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ELECTRIC POWER RESEARCH INSTITUTE

THE ELECTRIC CAR IN 2050

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The New Normal—Natural Gas and Coal Plants

Technology Meets Business Strategy

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Viewpoint—EPRI CEO Goes Time Traveling; You're Invited

As we head into 2016 and mark the 40th anniversary of *EPRI Journal*, I ask this question: If I could travel back 40 years to 1976, what would I tell the dedicated EPRI employees about today's electricity sector and today's research and development?

Here is a "top 10 list" of things I'd tell them (I invite you to read through the *Journal* to find the articles and interviews that touch on these areas):

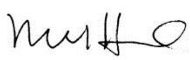
1. The power system is becoming more like the Internet, a vast communicating network of computers, sensors, processors, controllers, people, and machines that collectively produce and deliver power, and integrate diverse energy resources. "The Internet" would require a lot of explanation in 1976—and imagine how much time I could spend just on "digital."
2. I'd follow that by introducing cyber security and the imperative to make it effective for everything on the system, including nuclear plants, power delivery systems, and customers' homes, businesses, and factories.
3. I'd give them the good news that EPRI's research over 40 years contributed to effective controls to reduce emissions of nitrogen oxides and sulfur oxides. I'd follow that with the news of the global effort to reduce emissions of carbon dioxide. I'd use the opportunity to highlight technical challenges and the powerful analytical tools we are now using for both science and strategic planning.
4. To give my audience a slight break from future shock, I'd turn to electric vehicles. They'd be eager to learn about Volts, Leafs, and Teslas. But I'd use these also as a vehicle for describing distributed energy resources and The Integrated Grid. After putting them mentally behind the wheel of an electric car, I'd shift gears to load control and grid resilience. And what a great way to showcase the growing consensus that "the future is electric."
5. From EPRI's earliest years, we have focused on batteries and energy storage technologies, so I'd expect ready interest in these for my 1976 Time Travelogue. I'd spotlight lithium to show how different elements and materials can become essential and highly valued as the power system transforms.
6. From our beginning, EPRI researchers have worked to develop and advance wind, solar, hydropower, and other renewable energy sources. I would enjoy the opportunity to describe not only the scale of their deployment today, but also their diverse settings, applications, and configurations.
7. I would also emphasize that much in the far off future of 2016 is familiar. Many EPRI people in 1976 were working to ensure the safe, reliable operation of nuclear and fossil-fueled baseload plants. They would be pleased indeed to see our long-term contributions to extend the life of these plants, to improve virtually every major aspect of their performance, and to reduce their environmental impacts. They would take a keen interest in how the U.S. nuclear industry's mandate to store spent nuclear fuel now extends for decades, requiring important R&D from EPRI.
8. Following that I'd offer a back-to-the-future description of how the "mission profiles" of baseload plants are being changed to integrate effectively with more dynamic loads and contributions from wind and solar. The old-time "plant guys" would be fascinated to learn how we are helping plants ramp production up and down more rapidly, even though they were not built and engineered to do that.
9. Speaking of people, I'd take the opportunity to thank the more experienced career people in 1976 for their pioneering contributions to EPRI (founded just four years earlier), and then I'd focus on the early-career people in the room. I'd remind them that I traveled from the 21st century—their retirement years. I'd share today's imperative to gather their knowledge and accumulated wisdom, for use by thousands of people worldwide who (in 1976) aren't even born yet. I'd come back to the word "digital" to describe how we're working with members to record many kinds of expertise and knowledge, including crucial "hands-on" knowledge in the plants. I think some of the early-career "baby boomers"

of 1976 would like the idea that their images and words could be stored and called up for decades to come—on a computer that fits in their pocket.

10. And that brings me to the final point I'd share in 1976 with my future colleagues, collaborators, and mentors: the privilege of talking with them early in our long march of progress. I have always emphasized my personal appreciation of EPRI's history and the people who make it. They understand more fully than most how every "eureka" moment is built on years of patient and painstaking work.

I mentioned at the beginning that my thoughts were prompted by the 40th anniversary of *EPRI Journal*. We now provide an online archive of the magazine, and I encourage you to check it out. While we cannot travel back to 1976, *EPRI Journal* can now bring to the present the people and work of EPRI stretching back 40 years. That's time travel in the right direction: *Moving forward*.

Mike Howard



President and Chief Executive Officer, EPRI

Feature—The Electric Car in 2050

By Chris Warren

Is electric transportation a reality, or is it plugged into science fiction? Today a mere 300,000 of the 250 million automobiles on U.S. highways can be plugged into a charger and propelled by electricity. The internal combustion engine dominates.

But history reveals that a future dominated by electric vehicles is entirely possible. The marriage of transportation and electricity predates Henry Ford and the rise of gasoline-powered automobiles. As early as the 1890s, Indiana power generators helped streetcars replace the horse and buggy for local transportation, and within a few decades electric railways known as interurbans connected cities and towns in the Hoosier State. Public Service Indiana, the predecessor of Duke Energy Indiana, owes its beginning in part to the need to transport passengers to and from places such as New Albany, Kokomo, and Indianapolis.

The Electric Car in 2050

This *EPRI Journal* series examines the future of electric transportation and its potential impacts on emissions, the grid, business models, and driver experience.

"The original business model of some electric utilities in the United States was based on providing electricity to the electrified railroads that existed 100 years ago," said Mike Rowand, director of technology development at Duke Energy. Only later did their core business expand to delivering power to homes and businesses.

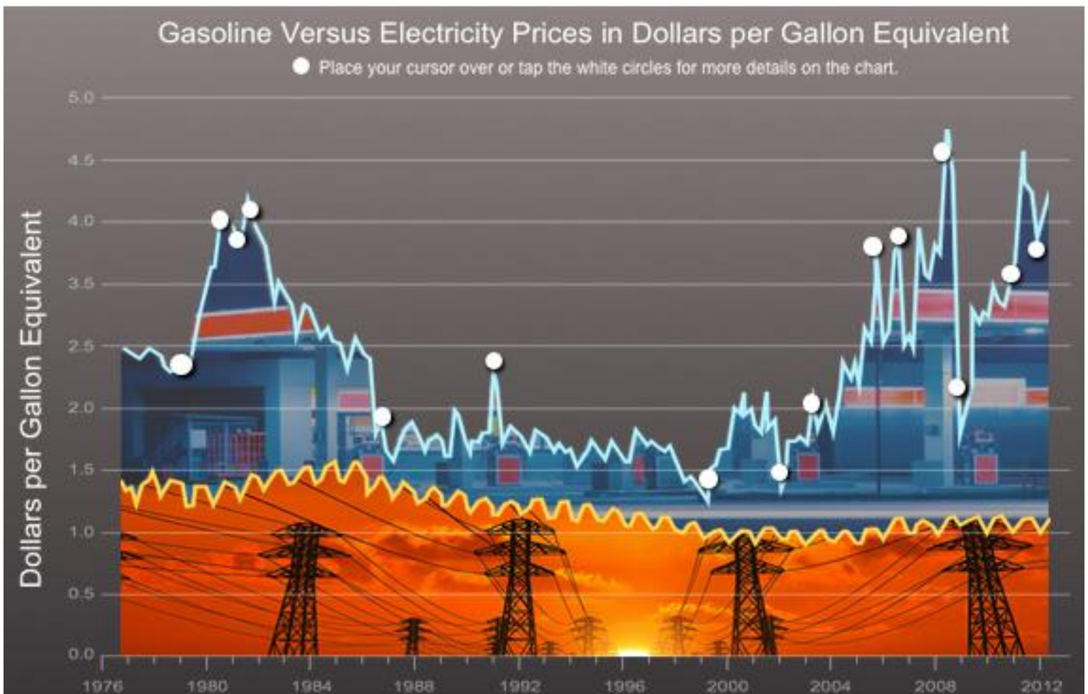
With that in mind, there's evidence today that transportation is moving back to an electrified future. Dan Bowermaster, EPRI's electric transportation program manager, points out that plug-in hybrid vehicles are selling at more than double the rate that non-plug-in hybrids did a decade ago.

