in more-efficient use of uranium resources.

But the long-term performance and reliability of precision-engineered and precision-manufactured commercial fuel—operating several years inside a light water reactor core under high temperature and pressure as well as intense radiation—can directly affect a nuclear plant's cost of producing electricity. Fuel failures can jeopardize the competitive advantage of nuclear power's low production cost through lost generation, increased inspection and repair costs, and the premature discharge of fuel assemblies, which alone can be substantial (the replacement cost of the fuel in a single plant is on the order of $150 million to $200 million). Fuel failures can also contribute to increased plant background radiation, which impacts plant outage operations, where minimizing worker exposure is a primary concern. (After all, nuclear fuel cladding is the first of three engineered barriers designed to prevent the environmental release of radioactive fission products.)



A steady increase in fuel enrichment, burnup, and operating cycles over the last 15 years has enhanced the economics of BWRs. But these operating changes, along with modifications to the water chemistry environment, have also led to an increase in fuel failures. PWRs have experienced similar problems.

That is not to say fuel failures pose a plant safety issue; their number and extent remain well within accepted safety and licensing limits. The primary impact remains economic: fuel failures affect both the operating cycle and such downstream issues as spent fuel storage, transportation, and disposal. Fuel failures can also influence public acceptance of nuclear power.

Considering that a typical reactor contains more than half a million fuel rods, defect-free operation is a real challenge, and the fuel's operating environment adds to the challenge. With peak temperatures higher than 1000°C, the fuel is by far the highest-temperature component in the steam supply system. The fuel is also subjected to the highest radiation fields, where neutrons passing through the cladding literally knock atoms out of their way. At the end of a fuel rod's life, most atoms in the cladding have been displaced once or twice, and the cladding microstructure can be substantially changed. Despite the challenging environment, the industry continues to expect, and strive for, zero defects.

Problems Arise

After the performance of commercial nuclear fuel had trended upward for 20 years, signs that it was on the decline began to appear in the late 1990s, first in some pressurized water reactors (PWRs) and more recently in some boiling water reactors (BWRs). Fuel failures increased significantly from 2001 through 2004, with more than one-third of the U.S. nuclear fleet experiencing at least one fuel defect. The increase in fuel failures is thought to result primarily from the operating regimes adopted to boost plant performance: higher enrichment, longer fuel cycles, higher burnup, low neutron leakage, new core reload strategies, and plant upratings.

But other factors contribute to fuel reliability problems as well. For example, as the plants themselves have aged, they have experienced a number of materials-related problems, such as stress corrosion cracking, in piping and components in the reactor vessel, primary cooling system, and other areas of the plants. Operators have generally modified a plant's water chemistry to control or limit such corrosion and cracking: the addition of lithium to the PWR primary coolant will raise its pH, the addition of zinc can reduce the plant's corrosion source term, and additions of noble metals can alter the coolant's electrochemical potential to inhibit stress corrosion cracking. Many of these changes, initiated to improve balance-of-plant performance, may further increase demands on the fuel.

Explains Chuck Welty, director of EPRI's nuclear materials and chemistry department, "As the industry strives to address degradation and aging in other components exposed to primary coolant, it is important to consider alternative water chemistry regimes. But it is also essential that the impact of any proposed changes on fuel performance be fully understood." Rosa Yang, technical executive for EPRI's Fuel Reliability Program, agrees: "While the industry has been increasingly pushing fuel to higher enrichment, higher burnup, and longer operating times, we have also been operating fuel in continually changing water chemistry environments that have turned out in some cases to have unpredicted, unintended consequences on fuel performance. To develop effective solutions to fuel reliability problems, we have to consider the interactive effects of all the variables involved—fuel design, duty cycle, coolant chemistry, crud buildup, and so on."

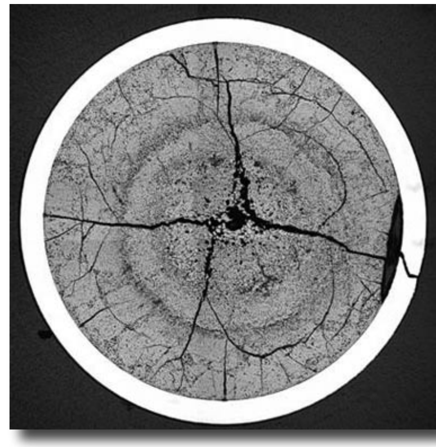
The buildup of corrosion products on the fuel cladding surface has proven to be particularly significant for both BWRs and PWRs. The high temperature of the cladding surface attracts impurities and chemical additives in the reactor coolant that deposit on the fuel rod surface in a process not unlike what occurs in a tea kettle. The deposits on a fuel rod, known as crud, can be tenacious, insulative compounds capable of increasing the local clad temperature and accelerating clad corrosion—sometimes to the point of fuel failure.

The difficulties in quantifying such effects have contributed to a number of surprises. Some of these are actual fuel failures, such as corrosion failures in BWRs, power change–induced failures and crud-induced failures in both BWRs and PWRs, and severe degradation of failed fuel in a few plants. Other surprises have been operational difficulties, such as unanticipated changes in the power profile of some PWR cores—known as axial offset anomaly (AOA)—as a result of crud deposits on fuel. Both BWRs and PWRs have also experienced difficulties with control rod insertion as a result of fuel assembly or fuel channel deformation.

"These surprises have been recognized by the industry and EPRI as having the potential for adverse cost impacts, since they could result in plant deratings, operational restrictions, or unscheduled outages for repairs," notes Yang. Several recent fuel failure events at U.S. nuclear plants have cost between $40 million and $80 million each, not including the long-term effects of plant contamination. According to Yang, the most recent data reported by utilities on fuel performance suggest that the downward trend of the previous four years is leveling off, but it is not yet clear that an actual reversal is in sight.

New Emphasis on Reliability

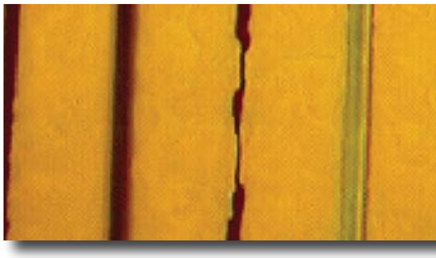
In 2003, under the leadership of Jack Skolds, former chief nuclear officer at Exelon Corporation—the largest U.S. nuclear power plant operator—a group of industry chief nuclear officers made a number of recommendations for reversing the downward trend in fuel reliability. These recommendations were presented to the chairmen of the nuclear industry's



Fuel failure is not a matter of damage to the fuel pellets themselves, but rather involves cracking of the metal cladding that surrounds them, as seen at the right in this cross-section. A crack in the cladding allows radioactive material to leak from the fuel rods into the reactor coolant.

Materials Executive Oversight Group and EPRI's Fuel Reliability Program—the lead industry fuel R&D organization. The overarching efforts are part of the larger Industry Materials Initiative, which includes fuel reliability in its scope, since water chemistry and corrosion mitigation strategies can affect primary system components and fuel in different ways. "Our fundamental focus is on enabling the industry to optimally balance fuel performance and reliability," says Yang. "Plant operators have a lot to gain by pushing the fuel," she adds, "but if the fuel fails, they stand to lose a lot as well."

To avoid recurring fuel failures, the EPRI program leverages extensive capabilities for fuel failure root-cause investigations, ranging from nondestructive examination of fuel in plant storage pools to transporting fuel to heavily shielded, remotely operated laboratories known as hot cells for destructive examination. A shortage of suitable hot cell capabilities in the United States has in some cases led to the shipment of failed fuel overseas, extending an already long turnaround time for results and analysis. The program is pursuing possibilities for new collaboration with the Idaho National Labora-



The buildup of corrosion products, known as crud, on fuel rod exteriors (top) can distort normal heat distribution in the reactor core and accelerate corrosion and failure of the rods themselves (bottom).

tory (INL)—now managed for the U.S. Department of Energy under a team contract, led by Battelle Energy Alliance LLC, that includes EPRI—for upgrading certain INL hot cell facilities that are being adapted for use by the nuclear industry. DOE has designated INL as the center of the U.S. R&D effort for the renaissance of nuclear power.

In fact, such collaboration is at the heart of virtually all aspects of the research effort. EPRI's Fuel Reliability Program is currently supported by all U.S. utility members and more than half a dozen major international nuclear utility organizations, including Electricité de France, UNESA in Spain, Sweden's Vattenfall, Tokyo Electric Power Company, Taiwan Power Company, and Kernkraftwerk Leibstadt and Kernkraftwerk Mühleberg in Switzerland. The international collaboration brings nuclear plant operators and fuel manufacturers together in a highly leveraged, integrated effort focused on quantifying operating margins, providing insight for fuel designs with enhanced performance, and eliminating fuel failures. The ultimate goal of the industry is zero fuel defects.

The program is working with the Institute of Nuclear Power Operations (INPO) to implement a time-critical fuel failure database, called FRED, to capture timely fuel performance and reliability data. The web-accessed database is the industry's first comprehensive fuel performance and reliability information resource; now in beta testing, it will be fully online by the end of this year. FRED provides nuclear utilities and fuel suppliers with an accurate, comprehensive, and up-to-date database on fuel performance and reliability.

Sharing Responsibility

Fuel vendors participate directly in the Fuel Reliability Program, which works closely with them to ensure that fuel performs as advertised—a goal that has become more elusive in the current business climate. Years of oversupply in the increasingly competitive and global fuel marketplace, combined with a reduction in the number of fuel assemblies purchased due to higher burnup capabilities of current designs, have depressed prices for nuclear fuel. This, in turn, has reduced spending for R&D and led to the introduction of some new fuel designs that have undergone less-than-adequate testing. While some believe the vendors should pay all the costs of ensuring fuel reliability, most recognize that this expectation is probably not realistic, given current fuel prices. In addition, some fuel performance factors, such as the water chemistry conditions under which the fuel is operated, are clearly more the responsibility of plant operators than of fuel vendors.

EPRI works both sides of the vendor-customer relationship. The costs of most joint efforts are shared equally with the appropriate vendor, giving EPRI members the opportunity to focus both their own resources and those of a vendor in an area of direct benefit to utilities. For vendors, the interaction provides the opportunity to address important areas that might not be addressed otherwise. The Fuel Reliability Program currently has multimillion-dollar efforts under way with all of the vendors supplying fuel in the United States to confirm the margins of existing designs, demonstrate a new fuel design, or resolve a failure root cause.