Electric Renaissance on Wheels?

As electric transportation enters what appears to be a renaissance, *EPRI Journal* examines its prospects in 2050. Through more than a dozen interviews with utilities, automakers, and EPRI experts, we gathered insights on how electric vehicles could affect emissions, the grid, utility business models, the driver experience, and more. Two common themes emerged in these perspectives: Many electric vehicles are on their way, and thank goodness they are.

“I think there will be some huge changes in the transportation sector, all for the better,” said Bowermaster. For one, the prevalence of electric vehicles will drastically reduce or eliminate trips to gas stations. “For most drivers of the future, 70% to 90% of fueling will be done at home or work,” said Bowermaster.

Mid-century car owners will be able to drive inexpensively. Even though gasoline prices are currently low, few expect that to last for decades. Indeed, the economics of fueling electric vehicles have long been superior to gas fueling and likely will become more so. Michael Tinskey, global director of electrification and infrastructure at the Ford Motor Company, points out that the gallon-of-gasoline equivalent for electricity prices has been cheaper since the middle of the 20th century. “Where electricity used to be eight times more expensive than gas, now it’s one quarter the cost or less. We believe that trend will continue,” said Tinskey.



It may cost more today to purchase electric vehicles than their gasoline-powered counterparts, but history reveals that lifetime fuel costs for gasoline vehicles are significantly greater and more unpredictable. This chart from the Edison Electric Institute shows the historic average national monthly retail price for a gallon of gas compared to the equivalent price for electricity. **The blue line** shows how gas prices in dollars per gallon fluctuate with changing geopolitics, oil market dynamics, and natural disasters. **The yellow line** tracks the price of electricity in dollars per gallon equivalent—a measure that assumes a gas vehicle fuel economy of 30 miles per gallon and an electric vehicle efficiency of 3.4 miles per kilowatt-hour. Since 1976, these prices have consistently been in the $1-$1.50 range.

Among those interviewed, broad agreement emerged that electrification will be standard by mid-century. “I could see every vehicle having a battery that does some or all the work,” said Britta Gross, director of advanced vehicle commercialization policy at General Motors.

Though questions remain on what the future of electrified transportation will look like, we know this: It’s going to be an interesting ride.

Key EPRI Technical Experts

Dan Bowermaster

Feature—More Cars = Cleaner Air?

Study: Millions of EVs Charged by a Cleaner Grid Could Dramatically Reduce Greenhouse Gas Emissions

By Chris Warren

With global momentum building toward a lower carbon economy, the electric power sector is poised to play an important role. According to growing body of research by EPRI and others, decarbonizing electricity and then using electricity to enable greenhouse gas emissions reductions in other sectors is one of the most efficient pathways to a low-carbon economy.

What happens to greenhouse gas emissions if millions of electric vehicles take to the road, powered by a cleaner grid? EPRI and the Natural Resources Defense Council (NRDC) addressed this question in the study, *Environmental Assessment of a Full Electric Transportation Portfolio*. A follow-up to a *similar analysis in 2007*, the researchers used several models to project greenhouse gas emissions reductions by 2050 from widespread adoption of electric transportation.

The Electric Car in 2050

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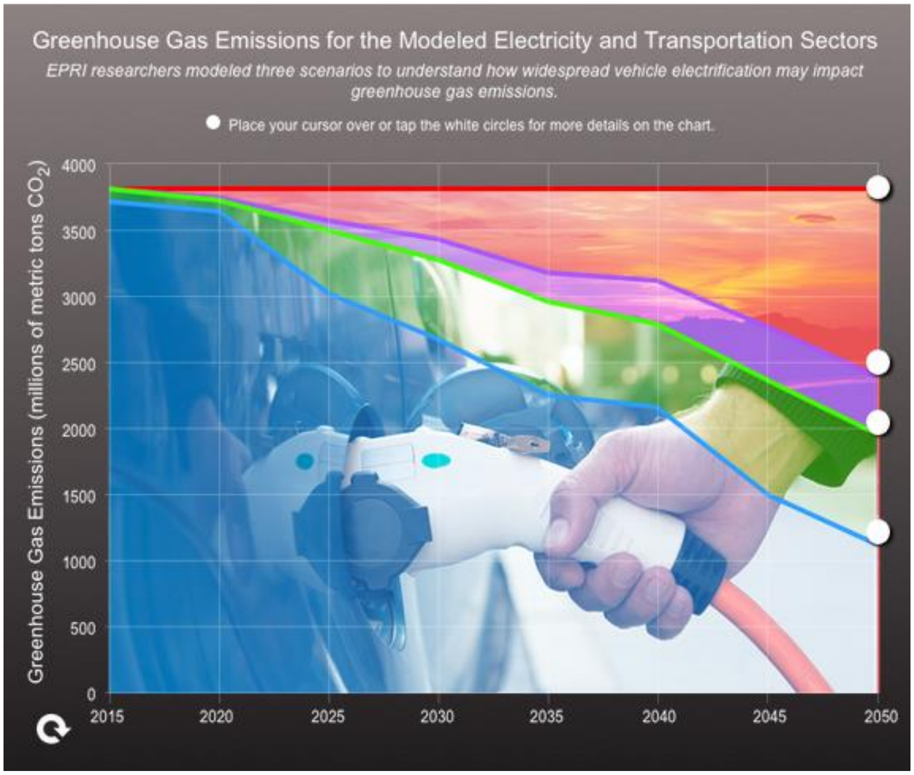
Researchers analyzed two power sector scenarios for 2050, both of which assumed that electric vehicles would account for 53% of all miles driven by cars and trucks—up from less than 1% today—and that carbon capture and storage would be available by 2025. In the conservative scenario, the combined emissions reduction in 2050 from electricity generation and transportation is about 48% relative to today's levels. In the more aggressive scenario, the reduction is about 70%. The main difference between the two scenarios is that the latter assumes that a carbon tax of $20 per ton of carbon dioxide emissions begins in 2025, then increases 5% each year.

"We consider these scenarios to be reasonably aggressive but achievable," said Marcus Alexander, a principal technical leader at EPRI, who worked on the report. "The main point is that increased electrification in transportation means substantial reductions in greenhouse gas emissions. Even with today's electricity generation mix, electrification reduces emissions because electric motors and batteries convert energy into motion more efficiently than internal combustion engines."



Four Steps, Four Models

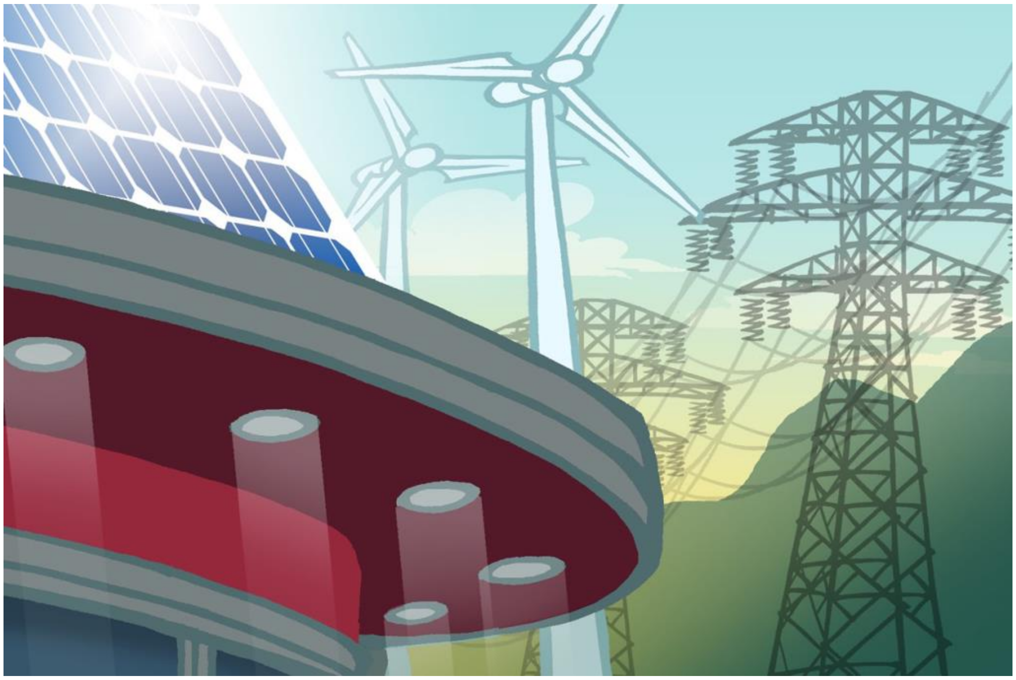
Because no single model can project emissions reductions from a large increase in electric vehicles, researchers based their analysis on four established models that enable projections of electric vehicle adoption rates, driving habits, changes in electricity generation, and more.

EPRI's Market Analysis Tool software charted electric vehicle market share over the next few decades, as well as electricity and fuel consumption in the transportation sector. EPRI analysis of national transportation statistics resulted in a set of *utility factors*—ratios of electric- to gasoline-powered mileage based on daily driving patterns and characteristics of plug-in hybrid electric vehicles. To determine total emissions, researchers built a model that used these ratios, along with per-mile emissions figures for gasoline- and electric-powered driving.

The Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model, or GREET, provided data on life cycle emissions from transportation fuels, and EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy model (US-REGEN) evaluated how energy policies and power sector and economic trends may impact the future generation mix.

The analysis involved four steps:

1. Model baseline emissions assuming no electrification.
2. Model an electrified transportation sector, quantifying the reduction of petroleum use and the increase of electricity consumption for vehicle charging.
3. Use US-REGEN to determine the generation mix charging all the new electric vehicles in the aggressive and conservative grid scenarios.
4. Based on the generation mix, calculate emissions from both grid scenarios, including emissions from battery production. These were compared to the baseline emissions projections.



Greater Reductions Possible

While the 70% reduction in greenhouse gas emissions projected by the EPRI-NRDC study is ambitious, steeper cuts are possible. The analysis did not include the Clean Power Plan, which could speed the transition to a cleaner generation portfolio. Researchers also assumed that two significant drivers of renewable energy development—the federal Investment Tax Credit for solar and the Production Tax Credit for wind—will not be renewed for an extended period. The solar tax credit was slated to fall from 30% to 10% in 2017, though it was recently extended to 2021. The wind Production Tax Credit has expired and received a series of short-term extensions in recent years. If these tax credits remain, grid electricity could be even cleaner.

Also, the analysis did not factor in possible breakthroughs in energy storage or an expansion of vehicles fueled by natural gas, hydrogen or biofuels, which could significantly reduce transportation sector emissions. Nor did it consider a more expansive definition of electrified transportation. "We looked at emissions reductions that are possible without significant changes across many transportation sectors," said Alexander. "For example, replacing long-distance trucking with electrified rail is an economically viable option by 2050, but because it would require large changes in multiple sectors, we decided not to include that."

The results indicate that electric vehicles can be a powerful tool to reduce greenhouse gas emissions. "The study shows that electricity is a low-emissions transportation fuel today and has the potential to be significantly lower-emitting in the future," said Alexander.

Key EPRI Technical Experts

Marcus Alexander, Eladio Knipping

Feature—For Electric Vehicles, Timing Is Everything

Off-Peak Charging Can Minimize Grid Impacts, Aid Grid Balancing

By Chris Warren

Jim Avery sounds Dickensian as he talks about the possible grid impact of charging tens of millions of new electric vehicles. "It could be the best thing to happen to the industry—or the worst," said Avery, who is San Diego Gas & Electric's (SDG&E) chief development officer.

Avery's tale of two grid futures is based on straightforward math. He explains that California's peak load of about 60,000 megawatts can be expected to grow dramatically by 2050, based on the projected population increase from 30 million to 50 million, coupled with the state's ambitious targets to reduce greenhouse gas.

Avery expects the targets to drive extensive electrification of the transportation system, including passenger cars, light and heavy trucks, and railroads. Consider passenger cars. Assuming today's ownership level of one car per Californian, there could be 50 million cars in 2050. "Let's further assume that three-fifths of these 50 million vehicles will require some level of charging," said Avery. "That's 30 million full electric or hybrid vehicles. If these 30 million vehicles consume 4 kilowatts during a typical charge and they all charge in the evening when demand is highest, that's a total of 120,000 megawatts—or twice the current peak load. That could strain a utility's ability to keep up with demand, but it also offers an exciting opportunity."

The Electric Car in 2050

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A Program to Encourage Off-Peak Charging

When charging electric vehicles, timing is everything. If 30 million drivers plug in during peak demand, utilities would need to make large investments in new generation and grid infrastructure. If those drivers charged during off-peak times, such investments may not be necessary.

With this in mind, SDG&E in 2014 proposed a pilot program to supply chargers to the public while influencing when people charge. In January, the California Public Utilities Commission approved SDG&E's Electric Vehicle-Grid Integration program, which will enable SDG&E to install 3,500 new chargers at businesses and multi-family residential complexes throughout its Southern California service territory. It would feature special rates to encourage charging during off-peak hours in the middle of the day, when renewable energy is plentiful. Customers could use a mobile phone app to schedule charging when the price is low.

"When planning for the future, it's critical for utilities to think about how to influence charging behavior," said Avery. "Our pilot could help meet the increased load demand from millions of new electric vehicles with relatively minimal impact on the grid."

Preparing for Droves of Electric Vehicles

SDG&E's program points to the conditions necessary for charging electric transportation on a large scale. One is a widespread network of public chargers. "Electric vehicles will flourish when there's enough public infrastructure so people can drive around and feel comfortable that they won't be stranded," said Mark Duvall, director of electric transportation at EPRI.

Equally important is timing of charging. "Today, each electric vehicle has a relatively high grid impact," said Duvall. "Many drivers are on a flat rate, and there are no incentives to charge at off-peak times. So they plug in when they arrive home at 5 or 6 in the evening during peak demand. That behavior is okay when there are few electric vehicles, but it's not sustainable when there are millions and millions of them."

A New Tool for Balancing the Grid

Off-peak charging can potentially help grid operators balance demand and generation. "What's in an electric vehicle?" said Tom Reddoch, who manages energy utilization research at EPRI. "A battery that can be used for electric storage to hold excess generation." Pumped storage hydroelectric facilities are commonly used to store excess electricity from baseload nuclear and fossil power plants. As more variable solar and wind power capacity is deployed, electric vehicles can provide a similar service, storing excess generation during the sunniest or windiest periods.

"With electric vehicles, utilities have another potential balancing agent, which could be valuable in a future with cleaner electricity," said Reddoch.

With respect to the grid's ability to charge millions of vehicles, Reddoch is an optimist. In part, this reflects efforts to optimize charging times for more efficient grid operations. But it also reflects the electric power industry's demonstrated ability to handle challenges of this scale and complexity. "In the past 25 years, the most significant electric load to hit the grid has been air conditioning and heat pumps, which consume more energy per unit than any electric vehicle," he said. "So what's the big fuss? As long as we account for the new load in our operations, it's not a big deal."

Key EPRI Technical Experts

Dan Bowermaster

Feature—The Dawn of Electric Transportation Utilities?

Millions of Electric Vehicles May Drive New Business Models

By Chris Warren

In a future with widespread electric transportation, there is at least one certainty: An enormous flow of electrons will be required to power millions of vehicles. What's uncertain is how the additional demand will affect utility operations. That depends in part on how and where that charging occurs.

In one scenario, utilities deliver energy to batteries in vehicles parked at residences and commercial and industrial centers. This is similar to electricity delivery today, so it wouldn't require a fundamental shift in utility business models.