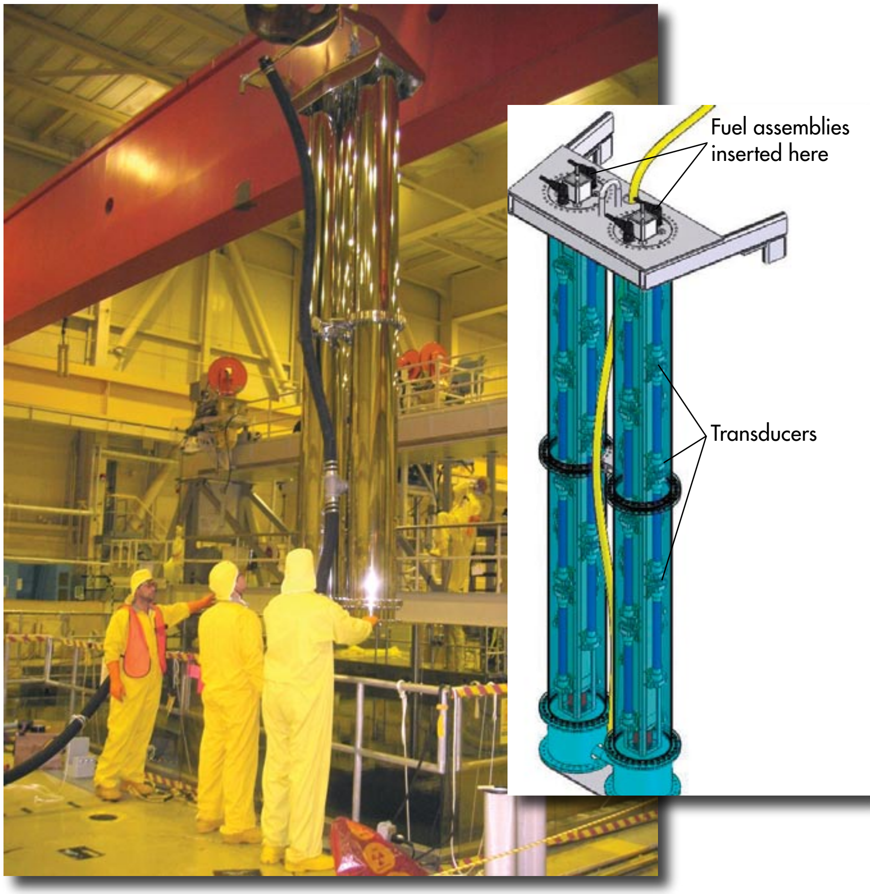
Another focus of the EPRI model is to better characterize fuel duty/water chemistry interaction so that vendors get the data they need to improve fuel designs and utilities get the data they need to operate the fuel efficiently and fine-tune plant water chemistry. "Zero defects in nuclear fuel can be reached only through teamwork and integration," notes Yang, "and EPRI's role is to bring all of the necessary capabilities and resources together to ensure that vendors and plant operators can work effectively toward the common goal." Such teamwork extends down to the individual plant level to foster understanding between the fuel and water chemistry experts, who sometimes operate in a state of naturally opposing tension with each other.

Challenges and Successes

Despite continuing, evolving technical challenges to achieving zero-defect nuclear fuel performance, EPRI's Fuel Reliability Program has had some notable successes—R&D efforts that have helped tip the balance in favor of higher performance without sacrificing reliability.

"When fuel failures occur, it's important to fully understand their root causes in order to avoid future failures of the same type," points out Kurt Edsinger, senior project manager in the Fuel Reliability Program. "Unfortunately, root-cause investigations typically require destructive analysis of fuel elements in hot cells, and transporting fuel from nuclear power plants to hot cells adds to the time and expense of investigations. Still, if you can identify the root cause of a failure and take actions that minimize or eliminate future problems, it's well worth the cost."

In a recent example involving failed fuel from a BWR, the effort paid off in just this way. The hot cell analysis, expedited by EPRI for a fast turnaround, revealed a



An EPRI-patented fuel cleaning technology allows utilities to remove crud from fuel assemblies during a routine reload outage. In this process, a complete assembly is placed in each of two canisters, which contain high-energy ultrasonic transducers that loosen the crud by the repeated formation and collapse of tiny bubbles. The technology, which received the prestigious R&D 100 Award in 2005, will have been applied at a dozen nuclear plants worldwide by the end of the year.

manufacturing defect on the fuel pellet surface that was creating an additional stress on the zirconium alloy cladding, leading to a failure mechanism known as pellet-cladding interaction. As a result of this finding, which could not have been made except through destructive examination in a hot cell, all fuel vendors have changed their manufacturing practices, improving the quality of fuel pellets industrywide and benefiting all fuel users by effectively eliminating a common fuel failure mode. EPRI's involvement facilitated a rapid feedback loop that helped avoid costly operating restrictions on fuel and led to a quick return to economical operation.

Sometimes innovation comes through the use of existing technology in new ways. Entergy, Areva, and EPRI shared the Nuclear Energy Institute's (NEI's) 2005 "Best of the Best" Top Industry Practice (TIP) Award for developing an advanced technique for fuel crud sampling and analysis at Entergy's 966-MW River Bend nuclear plant in St. Francisville, Louisiana. The team developed new remote tools and procedures to obtain small flakes of corrosion deposits on fuel and developed advanced methods to analyze the flakes. The technique, based on other EPRI and vendor work on PWR fuel, revealed detailed information about the nature of fuel corrosion products that was previously available only through the expensive and time-consuming route of destructive hot cell examinations. The ability to collect the information from the poolside results in a quicker analysis that allows plants to adjust water chemistry and correct fuel problems in time for the next operating cycle.

Several other successes have come out of research to reduce AOA, where crud buildup on fuel cladding surfaces causes uneven heating of the reactor core. The situation is exacerbated by boron, which is added to the coolant to control power levels but which also becomes concentrated and deposited within thick crud deposits. The boron depresses power locally, shifting power from high-crud regions to lower-crud regions. Utilities are faced with the choice between reducing overall reactor power, which is economically undesirable, and finding a way to better control crud.

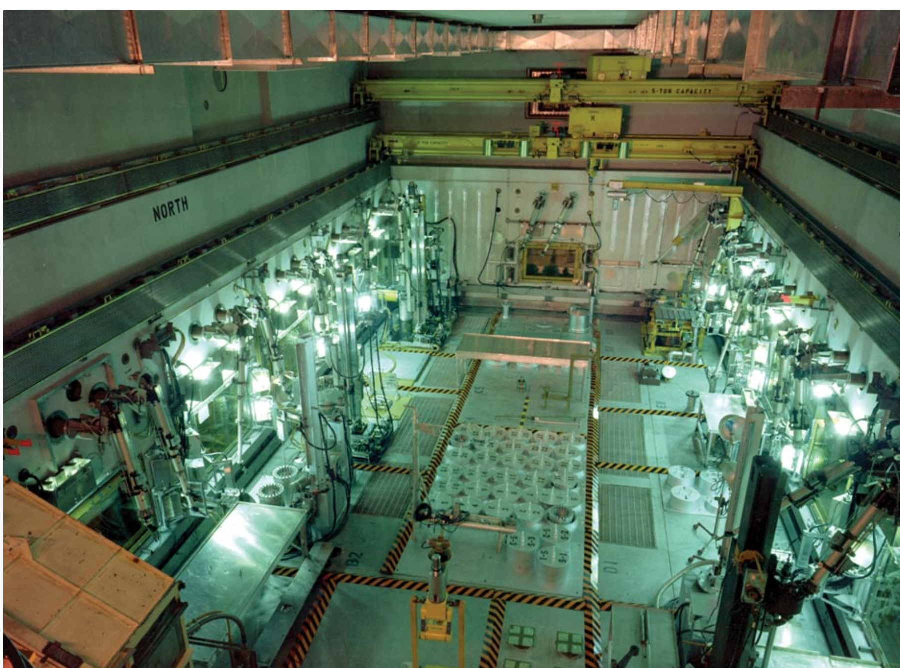
The initial approach for PWR utilities to avoid AOA was through conservative reload management, which translated to the purchase of additional fuel. More-advanced approaches, based on EPRI-led research, use higher coolant pH levels and zinc injection to reduce crud transport and make use of the AOA analytic code BOA (Boron-Induced Offset Anomaly) developed by EPRI and Westinghouse. Notes Jeff Deshon, a project manager in the Fuel Reliability Program, BOA is a valuable software tool many utilities use to assess AOA risk; BOA can predict a specific core design's likely onset of AOA, as well as the extent and location of crud deposits. A major revision to the code is expected soon. Another strategy that has been investigated includes using boric acid specifically enriched with the boron's neutron-absorbing isotope so that the overall concentration of the element can be reduced.

While such mitigation techniques represent important advances, an EPRI-patented ultrasonic fuel-cleaning (UFC) technology attacks the problem more directly. In this process, the complete fuel assembly is placed in a canister surrounded by high-energy ultrasonic transducers that loosen the crud by the repeated formation and collapse of tiny bubbles. The crud is then swept out of the canister and captured in specially designed filters. It takes only about 4–6 minutes to clean each assembly, so the entire batch of reloaded fuel can easily be cleaned during a routine outage. Removing the crud by UFC has been proven beneficial in two areas—increasing the margin to AOA by reducing the crud available for boron hideout, and reducing plant dose rates from the overall decrease in crud inventory.

UFC technology has now been licensed to a number of service providers for PWR applications, although the technology has also been qualified and demonstrated for use in BWRs. EPRI and four of its member companies—AmerenUE, Exelon Corp., South Texas Project Nuclear Operating Co., and Dominion Engineering, Inc.—were given *R&D Magazine*'s prestigious R&D 100 Award in 2005 for the UFC technology. By the end of 2005, the technology will have been applied at 12 plants worldwide.

Not all success stories are purely technical. The Fuel Reliability Program has been extremely valuable as the industry focal point for interaction with the NRC and other regulators regarding potential safety implications of fuel behavior under postulated design-basis accidents. EPRI's industrywide perspective and support have helped to avoid regulatory "ratcheting" to the most conservative, restrictive interpretations and assumptions for experimental results or regulatory criteria. The program participates in experimental efforts sponsored by nuclear regulators in the United States and overseas, and it sponsors additional separate-effects experiments and independent analyses. Results of these efforts have prevented the NRC from backfitting the criteria for avoiding reactivity-initiated accidents (RIA) for the currently licensed burnup limit of 62 gigawatt-days per metric ton of uranium. The program has also submitted a topical report proposing a new RIA criterion for high-burnup fuel. The report is currently under review by the NRC.

Currently, the regulatory issue of greatest concern involves the criteria for loss-of-coolant accidents (LOCAs) for fuel at mid-to-high burnup levels. Under postulated LOCA conditions, the temperature



The most reliable way to determine the root cause of a fuel failure is through destructive examination of the failed rod in a hot cell—a huge, heavily shielded laboratory where technicians manipulate test samples by the use of robotic arms. The limited number of such facilities in this country has meant long turnaround times for hot cell examination and analysis. EPRI is pursuing a collaborative effort with the Idaho National Laboratory to upgrade its hot cell facilities and streamline the process of fuel failure analysis.