Dan Bowermaster, program manager of EPRI's electric transportation initiative, points out that this scenario is a natural outgrowth of today's customer habits and infrastructure. "Most people charge at home or work because that is where their cars sit most of the day," he said. "Houses and businesses will have the wiring and charging stations needed for people to plug in their vehicles and replenish their batteries. They're safe, reliable, easy to use, and make sense to people."

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Michael Rowand, Duke Energy's director of technology development, says that another scenario is that vehicles could be charged when they're on the road. "In 2050, we could be looking at electrified roadways that are providing transportation energy as vehicles are moving and consuming electricity, rather than stationary charging."

Duke Energy, Toyota, Cisco, Clemson University, and the U.S. Department of Energy are testing wireless charging at the International Transportation Innovation Center in Greenville, South Carolina. In 2015, batteries in stationary Toyota vehicles with wireless transfer systems were successfully charged. The next step is to test in-motion wireless charging.

According to Rowand, if in-motion wireless charging technology becomes cost-effective, it could be installed along a handful of five-mile stretches of Interstate-85 in Duke Energy's North Carolina service territory. But Rowand adds that this is still an early-stage technology. "We have no installation plans," he said.

Widespread wireless charging would require new rate structures, new metering technology, and new infrastructure, such as coils under roads that transmit current to vehicles. Together, these could lead to new utility business models. "Because this charging is so different from stationary loads, one possibility is that electric transportation will become its own customer class, separate from industrial, commercial, and residential," said Rowand.

Bowermaster is skeptical about widespread electrified roadways because of the complexity of construction, operations, maintenance, and safety. That said, he sees the possibility of "en route" charging for commercial and industrial transit vehicles—which may require a new type of electric utility. "It could be some kind of utility partnership with state or local road agencies," he said.

Bowermaster expects that while the bulk of charging will take place at drivers' homes and workplaces, a network of stationary charging infrastructure will emerge at stores and other public sites to support local driving and long-distance trips. "What this means for utility business models is up in the air," he said. "It will probably be a mixture of some infrastructure owned by municipalities, some owned by utilities, and some owned privately."

Feature—From Souped-Up Wheels to Digital Dashboards

How Electric Vehicles May Inspire New Expressions of America's Car Culture

By Chris Warren

There's no need to time-travel into the future to have an extraordinary experience driving an electric vehicle (EV). When the Tesla Model S P85D scored 103 on *Consumer Reports*' 100-point scale, it prompted the magazine's editors to adjust the scale. "That this electric car accelerates from 0 to 60 mph in 3.5 seconds without an engine's roar makes it frighteningly eerie in its silent velocity," wrote the magazine's reviewer, Mark Rechtin, adding: "Its significance as a breakthrough model that is pushing the boundaries of both performance and fuel-efficiency is dramatic."

Joining Tesla in earning praise for the driving experience is General Motors' Chevy Volt, which earned the top spot in *Consumer Reports*' owner satisfaction ratings and was named a top-five consumer favorite by Edmunds.com, an online car resource. Britta Gross, GM's director of advanced vehicle commercialization policy, believes that the superior behind-the-wheel experience and economics of EVs will be common knowledge by 2050. "Once you experience the quiet smoothness, elegance, and spaceship-like driving of an electric vehicle, how in the world would you go back to a gas vehicle?" said Gross. "The low cost of driving on electricity reinforces that positive experience."

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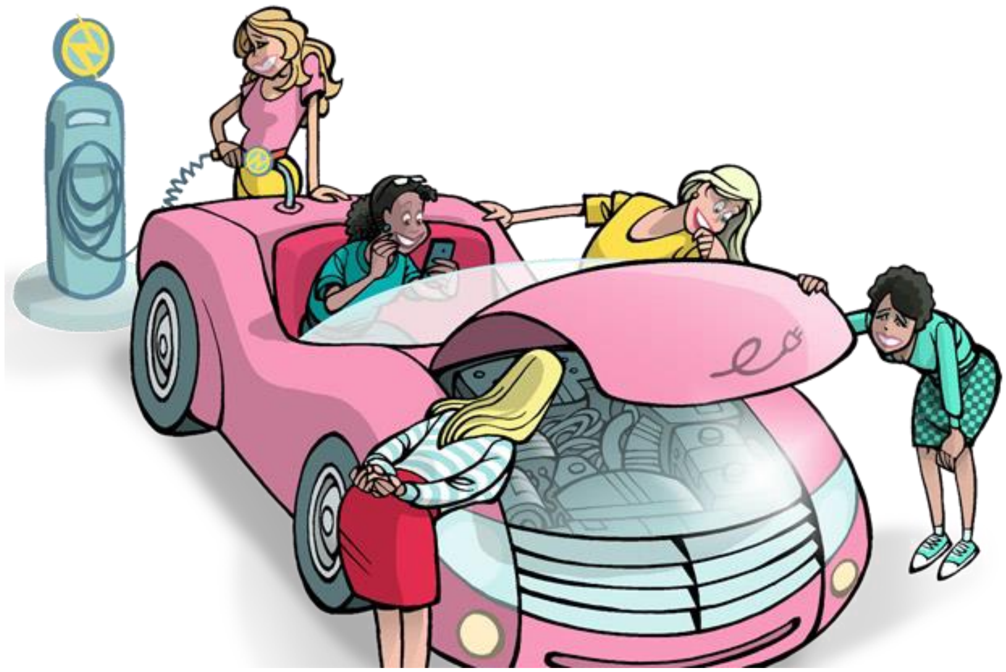


Car Culture Goes Electric

The personal experience of a car extends well beyond acceleration and cornering. The United States' distinct car culture is anchored in drivers' emotional attachment to their vehicles. Cars transcend transportation. They can symbolize freedom or embody the owner's personality. "I grew up in the 1970s, when guys would jack up their cars and buy special chrome Cragar wheels, or they'd buy vintage cars and customize them," said Watson Collins, manager of research and business development at the utility Eversource Energy.

Can EVs find true love in such a culture? It's unlikely that a culture of car clubs, car shows, television programs, and magazines will be able to ignore EVs, and it's equally unlikely that automobile designers and manufacturers will pass up the chance to spark automotive infatuation. So how will individuality and affection be manifested? Collins offers some predictions. When large numbers of used EVs are available, Collins expects that car lovers will customize them to suit their personalities. "Instead of installing Cragars, people are going to figure out ways to soup-up their electric motors and put bigger batteries in their used cars," he said.

Look for drivers to personalize new EVs as well, perhaps starting with the digital dashboard. "Like all things digital, dashboard customization might soon be possible through extra features offered by automakers or installation of third-party apps," said Collins. "It wouldn't be surprising to see options to have your dashboard look like your favorite NASCAR driver's display, to limit when or how far a teen can drive a car, or to enable autonomous driving functions. Who would have thought 20 years ago that app stores would emerge for our cell phones? An app store for cars could be next."

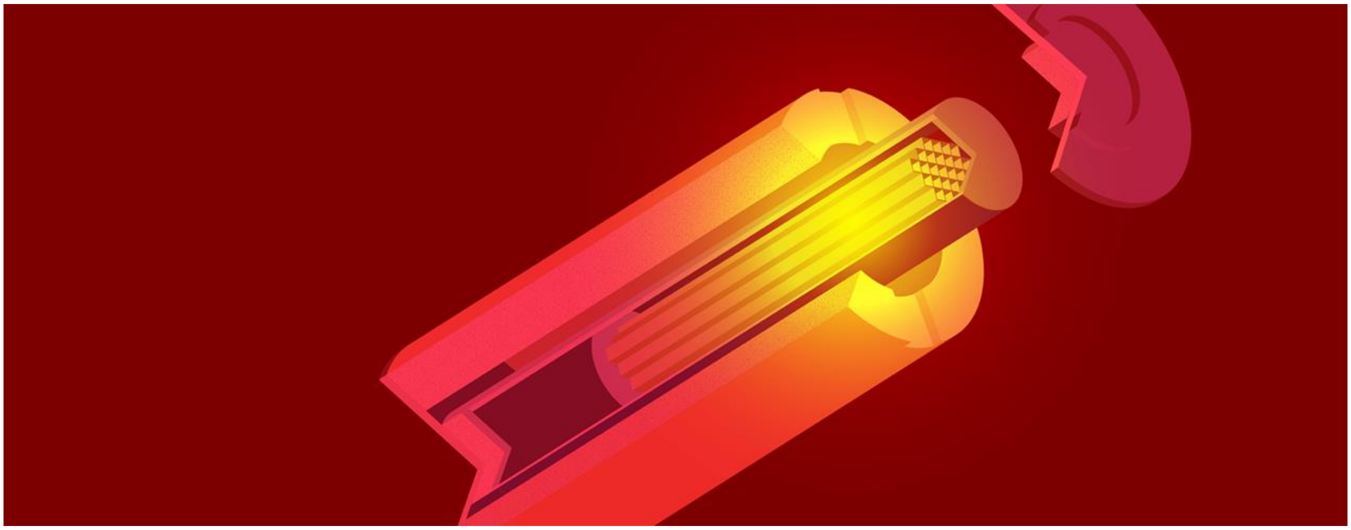
A New Kind of Car Club?

For serious electromechanics, there's the opportunity to do what Andrew Kasznay did. Ten years ago, Kasznay—formerly a manager of assets and strategy at Eversource Energy—converted his 1980 Ford Pinto into an EV. "It took about six months and $7,000," said Kasznay. "I installed 12 lead-acid batteries and a motor built by Advanced DC. This was well before electric vehicles were widely commercially available."

While the Pinto may not be an obvious choice for such a conversion, there are growing numbers of individuals and clubs devoted to replacing pistons, cylinders, and camshafts with something smoother. Entrepreneurs can readily be found online, selling complete kits or individual components such as battery packs, chargers, controllers, and braking kits. Interested buyers can find everything from converted Porsches to pickup trucks. (One advertised truck addressed range anxiety by including a free tow bar.) Conversion how-to videos can be found on YouTube in the great variety typical of that channel.

Beyond car aficionados, EPRI Electric Transportation Program Manager Dan Bowermaster expects more everyday drivers to consider making the switch as the EV market scales up. “If your gas engine or transmission from a 1990s or 2000s car needs to be rebuilt, more people will convert to an electric car as prices decrease,” he said.

Feature—Keeping Spent Nuclear Fuel Safe



EPRI Research Supports Longer Service Lives for Spent Fuel Dry Casks

By Margaret L. Ryan

In Albert Machiels' 33-year career at EPRI, the U.S. nuclear industry's mandate to store spent nuclear fuel safely has extended from a task measured in years to one that will stretch for decades or more.

"In the 1970s, utilities thought they would be responsible for spent fuel for a brief time—until it was cold enough to ship somewhere else," said Machiels, an EPRI senior technical executive who has worked on an array of research supporting safe spent fuel storage.

After four decades of shifting government mandates, utilities today face indefinite spent fuel storage at reactor sites. But nuclear plant spent fuel pools were not sized to store decades' worth of fuel. Since the mid-1980s, operators have been moving older spent fuel from pools into dry casks, in which fuel is typically sealed inside steel canisters surrounded by concrete shielding. EPRI is leading research on managing the aging of casks, so they can continue to be licensed and used for decades, perhaps centuries.

"The good news is that industrial experience with materials used in the storage casks indicates that casks can be used for very long times," said Machiels. "The caveat is that research has to be done to show that aging management programs will support long-term, safe storage."

From Reprocessing to Casks: A Brief History of Spent Fuel Storage

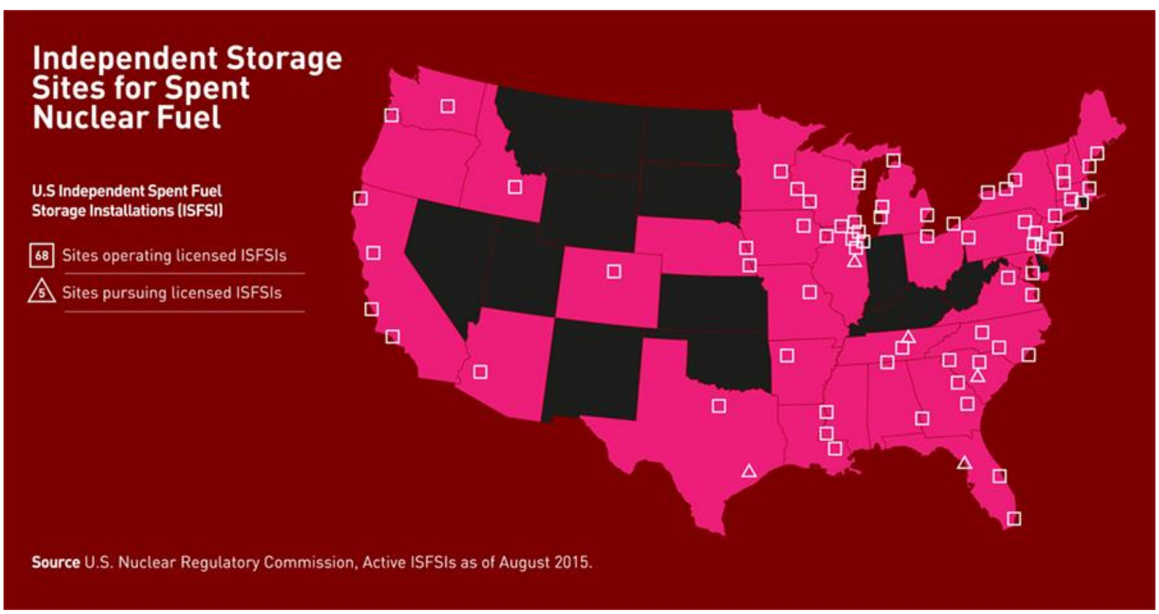
Until the mid-1970s, spent fuel pools in nuclear plants were designed to hold fuel from one to two decades of normal operation. The U.S. government originally planned to take spent fuel and reprocess it, extracting uranium and plutonium for recycling into new fuel and disposing of wastes in underground repositories. But reprocessing was controversial because some reprocessed material can also be used in warheads. In 1977, President Jimmy Carter banned it. President Ronald Reagan rescinded the ban in 1981, but by then the civilian reprocessing program was deemed too costly.

In 1982, Congress endorsed the construction of geologic repositories for underground disposal of high-level radioactive waste, including spent fuel from nuclear power plants and military wastes. In 1987, Congress designated a repository site at Yucca Mountain, Nevada, and the U.S. Department of Energy (DOE) signed contracts with utilities to take spent fuel beginning in 1998.

Meanwhile, “operators were running out of room in their spent fuel pools,” said Machiels. They began retrofitting pools with storage racks with neutron absorbers, so more fuel assemblies could be packed into the pools without going critical. “But that still had its limits,” he said. “So in the early 1980s, EPRI research explored alternatives including moving fuel assemblies into dry cask storage systems, a technology initially developed in Germany. That technology prevailed following a highly successful joint demonstration project conducted by EPRI, DOE, and Virginia Electric Power Company.”

Supported in part by EPRI research, the U.S. Nuclear Regulatory Commission (NRC) set safety standards for licensing casks and the outdoor concrete pads where they are stored (known as independent spent fuel storage installations). By 1986, the industry began moving the oldest fuel out of pools and into dry casks. Licenses were valid for 20 years, reflecting expectations that Yucca Mountain would soon begin operations. By the late 1990s, it was clear that those licenses would have to be extended. A joint EPRI-DOE-NRC project examined fuel that had been in dry cask storage for 15 years. No evidence of degradation was found, and NRC began approving 40-year license extensions.