Technical Working Groups Get the Job Done

EPRI's Fuel Reliability Program is managed through technical working groups that proactively identify high-priority and emerging issues related to fuel performance, water chemistry, and root-cause analysis of failed or defective fuel—along with cost-effective strategies for resolving them—and fuel-related regulatory issues.

Like all other technical programs in the nuclear industry's broad-based Industry Materials Initiative, the Fuel Reliability Program conducted an in-depth gap analysis to identify and prioritize critical knowledge gaps and to target R&D plans to bridge them. "As a result of the gap analysis, important new areas have been added to the program's overall scope," notes Kurt Edsinger, an EPRI senior project manager and manager of one of four working groups addressing the key technical areas of focus.

"Newly added areas address the response of BWR fuel to water chemistry changes and the lifetime of reactivity control elements," says Edsinger. "The gap analysis particularly recognized that issues related to BWR crud deposits and their effects on fuel performance could substantially benefit from a dedicated working group structure similar to what was already in place for PWRs, where fuel performance, chemistry, and core design experts are working as a team." The PWR Fuel and Crud Control Working Group addresses PWR performance issues related to AOA, particularly issues related to crud, and proactively identifies issues arising from new water chemistry regimes (for example, high pH and zinc injection).

Activities to establish fuel performance design margins and investigate fuel failures, both of which rely heavily on hot cell investigations, are managed by the Fuel Performance and Reliability Working Group.

The working group on fuel regulatory issues involves EPRI, fuel vendors, and utility experts who serve as the industry focal point, through NEI, for interaction with the NRC Regulatory Office to resolve generic fuel licensing issues and maintain regulatory stability.

The Fuel Reliability Program also collaborates with the NRC's Office of Research and other regulatory agencies worldwide to jointly conduct safety-related fuel research—for example, research involving reactivity-initiated accidents and loss-of-coolant accidents.

of the fuel increases rapidly, and even though a number of fuel rods would be expected to fail, the overall core geometry must be maintained to allow adequate cooling. The program is cosponsoring a series of LOCA-related experiments at Argonne National Laboratory jointly with the NRC, as well as other experiments to evaluate the adequacy of current LOCA criteria for currently licensed burnups and beyond.

Commitment to Progress

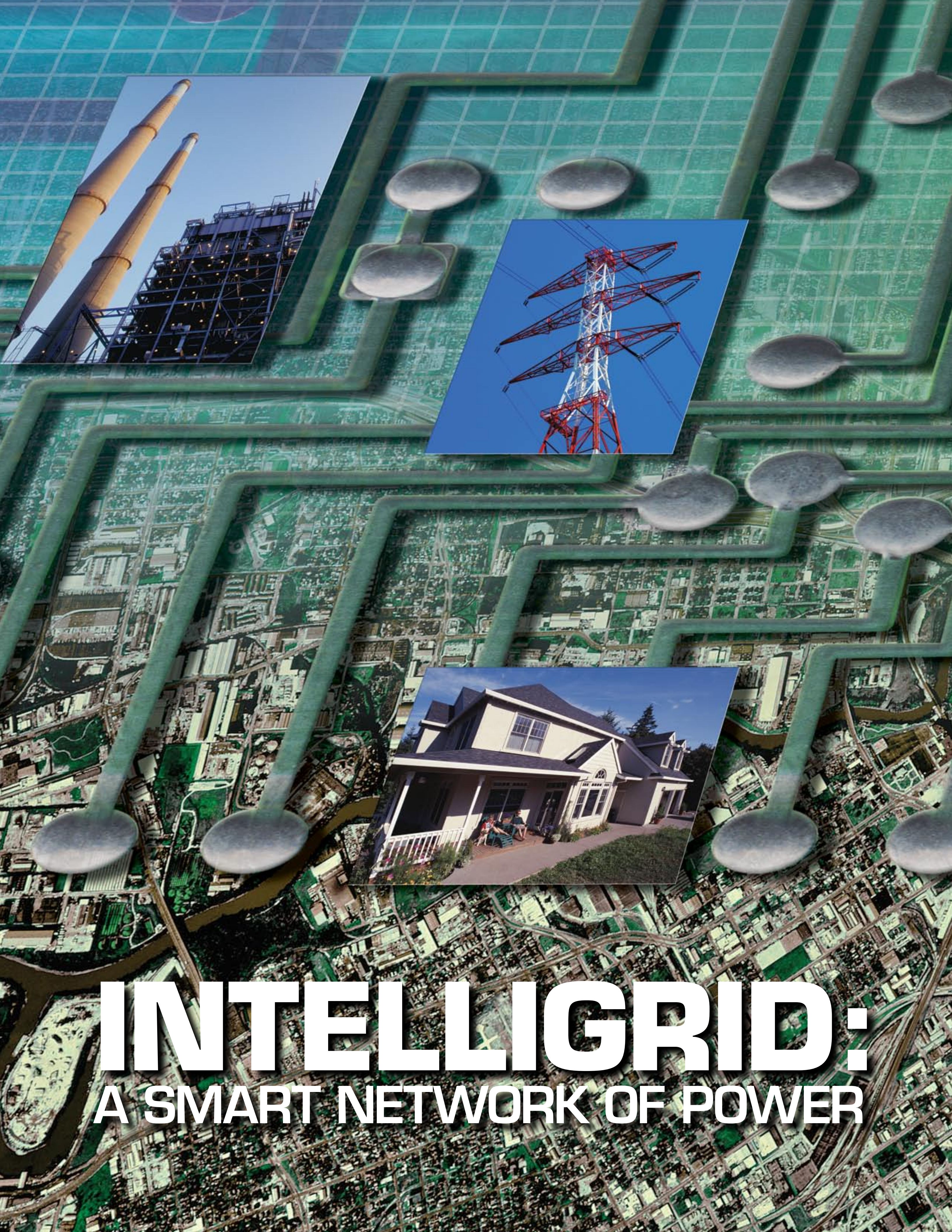
"The Fuel Reliability Program is a good example of where EPRI has worked closely with industry organizations and regulatory agencies both in the United States and internationally to address complex technical issues," notes Yang. "The industrywide nature of the program has allowed for more-effective use of funds through the pooling of resources from U.S. and international utilities. Fuel vendors participate directly to ensure the availability of robust fuel designs for defect-free operation, while NEI and INPO support the program in a liaison role. As a result, we have been able to respond to an industry challenge—that is, increased fuel failure rates—quickly and comprehensively."

Nevertheless, the challenges ahead remain formidable, and EPRI's utility-driven Fuel Reliability Program was formed with a clear understanding among its sponsors that resolving many of the key issues and achieving the program objectives will require an extended multi-phase, multi-year effort. "This is tough, painstaking technical work, and changing a problem situation sometimes takes longer than we initially anticipate," says Joe Sheppard, chief executive and chief nuclear officer for the twin-unit South Texas Project and chairman of the Fuel Reliability Program's executive committee. "We are making progress, albeit never as fast as we would want."

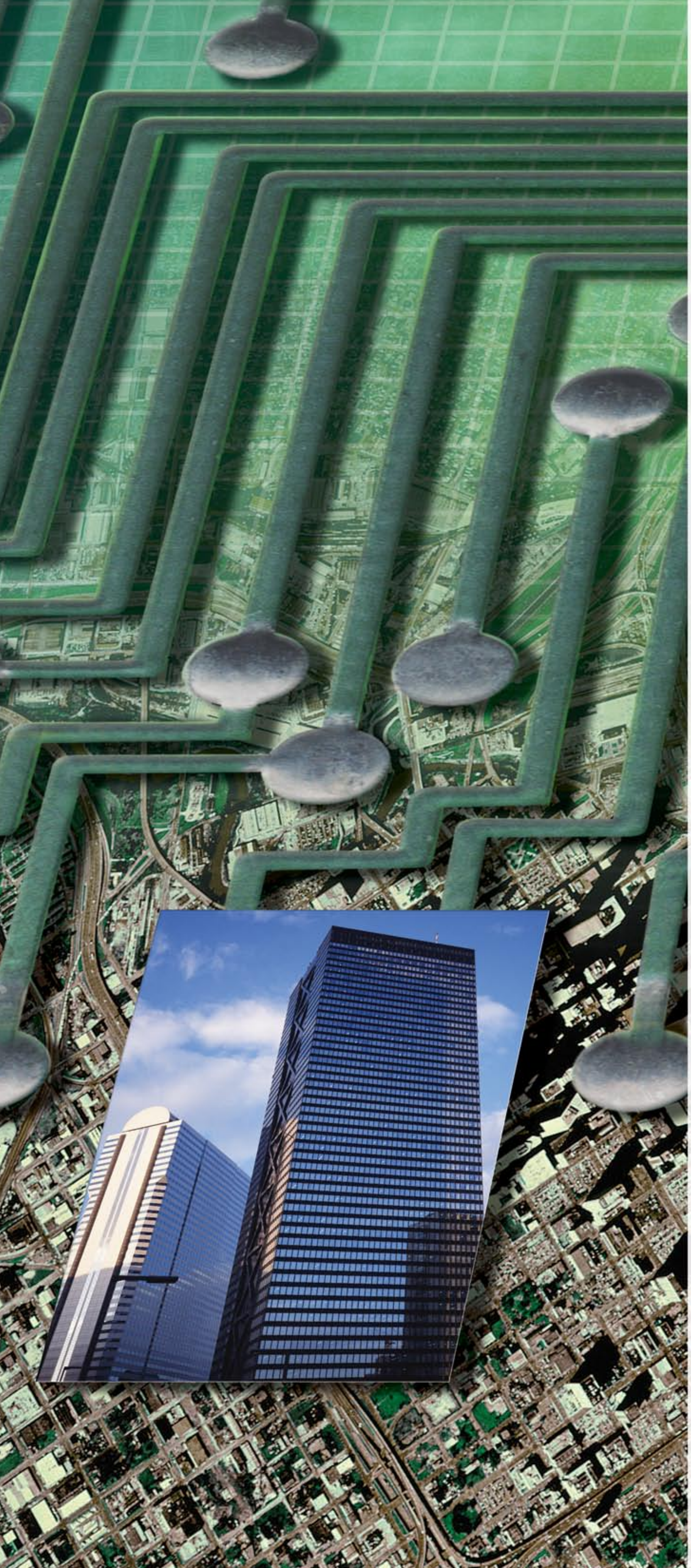
Sheppard points out that it can take as long as three years from the time a fuel rod develops a defect—and is removed during the next refueling outage, cools sufficiently in a plant's spent fuel pool for shipment to a hot cell, and can be examined and analyzed—until the time results are reported to a utility as to the root-cause mechanism of the failure. The Fuel Reliability Program's utility managers and executives have high hopes that the developing relationship with INL will help to reduce that turnaround time and speed up the feedback loop on performance data, Sheppard notes.