In 2009, the Obama administration canceled the unfinished Yucca Mountain project, and no alternative repository site has been identified. Reactor operating licenses all include a provision that radioactive wastes will be stored safely and that a repository will be available eventually. In 2012, a federal court ruled that, with the apparent demise of Yucca Mountain, NRC had to consider whether storage casks were safe for decades—well beyond 20 years, and possibly permanently. If NRC couldn’t make that finding, all reactor operating licenses were at risk. NRC studied the issue and in 2014 concluded that spent fuel could be stored safely up to 60 years in spent fuel pools, and indefinitely in dry casks, assuming that the casks were replaced once a century. NRC premised its conclusion on utilities’ implementing aging management programs to maintain cask safety.



Research to Look Deeply at Aging, Including the 'How' and 'Where'

For decades, EPRI has conducted research in aging management for multiple aspects of plant operations. "EPRI research has helped form the technical basis for aging management of significant reactor internal components," said Randy Stark, EPRI's director of Fuels, High-Level Waste, and Chemistry.

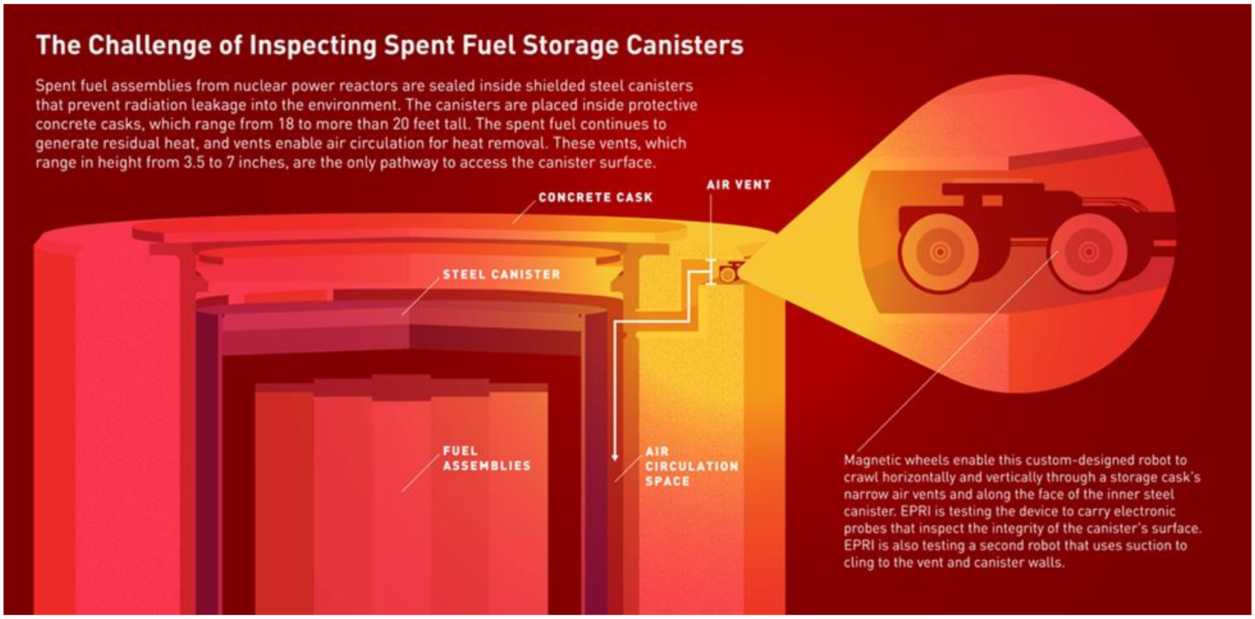
In April 2015, NRC asked the American Society of Mechanical Engineers (ASME) to develop a consensus guideline for spent fuel storage cask inspections, and EPRI agreed to support the ASME efforts. "Our charter is to identify whether degradation mechanisms exist in the stainless steel canisters, and which locations are most susceptible to these potential mechanisms," Stark said. "Once this is understood, aging management programs for these canisters can be better developed."

EPRI had already started examining longer-term storage safety in 2009 when it established the Extended Storage Collaboration Program with industry and government experts. "The program has grown to more than 400 members from 16 countries, all seeking to answer the same question: What needs to be done to ensure the safe, extended storage of spent fuel?" said EPRI Senior Technical Leader Keith Waldrop.

Aging management for storage casks should be far simpler than for reactors, Machiels said, because casks have no moving parts. A typical cask consists of a basket of fuel assemblies, sealed with a chemically inert gas inside a shielded stainless steel canister, which in turn is placed in a concrete overpack. Small air vents in the overpack carry off residual heat from the fuel. Casks range from about 18 feet to more than 20 feet high, have diameters of 7 to 12 feet, and can weigh more than 150 tons with fuel inside. Canisters are stored vertically or horizontally (see graphic below).

But cask inspection is not a simple matter. Casks were not designed to be inspected; at the time, operators expected a repository to open in a couple of decades, according to EPRI Program Manager Richard Reid. "They were designed to be sealed and transferred to DOE," he said. "Getting inspection equipment inside the overpack to the canister surface is a serious technical challenge." Heat vents can be used for access, but they measure just a few inches across. The space between the canister and the overpack is at most a few inches wide, and some designs have vertical fins that restrict movement in that space. "There is a need for not only small probes to examine the canister surface, but also small robotic devices to carry them there," said Reid. EPRI showed progress on this front in a recent demonstration (see box at end of article).

In 2014, researchers made their first on-site inspections—including visual scans, temperature measurements, and surface samples—of two casks that had been in service more than 15 years at Exelon's Calvert Cliffs Nuclear Power Plant, on the shore of the Chesapeake Bay. The two canisters exhibited no degradation of concern. Reid said that all EPRI research so far—at Calvert Cliffs and other field sites and from lab tests—indicates that canisters are "robust." But he added, "There is recognition that the same materials in other nuclear plant systems are prone to degradation, and these casks will be in service a long time. We have to make sure they are well managed." Researchers will use data now being gathered from other casks to strengthen EPRI's cask aging models.



A Related Issue: Evaluating High-Burnup Fuel Storage

Over time, the nuclear industry has increased its fuel burnup to improve reactor economics. According to the NRC, the average fuel discharged from reactors today has reached the high-burnup threshold, and more of this fuel is being stored in casks. Based on laboratory research, NRC is concerned that high-burnup fuel in dry storage may have a greater potential for cracking in the zirconium alloy rod that contains the uranium fuel.

EPRI has been investigating how to store high-burnup fuel safely since the 1990s. In 2002, NRC accepted EPRI-developed technical criteria to license cask storage of high-burnup fuel for 20 years. “Many casks with high-burnup fuel are approaching 20 years now,” Machiels said. “Researchers have to confirm that the existing criteria will ensure safe storage over extended periods.”

EPRI and DOE have launched a demonstration project to confirm the behavior of high-burnup fuel during extended storage. EPRI researchers are modifying a commercial storage cask with monitoring equipment, which Waldrop called the project’s “biggest challenge.” By 2017, the cask will be loaded with several types of high-burnup fuel at Dominion’s North Anna Power Station, and key parameters including temperature will be monitored for 10 years at the plant’s cask storage facility. Rods from the cask will be tested and the results compared to those from tests prior to storage to identify any changes. “The results will enhance the technical basis for longer-term storage of high-burnup fuel,” said Waldrop.

“We know that as spent fuel cools, temperature and radiation decrease; therefore, the potential for fuel degradation is reduced as well,” said Machiels. “There will be a time when conditions are mild enough that any degradation is unlikely. We are focused on aging management to make sure that the systems protecting the spent fuel will perform properly over all the time they’re needed.”

A Little Robotic Car with a Big Mission

It resembles a toy car with outsize metal wheels. It measures 6 inches by 6 inches by 2 inches. Its headlights blink on and, with a little whizzing noise, it moves forward to the edge of a metal ledge. Then it slowly drives over the edge and straight down the wall, its magnetic wheels never losing their grip.

EPRI is testing the ability of this robotic car to wriggle its way through the narrow spaces between spent nuclear fuel storage canisters and their concrete overpacks, carrying nondestructive evaluation probes into places no human can reach. EPRI is also testing a robot that uses suction to stick to surfaces. EPRI is working with vendors to design and build both the robots and the tiny cameras and inspection probes they will transport.

In September 2015 at the Palo Verde Nuclear Generating Station in Arizona, EPRI tested the robots with an eddy current array probe and an electromagnetic-acoustic transducer probe that generated guided waves. The eddy current array probe provides more detail of the metal surface, while the guided wave probe can "see" farther and detect indications of degradation in crevices and other inaccessible areas that the probe can't contact directly. According to EPRI Senior Technical Leader Jeremy Renshaw, EPRI research on canister and fuel aging will help determine where each probe could be most useful in detecting any degradation indications for future canister inspections.

Using full-scale mockups of two cask designs, the EPRI team demonstrated that either robot could navigate entry into the casks through available vents and maneuver in the constricted spaces inside. Both probes maintained contact with metal surfaces and recorded good data on the mockups' surface conditions.

"We were told that this couldn't be done, that it was impossible and we shouldn't even try," said Renshaw. "But both designs worked."

Although the demonstration went well, the EPRI team identified some areas for improvement. For instance, the electromagnetic-acoustic transducer probe encountered challenges entering and exiting the cask outlet vent. "This is a minor issue that we need to address," said Renshaw. "It illustrates how on-site demonstrations are valuable in working out the kinks in prototypes to prepare for actual field inspections."

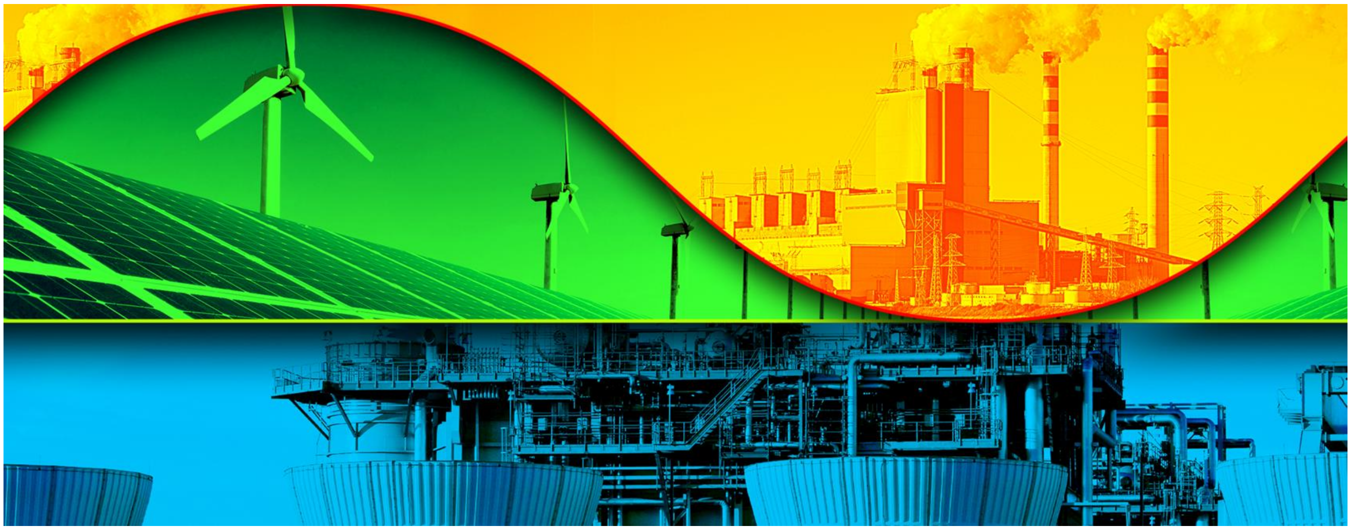
The storage casks now in use were designed by multiple vendors and vary somewhat in the pathways available for probe access. The EPRI team's goal is to develop generic robots that will work with most casks and can carry various inspection tools for emerging cask inspection standards. Plans include more tests on cask mockups and, by 2018, the first-ever inspection of a canister loaded with spent fuel using probes able to detect early signs of metal degradation.

Watch a video showing the demonstration of the magnetic-wheel robot in a cask mock-up at Palo Verde Nuclear Generating Station.

Key EPRI Technical Experts

Randy Stark, Richard Reid, Keith Waldrop, Albert Machiels, Jeremy Renshaw, Shannon Chu

Feature—The New Normal



EPRI Helps Old Plants Take on New Missions

By Chris Warren

When the 1,880-megawatt Monticello Power Plant in eastern Texas started operating in 1974, it had a straightforward mission: burn lignite to generate baseload power. For decades, Monticello's three units have consistently met this mission, supplying electricity for nearly one million Texas residences during off-peak demand.

However, persistently low wholesale power prices resulting from inexpensive natural gas and the emergence of renewable energy dramatically changed the Texas electricity market, and along with it Monticello's traditional baseload mission. "We have the most wind generation of any state by a long margin, more is coming, and we're adding other renewables such as solar," said Dale Higginbotham, vice president, fossil engineering and support at Luminant, which owns Monticello.

These factors, along with higher fuel costs, increased regulatory burdens, and Monticello's operating costs, prompted Luminant to reexamine how the plant can best compete in the ERCOT competitive market. "We brought together our operations and dispatch people to look at ways to become more dispatchable and flexible, and we discovered that it's not easy to develop solutions," said Higginbotham.

In 2012, Luminant shifted two Monticello units to seasonal operations—available for summer dispatch, when power demand is higher and generation makes economic sense. In January 2014, Luminant brought the units out of seasonal operation as a result of cold weather and higher power demand. Another shift to seasonal operations followed later that year, and the units returned to year-round availability in October 2015.

"We will need to stay nimble," Higginbotham said. "Shifting market prices, power demand, and plant operating costs will determine when Monticello runs."

Role Reversal

Luminant is not alone in facing the pressure to alter operations at fossil generation facilities. "The industry is undergoing dramatic change," said EPRI Senior Technical Executive Norris Hirota. "More and more plants are being operated in a manner that is inconsistent with their original design."

The traditional missions of natural gas and coal plants have flipped. “Coal assets, designed for baseload operation, are increasingly being operated at low loads, in load-following mode, or are shut down because demand is not there,” said Hirota. “On the flip side, you have gas plants that were designed as peaker plants now providing baseload power.”

A confluence of factors has led to this reversal. With low natural gas prices, power companies increasingly rely on gas plants to meet baseload demand, resulting in extended layups for many coal plants. Increasing intermittent renewable generation is a principal driver of flexible coal plant operations, which include load-following mode, frequent ramping up and down, and minimum-load mode to help balance electricity supply and demand. Another driver is more demand management, which leads to fluctuating customer loads. Some units operate only a few months or weeks in a year.

This fundamental shift raises many questions: When a coal plant ramps up and down to meet changing demand, what is the impact on equipment originally designed to run continuously? How does this affect maintenance? What training is needed as decades-old job descriptions become obsolete? It is critical to find answers backed by solid research.

“Take a coal plant that may now be called upon for three weeks in the dead of summer and two weeks in the dead of winter,” said Tom Alley, EPRI’s vice president of Generation. “Its viability to remain in the generation mix might depend on having a high degree of availability during that time. Maintenance and staffing are critical for managing costs and supporting reliability.”

Plant Site Visits and Working Group

In 2014, EPRI launched its Changing Mission Profile initiative to provide wide-ranging expertise to plant operators and identify research needs. “We’re evaluating changing missions from a whole-plant perspective,” said Hirota. “It can’t just be the boiler or turbine program that does this.”

Central to this work is a pilot project consisting of seven visits to EPRI members’ plants to improve the common understanding of technical and organizational issues related to changing plant missions. In 2015 and early 2016, visits to Luminant, Salt River Project, FirstEnergy, Entergy, Duke Energy, and Ontario Power Generation (OPG) provided on-the-ground views of plant and personnel impacts at coal, hydropower, gas boiler, and combined-cycle units. “There’s no better way to understand the impacts of a changed mission than with a deep dive at the unit level,” said Revis James, a senior technical executive in EPRI’s Generation sector.