"The challenges we're tackling require innovative, groundbreaking R&D," adds Sheppard, "for which it's not always evident at the start how widespread the benefits will be. An example is the ultrasonic fuel cleaning technology originally developed to address AOA in PWRs but now being commercially developed for dose-reduction application in BWRs—an unanticipated, ancillary benefit. Sometimes with R&D, you have to bet on the come: you'll run down a few blind alleys, but the flip side is that you'll often get more benefits than you had planned."

Background information for this article was provided by Rosa Yang (ryang@epri.com), Kurt Edsinger (kedsinger@epri.com), and Chuck Welty (cwelty@epri.com).



INTELLIGRID:
A SMART NETWORK OF POWER



The Story in Brief

Creation of an intelligent electricity grid promises utilities and their customers substantial advances in power reliability and enhanced services. By offering a vision for such a system and pursuing the development of its technical foundation and implementation tools, the IntelliGrid^{SM} Consortium strives to help the electricity industry evolve the grid into an integrated energy and communications system on a continental scale. The effort is not a centralized, top-down makeover, but rather a distributed, bottom-up transformation created by individual companies adding advanced capabilities piece by piece onto the existing grid. And it's already happening: the first IntelliGrid implementation projects are now under way at utilities.

by Paul Haase

Over the past one hundred years, the electricity industry has created a wonder of the age—the vast electric power delivery network that fueled the tremendous industrial development of the twentieth century. The power grid, as it has come to be called, was not designed from a grand top-down plan but rather took form from the incremental additions made by hundreds of different companies. These companies discovered the genius of the grid: interconnection. By integrating their own systems with those of their neighbors, power companies were able to lend and borrow power, back each other up during emergencies, and bring unprecedented efficiency and reliability to the electricity enterprise. The network of wires and transformers and switches, created through individual projects by individual companies over a period of decades, evolved into a $400 billion assemblage that now spans the continent. It's been called the largest and most reliable machine in the world and has been ranked the top engineering achievement of the last century. No single organization planned or built the grid, and to this day, no single entity oversees it; the grid operates through the cooperation of hundreds of electricity companies.

The industrial age of the past century has now given way to the digital age. Over the last few decades, advances in diverse fields—solid-state electronics, microprocessors, sensors, communications, and information technology (IT)—have transformed society and commerce, permanently increasing our capabilities and expectations. Not surprisingly, these advances also present new opportunities for operating and using the power network, opportunities undreamed of when the grid first formed. For the power system itself, there is the possibility of creating a nimbler, more flexible network that marries electric power with cutting-edge communication and computing capabilities—an intelligent grid that can predict power problems before they get out of hand and heal itself when damage is unavoidable. For electricity customers, a smart grid means not only enhanced power reliability and security but new services that can add value to electricity while controlling its cost. For example, customers may be able to monitor their home energy use in real time, choose from a menu of service packages that best fit their energy needs and use patterns, and even sell excess electricity from rooftop solar cells back to their power provider.

The promise of digital functionality for the power grid clearly carries advantages for utilities and ratepayers alike. But how will this change come about, given that no one owns or is responsible for the North American network as a whole? As with the additive, convergent formation of the early power grid, it will be a migration rather than a sudden transformation: the intelligent grid will come from the gradual confluence of innovative projects undertaken by individual companies. As EPRI CEO Steven Specker explains it, "The revolution will be evolution." But while the new smart devices and technologies developed for these projects will be of value individually, the greater benefit to the power network will be realized only when they all work together. To ensure that the individual sensing, communications, and computing equipment installed over the coming years will be able to be integrated with other systems and, eventually, come together to form a single machine, the power network needs an overall architecture—that is, common methods and tools for planning and designing these smart systems, and a complete suite of standards.

Developing this architecture has been the early mission of the IntelliGrid℠ Consortium. This international consortium, formerly known as CEIDS (Consortium for Electric Infrastructure to Support a Digital Society), is a collaborative effort of EPRI, electric utilities, public agencies, and leading equipment manufacturers—all working together to accelerate the evolution of today's power delivery infrastructure. The strategy that the IntelliGrid Consortium has developed to accomplish this goal is to (1) assemble a group representing all stakeholders to promote a common vision; (2) adopt an iterative, adaptive planning process that allows the best possible decisions to be made, given the current uncertainties; (3) conduct R&D efforts so that the needed methods, tools, and technologies for integration can be developed; (4) support demonstration projects that advance the IntelliGrid concepts and raise the awareness of what is possible; and (5) coordinate activities with other R&D efforts and make results widely available to encourage additional applications.

The first order of business is the development of the IntelliGrid architecture—an open-standards-based architecture for integrating the data communication networks and smart equipment needed to support the power delivery system of the future. Two special efforts are also being pursued in parallel because of their importance in implementing key applications. First, advanced systems for grid control will require real-time simulation and modeling capabilities; this is a basic requirement for a self-healing grid. The fast simulation and modeling project is developing an open software platform to provide the suite of simulation and modeling tools to support future electricity transmission and distribution system operations, planning, and management. The second special need is for the development of a consumer portal—essentially a two-way communication link between utilities and their customers that will facilitate the interactive exchange of information.

The Multidimensional Challenge

"IntelliGrid represents a process for dealing with the power grid as a perpetual system—one that is replaced completely many times, part by part over its lifespan, as are air traffic control systems and bank IT systems," says Richard Schomberg, vice president for research, Electricité de France International North America.

"Today's opportunity is to interconnect enterprise information systems with physical operation systems. Doing so dramatically increases the value of the overall system, by adding intelligence and communication on top of conventional infrastructure and well-known subsystems."

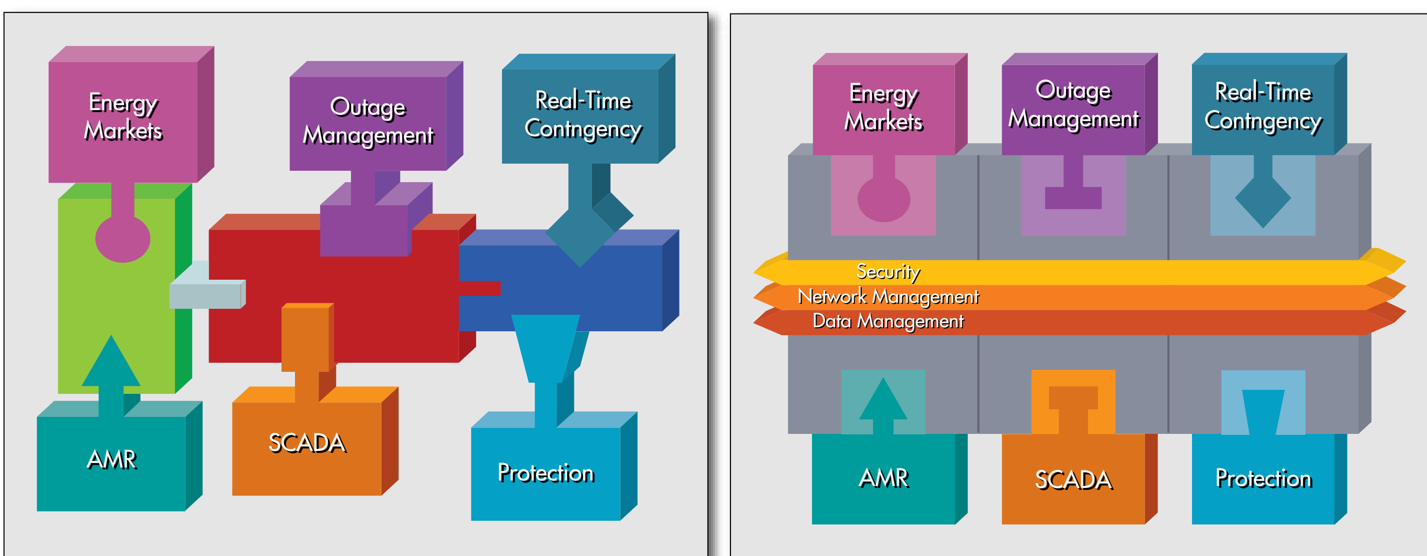
But adding progressively increasing amounts of intelligence to a continental-scale power network won't come easily. Technical challenges revolve around integrating communications among massive numbers of sensors and microprocessor-embedded smart devices on the grid; crunching data sufficiently fast to understand changes in real time; and coordinating myriad grid controls to address upsets quickly and automatically. Recent IntelliGrid Consortium efforts focus on these areas. The open-standards-based IntelliGrid architecture provides a process and tools to help utilities plan and design smart systems in a way that will make integration with other systems easier. But moving from the possible to the practical can be extremely difficult, especially when it involves melding new information technology systems with established hardware systems. "Industrial experience shows that adding IT systems to traditional infrastructure very often causes system complexity to explode beyond currently feasible limits," Schomberg says. "Manageable boundaries may be crossed without realizing it."

Indeed, a number of high-profile IT/infrastructure projects have recently succumbed to just this problem. February saw the U.S. Federal Bureau of Investigation scrap its new, $170 million computerized anti-terrorist casework system. And in June, United Airlines finally shut down its dysfunctional automatic baggage-handling system at Denver International Airport after spending 10 years and $230 million trying to get it to work. The list goes on. According to IT consultant Bruce Webster, "Humanity has been developing information technology for half a century. That experience has taught us this unpleasant truth: virtually every information technology project above a certain size or complexity is significantly late and over budget or fails altogether." Yet some projects succeed, tantalizing with their promise. For instance, in 2003, London implemented an elaborate video-based automatic toll system that reduced traffic congestion within the city's central core by up to 30%. The cost in money and time—$116 million and little more than one year—is but a tiny fraction of what it would take to expand the roads themselves, were that even feasible.

A Plan for Success

What can be done to ensure that power grid enhancement ends up on the success side of the ledger? After all, many of the North American power system's characteristics would seem to work against any comprehensive grid upgrade. First there's the sheer size of the project, which involves hundreds of millions of customers spread across a continent. Then there's the technical complexity: for a future intelligent grid to function, billions of bits of data must travel the power system as freely as does electricity now. And all the work must be coordinated across the hundreds of companies—each with its own personality and business priorities—that own the many pieces of the grid.

To deal with these issues, the IntelliGrid Consortium is working to rally the



Today's intelligent systems tend to be developed in isolation and are often connected to the utility system through proprietary communication interfaces (left). Because there is little integrative planning, systems that could benefit from common data and communications—outage management and automatic meter reading (AMR), for example—have difficulty "speaking" to each other. The IntelliGrid approach (right) defines standardized interfaces first and promotes the use of a common language; basic needs such as security and data management are built into the system from the outset. As a result, new applications can be added to the architecture more easily and effectively.

disparate members of the power industry community around a central vision, create a comprehensive and sound technical foundation for grid intelligence, and promote a modular, phased approach that can be adopted by individual companies either immediately or further down the road to advance their own strategic objectives. Outreach efforts now under way aim to engage the entire power community: electric utilities, public agencies, and equipment manufacturers.

To avoid problems of system complexity and compatibility, IntelliGrid recommends specific methods, tools, and standards that help projects sidestep common pitfalls. For example, one of the perennial mistakes for IT/infrastructure projects is to choose an existing solution technology first and then try to work the application around the inevitable limitations of the technology. To avoid the tendency of technology to drive IT projects, IntelliGrid promotes a rigorous requirements-driven approach. A so-called use case process helps participants sharply define the applications that will accomplish their objectives and identify the requirements of the desired system; only then are the requirements mapped to the appropriate technology solutions. IntelliGrid has developed and made available templates and other tools that support the use case process; standard strategies address common challenges, such as migrating to open systems and implementing security. "IntelliGrid is all about requirements first, analysis second, and technology selection last," says Joe Hughes, project manger for the IntelliGrid architecture.

When it does come to technology selection, the IntelliGrid architecture provides the mortar that will allow all pieces of the smart grid to work together. When the IntelliGrid architecture is used to develop a smart application on any particular part of the grid—on the transmission or distribution system or at the customer site—the application inherits the embedded capability to interoperate with all the other parts. The architecture's integrative mortar and a growing repository of project "bricks" allow the industry to build intelligence into the grid modularly over time while avoiding the explosion of complexity that has plagued other IT-based projects.

In 2005, the first IntelliGrid projects began to put technologies and the IntelliGrid foundation to the test. Some of these projects are real-world, full-scale efforts by utilities and public agencies; others test and demonstrate concepts or technologies. As companies work through these implementations, the consortium is documenting the lessons learned in order to transfer the knowledge gained to IntelliGrid partners and the power industry.

Risk Mitigation Through Data Integration

One early IntelliGrid project sees Arizona-based Salt River Project (SRP) working to integrate all intelligent electronic devices at its Browning 500-kV/230-kV transmission substation. Large receiving stations such as Browning represent significant investments. Protecting these investments from failure or other unplanned events is of paramount importance. SRP's Browning Integration Project will demonstrate how data integration can help a utility manage risk, while providing smart information that is both timely and useful. Benefits include improved system reliability, better planning of equipment maintenance, and reduced response time for outages.

SRP currently receives raw real-time data about system faults and substation equipment condition, but the information is not interpretive, integrated, or centralized. More than 50 sensors report faults, equipment conditions, and other issues without providing coordinated communications and analysis that can be acted on in a timely manner.

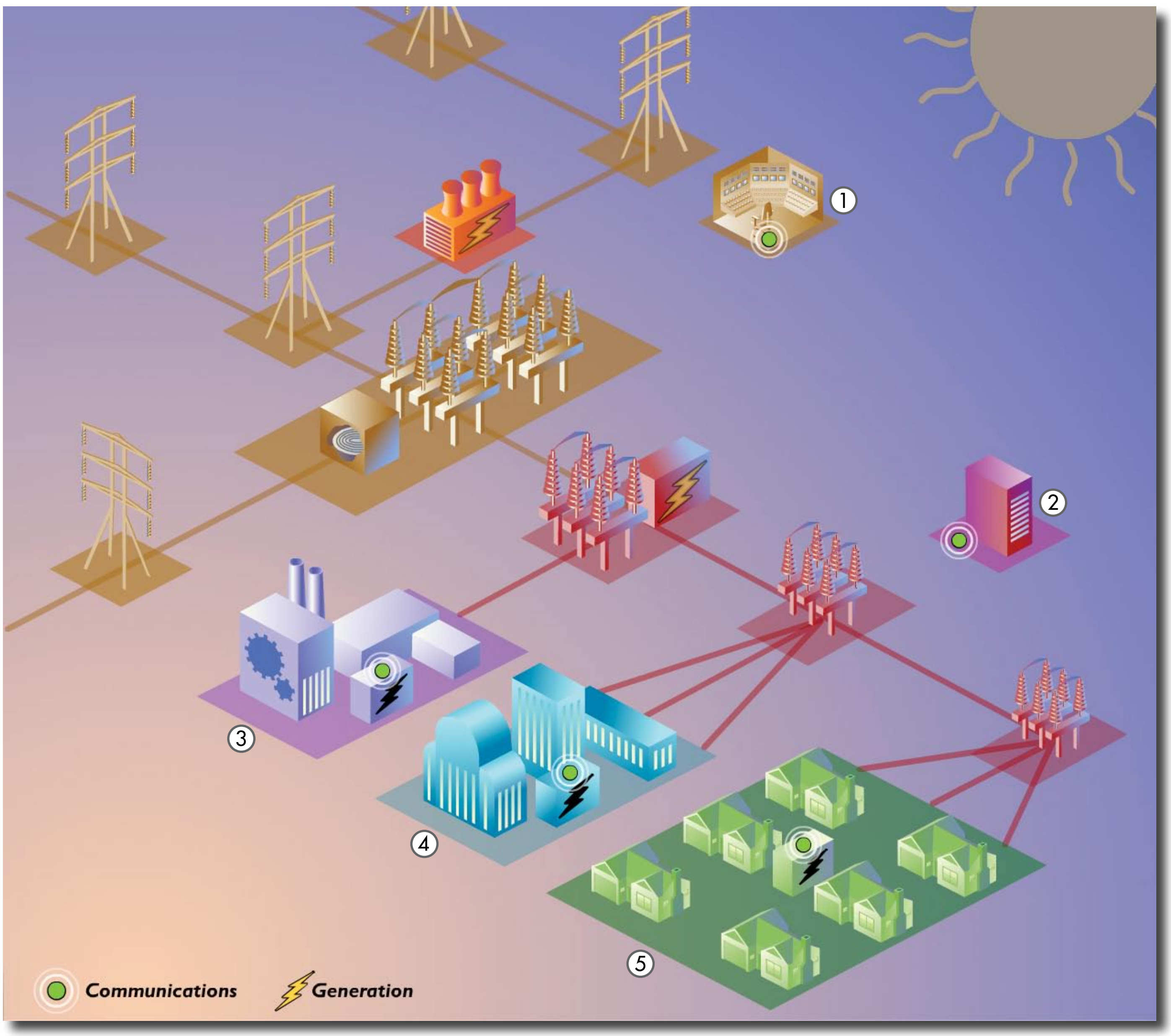
Such conditions typify the use of intelligent devices throughout the power grid, where microprocessors have enabled individual devices to capture more and better data but have not made possible the inter-device communications that can turn massive quantities of data into immediate knowledge for support personnel. SRP's objective with IntelliGrid is to create a system that processes these raw data into instantly useful information and to make those results available on the desktop PCs of maintenance, engineering, and planning groups.

Using the IntelliGrid approach, SRP can connect the intelligent devices—and any future additions—at the Browning substation to a common data network by means of a common information model. Initially, the DNP3 protocol will continue to be used for basic device communications. An innovative feature of this IntelliGrid project is the application of IEC 61850 information modeling methods to DNP3; IEC 61850, an outgrowth of EPRI's earlier UCA work, is an integral part of the IntelliGrid architecture. This approach will make it possible to manage intelligent electronic device configuration by means of a more-disciplined and deterministic approach than the classic method of maintaining massive, hard-to-maintain spreadsheets (points lists). The common information model, recommended in the foundational IntelliGrid reference architecture, employs a common data representation and common language. Data representation and language both follow open, nonproprietary international standards. As a result, all data can be transported from where they are created to where they are needed, and in a common format for analysis.

The model, however, is not so easy to put into practice. For example, just rationalizing data from two monitors with different temperature readings may be difficult. Perhaps one monitor reads temperature in degrees Fahrenheit and the other in degrees Celsius; or one monitor reports data to two decimal places and the other to four. These are just a few examples of the hurdles to be cleared. Extensive data decoding, manipulation, translation, and recoding are necessary to create the object model translators to put the various findings into the common IntelliGrid repre-

Example: IntelliGrid Deals With a Heat Wave

IntelliGrid's real-time assessment and control capabilities will help utilities avoid a variety of problems. One example involves an especially hot summer day, when increased customer air-conditioner use threatens to boost electricity demand sharply. The transmission system operator (1), integrating weather data with real-time information from sensors embedded in the grid, forecasts that it may not be able to meet the coming peak load for a part of its service territory. To prevent a shortfall, the operator calls for reduced customer usage and asks distributed generators to sell any surplus generation. The energy service provider (2) facilitates the curtailment request by sending a signal to its customers' communication portals, offering special incentives for customers who shed load during the peak period. In response, one industrial customer (3) decides to shut down one of its three assembly lines for several hours. A commercial customer (4) shifts over to an on-site backup generator and is able to sell some excess power back to the utility. Several residential customers (5) have preprogrammed their portals to automatically dim their lights and reset their thermostats higher in response to such an offer; another residence, which has rooftop solar panels, feeds electricity back onto the grid. Because the smart grid's power and communications systems are integrated, the utility can take advantage of all available supply- and demand-side options and avoid an almost certain power shortfall.



sentation and language. And missing equipment manuals, long-gone manufacturers, and retired expertise add real-world complications to the challenge of object model programming.

At present, SRP is completing the IntelliGrid use case templates for the Browning integration project. These templates identify the data the utility needs to collect at Browning substation on the basis of how the data will be used. The use case information defines the project requirements—in particular, what object models are needed to connect the intelligent devices at the substation to the new common information bus. Some of these models exist already, and the others will be developed as needed in later phases of the project.

Infrastructure for Automated Meter Reading

TXU Electric Delivery of Dallas, Texas, is making early use of the IntelliGrid approach to refine its efforts to implement automated meter reading (AMR) for its entire system—some three million meters—within the next few years. This $400 million project challenges the IntelliGrid concept. The sheer number of meters makes for a daunting task: swapping out three million of anything is not trivial. And tight economics, proprietary data systems, and the need to support additional applications make TXU's enterprise AMR task even tougher.

Fundamentally, AMR requires intelligent digital meters that automatically communicate energy use to a utility data center. By contrast, conventional electromechanical meters indicate energy use on dials or displays that must be read by hand. Over the years, utilities have become very efficient at reading such meters, to the point that meter reading costs less than $8 per meter per year. This low figure means that the economic justification for switching to an AMR system must be founded on careful analysis of every aspect of the system. To justify a changeover, utilities typically demand additional benefits from their new digital meter-and-communications infrastructure. Many possibilities exist. TXU expects to use AMR to speed the connection of electric service for high-transient locations through remote connection, to close accounts more quickly for customers who move by reading the meters nearly instantaneously, and to detect and manage power outages for faster restoration of service. In the future, AMR may also offer the capability of providing other services to market participants.

> IntelliGrid's modular, phased approach can be adopted by individual companies either immediately or further down the road to advance their own strategic objectives.

The trick to leveraging multiple benefits from interlinked intelligent meters is similar to that for intelligent devices at a substation: collecting and integrating dispersed data from the meters and moving the data into different utility computer applications for use by various departments. Not only must different equipment types, proprietary data representations, and diverse data languages be accommodated (as at a substation), but data must be exchanged among many groups: retail energy sales organizations, customer operations, distribution operations, reliability management operations, and so on.

Although TXU began its AMR changeover before the IntelliGrid architecture was complete, early application of IntelliGrid principles has caused the utility to change its original plans. TXU created a systems integrator/middleware vendor evaluation process that resulted in higher scores for proposals that are consistent with key IntelliGrid principles and technologies. The result of this process was the selection of a vendor that has committed to implement standardized interfaces and information models at the enterprise level that make data from proprietary metering systems available for company-wide applications at TXU and promote cross-department data exchange and migration to open-standards equipment in the future.

A Vision of the Future

An intelligent grid for North America won't be built in a day—or a decade. But the vision of a digital-age power delivery system is compelling, and the way to build it is becoming clear: plan carefully and integratively, incorporate flexibility, start small, and build on successes. The IntelliGrid foundation ensures that compliant intelligent equipment installed today will function with new equipment long into the future. Consequently, individual automation projects—to test new technologies, to realize competitive advantage, or for any other purpose—can be undertaken with confidence that the equipment will later become part of an integrated network. As existing and new intelligent systems coalesce over time to create more and more intelligence on the grid, a revolutionary, truly intelligent grid will eventually emerge. As Don Von Dollen, EPRI program manager for IntelliGrid, points out, it's happening now: "Utilities install intelligent electronic devices every day, so every day brings an opportunity to build the grid of the future."

Background information for this article was provided by Don Von Dollen (dvondoll@epri.com), Joe Hughes (jhughes@epri.com), and Richard Schomberg.

Technology at Work

Member applications of EPRI science and technology

SOAPP Supports Repowering Decision at Fitzhugh

Deciding what to do with underperforming power plant assets can be a difficult, complicated process. Arkansas Electric Cooperative Corporation (AECC) faced this issue as its 40-year-old Fitzhugh Plant boiler neared the end of its design life. Though the aging boiler was proving to be increasingly unreliable, many of the balance-of-plant assets, including the steam turbine, had years of useful life remaining. The existing plant also had a number of valuable attributes, including two gas pipelines, rail and interstate highway access, a transmission line, trained staff, simplified permitting requirements, and community acceptance.

The challenge for the utility was to find the best option for the future of the 59-MW plant in light of these problems and assets and the expected growth in capacity needs. Among the options were to completely refurbish the boiler; to retire the plant and build a greenfield replacement plant; to retire the plant and purchase capacity from merchant generators; and to repower the plant, selecting from a number of fuel and configuration alternatives.

AECC turned to EPRI to provide essential products and services that supported its decision-making process and conceptual plant design. Key among these products and services were two of the Institute's SOAPP (State-of-the-Art Power Plant) Workstation software packages. The first, SOAPP-CT, is an easy-to-use program for combustion turbine–based projects in simple-cycle, cogeneration, and combined-cycle configurations. The software generates detailed, site-specific conceptual designs, heat balances, cost estimates, emissions estimates, and technical and economic analyses for project development and bid evaluation. SOAPP-REPO—the second package—focuses on the combined-cycle repowering of existing fossil steam plants, integrating process design, costing, and financial analysis to enable users to quickly assess the viability of a repowering scenario on a site-specific basis.

By using the SOAPP-CT and SOAPP-REPO software packages, AECC was able to examine various technology options and make estimates of the cost and performance of each alternative on the basis of EPRI information and tools. A so-called fatal flaw screening was performed to eliminate repowering approaches that were incompatible with regard to capacity need, technology, or site limitations.

The results of the final evaluation showed that combined-cycle repowering of the Fitzhugh plant would be superior to greenfield self-build and power purchase options, given the site and expected operating conditions. Repowering was found to provide the AECC customer base with the lowest-cost electricity and a reduced risk of potentially high peak electricity rates. In addition, the repowering project is expected to support job retention in the local community.

Cost and performance estimates from SOAPP-REPO, combined with other in-house resources, were used not only to prepare detailed project capital and operating cost estimates and a detailed schedule, but also to determine the most economical way to secure additional generating capacity. In addition, SOAPP-REPO helped to establish a reuse plan for existing equipment, recommended potential combustion turbines compatible with the existing steam turbine capacity, and performed overall project economic analysis to help in the optimization of the plant configuration.

AECC found that conducting the SOAPP evaluations rather than retaining consultants and engineering/architecture firms to prepare the studies produced more high-quality information more quickly and at lower cost. The SOAPP software provided a hands-on framework for understanding the important issues in combined-cycle design and plant repowering and allowed more alternatives to be considered and screened effectively. And because the initial conceptual design included detailed performance and cost estimates, the utility was able to reserve scarce development resources for important plant condition assessments and detailed design engineering.

For more information, contact Dale Grace, dgrace@epri.com.

EPRI Solutions

Engineering services, business consulting, and information products

Eco-Asset Service Identifies Win-Win Conservation Opportunities

An emerging approach to habitat protection known as conservation banking is an appealing option for business landowners and environmentalists alike, according to EPRI Solutions. This and other market-based strategies allow utilities and other landowners to realize financial rewards for supporting ecological assets such as endangered species habitats, wetlands, and clean water. Permanently protecting and managing land according to its natural resource value can result in credits that can be applied to a company's own internal mitigation obligations or sold on the open market.

EPRI Solutions has found that new niche markets have resulted in valuations of up to $125,000 per acre for land that supports rare plants and animals and up to $250,000 per acre for wetlands.

To help electric utilities and other companies understand the benefits of market-based environmental protection, an approach expected to grow significantly during the next five years, EPRI Solutions is offering a new program called the Eco-Asset Strategic Information Service. The service provides an integrated package of deliverables—primary research, reports, newsbriefs, networking opportunities—as well as access to EPRI Solutions experts, all with an independent, market-neutral perspective. One study already available—"Status of Species Conservation Banking in the United States," published in the August 2005 issue of *Conservation Biology*—provides the first comprehensive information on the status of endangered species banking in the United States.

"In the past, companies such as utilities had no way to monetize healthy ecological assets like wetlands, endangered species, and riparian buffers—even if they clearly had environmental value," says Jessica Fox, a senior scientist with EPRI Solutions. "Market-based approaches offer win-win opportunities for corporations to reduce compliance costs, generate a positive corporate image, and create nontraditional revenue streams. Because landowners can now realize a financial return by protecting habitat, natural resources can be converted from corporate liabilities to strategic assets."

The system is attractive to landowners, developers, and environmentalists because it is simple, cost-effective, and ecologically beneficial. The Millennium Ecosystem Assessment, an international collaboration to assess human impacts on the environment, recently expressed support for such conservation approaches. The fact that many of the first-generation species and wetland credits are owned by for-profit organizations implies that these approaches provide an effective solution to the historically intractable conflicts between business profitability and environmental concerns.

As one of the first deliverables of the Eco-Asset Strategic Information Service, EPRI Solutions is organizing the first-ever multi-industry workshop to discuss hurdles, opportunities, and successes in utilizing market-based conservation approaches. Topics to be covered include endangered species banking, wetland banking, water quality trading, and carbon sequestration. Workshop participants will represent at least four industries—electricity, transportation, oil and gas, and pulp and paper. The Ecological Assets in Business Workshop is planned for March 13–14, 2006, in Palo Alto, California. See http://www.eprisolutions.com/eco-assets for detailed information on the Eco-Asset Strategic Information Service, the workshop, and other related offerings.

For more information, contact Jessica Fox, jfox@eprisolutions.com.

PQ Road Show Helps FirstEnergy Put the "CustomerFirst"

To help customers understand—and address—power quality (PQ) problems, FirstEnergy partnered with EPRI Solutions' PQ experts to conduct 11 customer workshops this past summer. The sessions brought leading-edge PQ information and solutions to more than 200 of FirstEnergy's largest industrial and commercial customers from across Ohio, Pennsylvania, and New Jersey. FirstEnergy experts from the engineering and customer support areas provide ongoing assistance to these key customers.

Power quality is an issue for many customers because most commercial and industrial facilities employ electronic technologies, such as process controls, robotics, computers, and automated systems, that can be extremely sensitive to electrical disturbances. Even minor disturbances can cause computers to crash and electronically controlled industrial equipment to shut down—effectively forcing manufacturing processes to grind to a halt. As a result, PQ problems now cost U.S. companies billions of dollars in scrapped material, downtime, damaged data, and delayed orders.

Utilities have many systems in place to protect service reliability and continuity. Nonetheless, severe weather, vehicle-pole accidents, equipment failure, and vandalism invariably cause power disturbances. Also, a significant number of electrical disturbances originate from sources within the customer's facility, such as adjustable-speed drives, air conditioners, compressors, and arc welders, to name a few.

FirstEnergy's workshops with EPRI Solutions illustrated the complexity of the PQ problem while demonstrating simple and cost-effective solutions for protecting sensitive production equipment. The sessions focused on customers' most common PQ problems, including voltage sags, flicker, and lightning strikes. Working together to identify and resolve these problems benefits both the customer and the utility. Subsequent collaborative work by EPRI Solutions, FirstEnergy, and individual customers has also helped resolve specific problems at key customer sites, including an automotive plant, a large printing facility, and a steel facility.

"Our customers clearly recognize EPRI Solutions as an expert in the power quality arena," says Doug Elliott, FirstEnergy's senior vice president for customer service and service area development. "Using EPRI Solutions to facilitate these PQ workshops—and then following up with audits in certain cases—made this effort a success. We've received great response from our customers and plan additional programs for specific industries that demonstrate what our 'CustomerFirst' approach is all about."

EPRI Solutions has been conducting PQ workshops for utilities and customers since 1986. Among other services, it offers PQ monitoring, detailed site audits, and studies of PQ problems and solutions for specific industries.

For more information, contact Karen Forsten, kforsten@eprisolutions.com.

Alabama Electric Cooperative Averts Costly Transformer Failure

Last spring, experts from EPRI Solutions helped Alabama Electric Cooperative (AEC) avoid a costly transformer problem at one of its power plants, just in time to meet heavy summer demand for electricity. "By averting a catastrophic failure of a GSU bushing at the Lowman generating station, EPRI Solutions' Predictive Maintenance Equipment Condition Inspection & Assessment Program allowed us to avoid a $4.5 million operating loss," reports Jay Farrington, operating services manager for AEC.

GSU, or generator step-up, transformers play a critical role in the electricity delivery system, linking relatively low-voltage generation with high-voltage transmission. Because loss of a GSU transformer can mean loss of generation and extra costs for electricity purchases as well as for transformer replacement, it's important for electric utilities to

carefully manage the life of these devices. The aged condition of many GSU transformers and the often long lead times for securing replacements add to the concern for utility operations managers.

For AEC, the solution was an integrated predictive maintenance (PdM) program for GSU transformers and other key components of its transmission infrastructure. To implement the program, the utility contracted with EPRI Solutions to conduct a comprehensive condition inspection and assessment of existing assets, evaluate the financial risk of all identified problems, and train AEC engineers in a rational and economic PdM approach.

It was during the condition assessment that EPRI Solutions identified the GSU transformer problem, which involved significant heating in the oil expansion chamber of the B-phase bushing. Additional potential equipment problems were identified during the battery of state-of-the-art diagnostic procedures, which included visual and infrared thermography, corona imaging, functional testing, ultrasound noise analysis, vibration analysis, and sound-level measurements. EPRI Solutions then integrated the condition data with historical information about equipment operations, loading, and maintenance, as well as prior test results, to provide AEC with a complete PdM equipment status report and risk assessment. This report described critical parameters, including present transformer condition, level of performance, estimated service life, condition-based rating for continuous operation, and risk of failure and associated financial costs.

Armed with this information, AEC engineers immediately put their EPRI Solutions PdM training to work in the field. The company met its summer load peak without problems and expects continuing benefits in coming years.

For more information about EPRI Solutions' Equipment Condition Inspection & Assessment Service, contact either Mark Ostendorp, mostendorp@eprisolutions.com, or George Waidelich, gwaidelich@eprisolutions.com.

Technical Reports & Software

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

Environment

Field Evaluation of the Co-management of Utility Low-Volume Wastes With High-Volume By-Products: CY Site
1005504 (Technical Report)
Program: Groundwater Protection and Coal Combustion Products Management
EPRI Project Manager: Kenneth Ladwig

Application of the Tar-Specific Green Optical Screening Tool (TarGOS™) at a Manufactured Gas Plant Site in New Jersey
1012131 (Technical Report)
Program: MGP Site Management
EPRI Project Manager: Andrew Coleman

CMAQ–MADRID/CMAQ-APT 2004—Community Multiscale Air Quality–Model of Aerosol Dynamics, Reaction, Ionization, and Dissolution/Community Multiscale Air Quality–Advanced Plume Treatment, Version 2004
1012138 (Software)
Program: Air Toxics Health and Risk Assessment; Assessment Tools for Ozone, Particulate Matter, and Haze
EPRI Project Manager: Eladio Knipping

Generation

Condenser Technology Conference
1010322 (Technical Report)
Program: Combustion Performance and NO_x Control
EPRI Project Manager: Jeffrey Stallings

State-of-the-Art Power Supplies for Electrostatic Precipitators
1010363 (Technical Report)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph Altman

Guidelines for Obtaining Compliance Assurance Monitoring (CAM) Permits
1010751 (Technical Report)
Program: Particulate and Opacity Control
EPRI Project Manager: Ralph Altman

Investigation of Cracking in Fossil Boiler Drums—Finite-Element and Fracture Mechanics Analyses
1011916 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: Kent Coleman

SOAPP-CT O&M Cost Estimator 3.4—SOAPP Combustion Turbine/Combined-Cycle Operations and Maintenance Cost Estimator, Version 3.4, for Win 95/98/NT 4.0/2000/XP
1012048 (Software)
Program: SOAPP Software
EPRI Project Manager: Dale Grace

Assessment of California Combined Heat and Power (CHP) Market and Policy Options for Increased Penetration
1012075 (Technical Report)
Program: Distributed Energy Resources
EPRI Project Manager: Daniel Rastler

Productivity Improvement for Fossil Steam Power Plants 2005: One Hundred Case Studies
1012098 (Technical Report)
Program: Steam Turbines, Generators, and Balance-of-Plant
EPRI Project Manager: Anthony Armor

2005 Continuous Emission Monitoring User's Group Meeting
1012100 (Technical Report)
Program: Continuous Emissions Monitoring
EPRI Project Manager: Charles Dene

Grade 22 Low Alloy Steel Handbook
1012840 (Technical Report)
Program: Fossil Materials and Repair
EPRI Project Manager: David Gandy

Nuclear Power

MOV PPM 3.3 (Build 3.3.35)—Motor-Operated Valve Performance Prediction Methodology, Version 3.3 on CD-ROM for Win NT/2000/XP, QA Software
1009511 (Software)
Program: Nuclear Power
EPRI Project Manager: John Hosler

Instrument Drift Study
1009603 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Ramesh Shankar

The Use of Proton Irradiation to Determine IASCC Mechanisms in Light Water Reactors
1009898 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

MOV Long Life Grease—Evaluation for Limitorque Limit Switch Gearboxes: Used in Nuclear Safety Related Applications, QA Safety Related
1010058 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Neil Wilmshurst

Service Water Piping Guideline
1010059 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Timothy Eckert

Materials Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guidelines (MRP-139)
1010087 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christine King

Materials Reliability Program: Crack Initiation Testing and Slow Strain Rate Tensile (SSRT) Testing of Boris-60 Irradiated Materials, and Effect of Hydrogen on IASCC Susceptibility (MRP-159)
1010096 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

Resolving Our Understanding of REP-Na1
1010958 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Odelli Ozer

Potential Igneous Processes Relevant to the Yucca Mountain Repository: Intrusive-Release Scenario
1011165 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Kessler

BWRVIP-143: BWR Vessel and Internals Project, On-Line Noble Metal Chemical Application Generic Technical Safety Evaluation
1011698 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

BWRVIP-142NP: BWR Vessel and Internals Project, Part 1: Effects of Noble Metal Chemical Application on Fuel Performance
1011704 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

BWRVIP-144: BWR Vessels and Internals Project, Description and Installation of In-Reactor Noble Metal Surface/Crack Deposition Monitoring Device
1011707 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Program on Technology Innovation: Network Management Technology Applied to Power Plant Instrumentation, Control, and Maintenance
1011711 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Raymond Torok

Program on Technology Innovation: Staff Optimization Scoping Study for New Nuclear Power Plants
1011717 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Layla Sandell

Program on Technology Innovation: Materials Database Extension
1011719 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Layla Sandell

ANP LLW Management Review
1011724 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Layla Sandell

Groundwater Monitoring Guidance for Nuclear Power Plants
1011730 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christopher Wood

Proceedings: Third EPRI International Decommissioning and Radioactive Waste Workshop
1011731 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christopher Wood

Proceedings: 2004 EPRI Topical Workshop—License Termination Plans/Final Site Release
1011732 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Christopher Wood

Modeling PWR Fuel Corrosion Product Deposition and Growth Process
1011743 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Jeffrey Deshon

BWR Ultrasonic Fuel Cleaning Qualification
1011747 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Kurt Edsinger

Design Basis Accident Testing of Pressurized Water Reactor Unqualified Original Equipment Manufacturer Coatings, QA Report on CD-ROM
1011753 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Timothy Eckert

CIR II Program: Description of the Boris 6 and 7 Experiments in the BOR-60 Fast Breeder Reactor
1011787 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Rajeshwar Pathania

Application of Critical Strain Energy Density to Predicting High-Burnup Fuel Rod Failure
1011816 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Albert Machiels

PMB C/S 1.5–Preventive Maintenance Basis Database Client/Server, Version 1.5
1011923 (Software)
Program: Nuclear Power
EPRI Project Manager: Martin Bridges

Materials Reliability Program: Integrated Fatigue Management Guideline (MRP-148)
1011957 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Carey

Materials Reliability Program: Third International Conference on Fatigue of Reactor Components (MRP-151)
1011958 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Carey

Development of Probabilistic Risk Assessment (PRA) Qualification and Curriculum
1011981 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Volume 1: Summary and Overview, Volume 2: Detailed Methodology
1011989 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Kassawara

Materials Reliability Program: Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application (MRP-47, Revision 1)
1012017 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Carey

Materials Reliability Program: Thermal Fatigue Licensing Basis Monitoring Guideline (MRP-149)
1012018 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: John Carey

Assessment of a Performance-Based Approach for Determining Seismic Ground Motions for New Plant Sites, Version 1
1012044 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Layla Sandell

Assessment of a Performance-Based Approach for Determining Seismic Ground Motions for New Plant Sites, Version 2
1012045 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Layla Sandell

Materials Reliability Program: Fracture Toughness Testing of Decommissioned PWR Core Internals Material Samples (MRP-160)
1012079 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

PWR Steam Generator Secondary-Side IGA/SCC: Correlations With Deposit Lead and Phosphate History
1012097 (Technical Report/Software)
Program: Nuclear Power
EPRI Project Manager: Allan McIlree

BWRVIP-57-A: BWR Vessel and Internals Project, Instrument Penetration Repair Design Criteria
1012111 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-16-A: BWR Vessel and Internals Project, Internal Core Spraying Piping and Sparger Replacement Design Criteria
1012113 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-19-A: BWR Vessel and Internals Project, Internal Core Spray Piping and Sparger Repair Design Criteria
1012114 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-50-A: BWR Vessel and Internals Project, Top Guide/Core Plate Repair Design Criteria
1012115 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-51-A: BWR Vessel and Internals Project, Jet Pump Repair Design Criteria
1012116 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-55-A: BWR Vessel and Internals Project, Lower Plenum Repair Design Criteria
1012117 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-56-A: BWR Vessel and Internals Project, LPCI Coupling Repair Design Criteria
1012118 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-52-A: BWR Vessel and Internals Project, Shroud Support and Vessel Bracket Repair Design Criteria
1012119 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-53-A: BWR Vessel and Internals Project, Standby Liquid Control Line Repair Design Criteria
1012120 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-41, Revision 1: BWR Vessel and Internals Project, BWR Jet Pump Assembly Inspection and Flaw Evaluation Guidelines
1012137 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

Pipe Rupture Frequencies for Internal Flooding Probabilistic Risk Assessments (PRAs)
1012302 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Frank Rahn

Assessment of Nuclear Qualification for Data Systems and Solutions SPINLINE3 Digital Safety Instrumentation and Control Platform
1012574 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Joseph Naser

BWRVIP-58-A: BWR Vessel and Internals Project, CRD Internal Access Weld Repair
1012618 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

BWRVIP-75-A: BWR Vessel and Internals Project, Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules
1012621 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

Materials Reliability Program: Fracture Toughness Testing of Decommissioned PWR Core Internals Material Samples (MRP-160)
1012655 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Hui-Tsung Tang

BWRVIP-02-A: BWR Vessel and Internals Project, BWR Core Shroud Repair Design Criteria, Revision 2
1012837 (Technical Report)
Program: Nuclear Power
EPRI Project Manager: Robert Carter

Power Delivery and Markets

Global Survey of Regulatory Approaches for Power Quality and Reliability
1008589 (Technical Report)
Program: Global Power Quality
EPRI Project Manager: Robert B. Schainker

Field Guide: Corona Rings for Polymer Insulators
1008741 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: Andrew J. Phillips

Plug-in Hybrid Electric Vehicle Battery Test Results
1008764 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Robert Graham

Field Guide: Visual Inspection of Polymer Insulators
1010221 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: Andrew J. Phillips

Formation of Nanovoids in Extruded Dielectrics Caused by Mechanical Fatigue and Fracture
1010497 (Technical Report)
Program: Underground Transmission Systems
EPRI Project Manager: Walter Zenger

Equipment Performance Database With Common Information Model (CIM) Data Models and Performance Data for Transformers
1010592 (Technical Report)
Program: Substations
EPRI Project Manager: Barry Ward

Program on Technology Innovation: Utility Integration Bus (UIB) Toolkit Technical Reference and Tools
1010593 (Technical Report)
Program: Substations
EPRI Project Manager: Bhavin Desai

Handbook of Alternative Technologies for Substation Emergency Power
1010603 (Technical Report)
Program: Substations
EPRI Project Manager: Steven Eckroad

Energy Portfolio Manager (EPM), Version 3.10.5000 on CD-ROM for Win 2000/XP
1010685 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art M. Altman

Static Equilibrium: Forecasting Long-Term Energy Pricing
1010688 (Technical Report)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Eberhardt Niemeyer

Generation Asset Manager (GAM), Version 3.10.5000 on CD-ROM for Win 2000/XP
1010697 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Art M. Altman

Pilot Evaluation of Bag and Cartridge Filters
1011148 (Technical Report)
Program: EPA Small Water Systems
EPRI Project Manager: Andra M. Rogers

Transmission Line Lightning Protection (TFlash), Version 4.1 on CD-ROM for Win 2000/XP
1011388 (Software)
Program: Overhead Transmission
EPRI Project Manager: Andrew J. Phillips

Transmission Line Lightning Protection, Version 4.1 Southern Co. Customization, (TFlash SoCo)
1011389 (Software)
Program: Underground Transmission Systems
EPRI Project Manager: Andrew J. Phillips

Power Quality Solutions Database—Integrated Power Quality Diagnostic System Economic Assessment Module, (PQSDB-EAM), Version 1.0 on CD-ROM for Win 98/NT/2000/XP
1011460 (Software)
Program: Global Power Quality
EPRI Project Manager: Robert B. Schainker

Best Practices for HPFF Pipe-Type Cable Assessment, Maintenance, and Testing
1011489 (Technical Report)
Program: Underground Distribution Systems
EPRI Project Manager: Walter Zenger

Electric Industrial Lift Trucks
1011498 (Technical Report)
Program: Electric Transportation
EPRI Project Manager: Gloria Del Recio Krein

Advanced Diagnostics: Life Estimation of Extruded Dielectric Cables
1011499 (Technical Report)
Program: Underground Distribution Systems
EPRI Project Manager: Robert J. Keefe

Field Guide: Visual Inspection of Steel Structures
1011545 (Technical Report)
Program: Overhead Transmission
EPRI Project Manager: Andrew J. Phillips

System Compatibility Guidebook 2004
1011602 (Technical Report)
Program: Power Quality Mitigative Solutions
EPRI Project Manager: Robert B. Schainker

Transmission Fast Simulation and Modeling (T-FSM)—Functional Requirements Document
1011666 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: Peter Hirsch

Transmission Fast Simulation and Modeling (T-FSM)—Architectural Requirements
1011667 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: Peter Hirsch

Development of Operator Training Scenarios at New York Power Authority (NYPA) Using a Simulator
1011696 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

Development of a New Acoustic Emissions Technique for the Detection and Location of Gassing Sources in Power Transformers and LTCs
1011708 (Technical Report)
Program: Substations
EPRI Project Manager: Barry Ward

AEP Sodium-Sulfur (NAS) Battery Demonstration
1012049 (Technical Report)
Program: Energy Storage for Transmission or Distribution Applications
EPRI Project Manager: Steven Eckroad

HTC Matrix, Version 1.1 on CD-ROM for Win 95/98/NT/2000/XP High Temperature Conductor Knowledgebase Matrix
1012069 (Software)
Program: Overhead Transmission; Increased Transmission Capacity
EPRI Project Manager: John Kar Leung Chan

Report on the ELES CIM/GID Conformance Test: The Power of the Common Information Model (CIM) and Generic Interface Definition (GID) to Exchange Power System Data and Provide an Integration Platform
1012086 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

Capturing Undocumented Expert Knowledge
1012127 (Technical Report)
Program: Substations
EPRI Project Manager: Steven Eckroad

Electrochemical Capacitors for Utility Applications
1012151 (Technical Report)
Program: Energy Storage for Transmission or Distribution Applications
EPRI Project Manager: Steven Eckroad

Program on Technology Innovation: Development and Characterization of a One-cm^2 4H-SiC Thyristor
1012188 (Technical Report)
Program: Substations
EPRI Project Manager: Raymond Lings

Generation Asset Manager (GAM) for KEPRI, Version 3.10.6000 for Win 2000/XP
1012189 (Software)
Program: Value and Risk in Energy Markets
EPRI Project Manager: Eberhardt Niemeyer

Program on Technology Innovation: Future Control Centers
1012307 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: Stephen Ting-Yee Lee

Accurate Short-Term Load Forecasting for an ESKOM Major Distribution Region in South Africa: An Application of EPRI ANNSTLF
1012628 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

Short-Term Load Forecasting for the Belgium Market: An Application of ANNSTLF at the ELIA National Control Center
1012629 (Technical Report)
Program: Grid Operations and Planning
EPRI Project Manager: David Becker

Technology Innovation

Preliminary Analysis of the Role of Nuclear Power in Achieving a Sustainable Electric System
1011513 (Technical Report)
Program: Strategic Science and Technology
EPRI Project Manager: Layla Sandell

Real World Background Luminance for Objects Viewed by Night Drivers
1011961 (Technical Report)
Program: Strategic Science and Technology
EPRI Project Manager: Andra M. Rogers

Program on Technology Innovation: Opportunities for Advancing End-Use Energy Efficiency
1012003 (Technical Report)
Program: Strategic Science and Technology
EPRI Project Manager: Jeremy Bloom

EPRI Solutions

Assessing Power Quality Impacts and Solutions for the California Food Processing Industry
1009176 (Technical Report)
Project Manager: Dale Eldredge

EPRI Events

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

November

29
Advanced Technologies for Substation Design
Webcast
Contact: Luke Van der Zel, 704.717.6436

29
Substation Auxiliary Equipment Management
Webcast
Contact: Luke Van der Zel, 704.717.6436

29–30
BWRVIP Assessment Committee Meeting
Sarasota, FL
Contact: Ulla Gustafsson, 650.941.8552

29–30
BWRVIP Mitigation Committee Meeting
Sarasota, FL
Contact: Ulla Gustafsson, 650.941.8552

30
SF_6
Webcast
Contact: Luke Van der Zel, 704.717.6436

30–December 1
Life Cycle Management/Long-Term Planning Workshop
Charlotte, NC
Contact: Nicole Stokes, 704.547.6005

30–December 2
NDE Steering Committee Meeting
Charlotte, NC
Contact: Sue Glenn, 704.547.6078

December

1–2
BWRVIP Steam Dryer Information Meeting
Sarasota, FL
Contact: Ulla Gustafsson, 650.941.8552

1–2
BWRVIP Workshop on BWR Vessel and Internals Application
Sarasota, FL
Contact: Ulla Gustafsson, 650.941.8552

5–8
Combined Seventh Piping and Bolting and Fourth Phased Array Inspection Conference
Miami Beach, FL
Contact: Jill Lucas, 704.547.6074

6–8
Improve Overall Substation Maintenance Optimization
Charlotte, NC
Contact: Barry Ward, 650.855.2717

6–8
Nuclear Utility Procurement Training Course
Charlotte, NC
Contact: Elizabeth Marlowe, 704.547.6036

6–8
SGMP Technical Advisory Group
Location to be determined
Contact: Ulla Gustafsson, UllaG@ix.netcom.com

7–8
2005 Hydrogen Electric Economy Workshop and Hydrogen Utility Group Founders Meeting
White Plains, NY
Contact: Laurie Goldie, 650.855.2560

13–15
EPRI BRIG Meeting
Atlanta, GA
Contact: Brent Lancaster, 704.547.6017

14–15
EPRI Nanotechnology Workshop
Charlotte, NC
Contact: nanotech@eprisolutions.com

14–15
Power Delivery Asset Management Task Force Workshop
Palo Alto, CA
Contact: Order Management—EPRI, eprievents@epri.com

January

9–11
CHECWORKS User Group
Orlando, FL
Contact: Katy Ahrens, 415.455.9583

9–11
EPRI Pressure Relief Device Interest Group
Orlando, FL
Contact: Linda Parrish, 704.547.6061

11–13
CHECWORKS Introductory Training
Orlando, FL
Contact: Order Management—EPRI, eprievents@epri.com

16–17
International Conference on Grid Interaction With Steam-Turbine and Generator
Las Vegas, NV
Contact: Linda Parrish, 704.547.6061

16–18
EPRI Radiation Protection Conference/North American ISOE ALARA Symposium
Lake Buena Vista, FL
Contact: Linda Nelson, 518.374.8190

23–26
Nuclear Power Advisory Meetings
Myrtle Beach, SC
Contact: Melissa Wade, 704.547.6043

February

5–8
EPRI Lighting Research Office Sixth International Lighting Research Symposium
Lake Buena Vista, FL
Contact: Andra Rogers, 650.855.2101

7–9
MRUG 2006 Winter Meeting
Location to be determined
Contact: Brent Lancaster, 704.547.6017

9–10
Power Delivery and Markets Council Meeting
Coronado, CA
Contact: Suzette Yu, 650.855.2798

13–15
Service Water Engineer Testing Course
Charlotte, NC
Contact: Beth Brockman, 704.547.6036

15–17
Microbiologically Influenced Corrosion (MIC) Training Course
Charlotte, NC
Contact: Beth Brockman, 704.547.6036

20–22
General Coatings Training Course
Charlotte, NC
Contact: Beth Brockman, 704.547.6036

JOURNAL

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