Each site visit included a workshop with EPRI technical staff and utility subject matter experts, examining topics such as materials, process chemistry, operations, and maintenance. Based on each unit’s design and its changed mission, the team reviewed, prioritized, and discussed the most important technical challenges along with solutions offering the most potential impact.

While the site visits highlighted a range of technical issues to guide future EPRI research and development, the focus on changing missions is not new. According to Hirota, as a result of feedback from member utilities over time, about 80% of the EPRI Generation sector’s current research portfolio addresses to some degree the needed improvements associated with flexible operations of fossil plants.

EPRI has launched its Mission Profiles Working Group to convene utility subject matter experts to identify key issues and share information. By 2017, EPRI will provide results from this effort, including an online database outlining technical challenges and possible solutions, applicable to various plant designs and missions. Hirota says that the database will be updated continually to reflect EPRI research findings and utility experiences and lessons.

“We are applying an approach from our colleagues in the nuclear industry,” said Hirota. “They have done a great job of sharing information about best practices, challenges, and experiences. If there is an event at one nuclear plant that’s relevant to other plants, they collect that information and share it so everyone benefits.”

Impacts on Maintenance, Environmental Controls, and Asset Management

Operating a power plant used to be straightforward and consistent. “Plant workers knew it was a good day if the plant was running and a bad day if it wasn’t,” said Alley. “That was the old story. The new story is that it might actually be bad if you’re running, because it may mean that another asset in your generation mix isn’t meeting its mission properly and your plant has to operate when it’s not scheduled to.”

A priority identified through the site visits and working group meetings is to increase the flexibility of plants that were not designed to respond to rising and falling demand. “We’ve talked with a lot of members who are interested in faster ramp rates,” said Alley. “They need to be able to bring these units up and down more quickly to respond to load changes.”

An important consideration for coal plants running at different loads is the impact on equipment. “When you shut down and start up a plant more frequently or increase and decrease the plant’s load, metal temperatures fluctuate. This can cause increased internal stresses and fatigue, which may lead to cracking and degradation,” said Hirota. “The maintenance staff needs to pay special attention to equipment undergoing thermal stresses beyond their original design. This may require changes to maintenance programs.”

Operating coal plants at lower loads and temperatures may reduce the performance of emissions control equipment needed for regulatory compliance. “This equipment is designed for full load,” said Hirota. “If you are running at lower loads, you might not be removing NOx or other pollutants as effectively, which may compromise your ability to comply.”

EPRI is investigating how to help enable a plant’s environmental controls to work effectively and in a sustained manner at low loads. “Given the staffing constraints that plants have, they can’t hire more people to monitor this,” said Hirota. “We are looking at better online monitoring of this equipment so that you might consider fewer, more centralized resources at a central location monitoring the entire fleet and better process controls to minimize the burden on plant operators.”

When a natural gas plant shifts from peaker to baseload operations, there typically are longer intervals between outages when equipment checks and maintenance can be done, forcing operators to make tradeoffs. “The strategy may become, ‘What maintenance can be put off while still maintaining the plant’s reliability?'” said James.

Changing plant missions may lead to the need for larger-than-expected investment in new equipment and maintenance, particularly in older plants. “We need to figure out how to build these long-term asset expenses into a utility’s planning process,” said James. “They will impact fleet management decisions and increase the complexity of long-term planning. Utilities will need to know the cost of flexible operations, when to make investments in maintenance, and when it’s best to retire a plant.”

Investigating Solutions

Luminant’s Higginbotham wasn’t expecting easy fixes when EPRI and FirstEnergy experts visited Monticello Power Plant last year. Instead, the purpose was to collect new perspectives and insights on how Monticello can effectively meet its new mission. For example, Monticello’s operators had been weighing whether to make certain equipment modifications to enable lower-load operations. “They weren’t comfortable moving forward until they got enough engineers together in a room saying, ‘We don’t see a problem making those changes,'” said Higginbotham. “This meeting of the minds helped us to determine which issues were critical and which ones weren’t big enough to worry about.”

Sharing knowledge and exploring solutions will accelerate with the launch of research projects sparked by site visits and working group meetings. In 2016, EPRI will release a report based on the pilot project site visits. “The industry has embraced the working group,” said Hirota. “They’ve offered both funding and their most experienced subject matter experts for two years to help resolve priority issues.”

Key EPRI Technical Experts

Norris Hirota, Revis James

Perspectives—Technology R&D: At the Heart of 21st Century Business Strategy

Significant changes are redefining the role of technology in electric power companies. To name just a few: Smart meters are providing more data that can enhance operations and reduce outage times. Distributed energy resources, batteries, and electric vehicles are reshaping the grid. Technology is revolutionizing basic functions such as dispatching, maintenance, and asset management. Improvements in voltage regulation are increasing grid efficiency. These and other changes span the full range of grid-related technologies. To play a critical role in any company's success, its technology strategies must align closely with business needs. Robust technology programs must be actively managed and agile if they are to deliver results in response to emerging needs.

Jim Crane, Director of Equipment Standards and Technology, Exelon Utilities

How can this be achieved? In a 2002 study, EPRI and several member utilities, including Exelon, identified the most successful technology management practices of 11 leading non-utility companies, such as Norfolk Southern, BP Chemicals, UPS, General Electric, and Williams Energy. These practices included:

- Technology integral to business strategy
- A supportive corporate culture and senior management
- Teamwork between central and business-unit organizations
- Clear accountabilities and results focus
- Strategic collaboration with external partners
- Projects that focus on customer and market needs

At Exelon Utilities, these findings are particularly relevant today, and we have integrated them into daily business operations. Our three utilities—Baltimore Gas & Electric, ComEd, and PECO—cooperated to establish common technology R&D policies and frameworks. These assign accountabilities and define how R&D activities are identified, reviewed, and executed. We have also established R&D groups at the corporate level and in each of the three utilities. These groups manage R&D on a broad range of technologies spanning all utility functions. We track the utilities' R&D performance with clearly defined metrics related to technology gaps, investment management, advisor engagement, and technology transfer.

To ensure that we align our technology pursuits and business needs, we assembled key managers to assess technology gaps across 18 core functions, such as customer solutions, billing and payment processing, corrective and preventive maintenance, safety, human performance, and electric operations. They identified 118 technology gaps.

EPRI staff reviewed these gaps and identified EPRI R&D programs to address them. This helped us determine which programs to fund in 2016, including two areas not previously part of our R&D portfolio.

Through this rigorous approach, Exelon Utilities has significantly improved its R&D engagement, its alignment with business strategy, and the delivery of meaningful, timely results. In 2015, for example, we worked with EPRI and its Energy Storage Valuation Tool to determine the value and financial benefits of energy storage for seven applications. The analysis factors in the possibility that regulated utilities may not be able to sell energy from batteries into unregulated energy markets—a scenario that could limit battery storage application unless new legislative or regulatory models are adopted.

Another example: Some electrical equipment that was manufactured before the U.S. Environmental Protection Agency banned polychlorinated biphenyls (PCB) in 1978 may contain low levels of PCBs. When ComEd and PECO wanted to evaluate potential PCB contamination in about 650 distribution transformers, our utility R&D oversight group reached out to EPRI to develop a suitable project. The ComEd and PECO analyses relied on EPRI's nationwide U.S. database encompassing more than 345,000 data points, including manufacturer, size, date of manufacture, type of transformer, and transformer oil PCB content. The evaluation helped ComEd and PECO better manage PCB-related risks by removing from service transformers with greater contamination potential.

Our utility R&D oversight group helps the utility operating companies identify the best strategy for each R&D need. This requires a deep understanding of the capabilities of many public, private, and collaborative R&D organizations. Indeed, Exelon's technology gap analysis has led to work with other research organizations besides EPRI, such as the National Electric Energy Testing Research and Applications Center (NEETRAC), Power Systems Engineering Research Center (PSERC), and the Centre for Energy Advancement through Technological Innovation (CEATI), as well as directly with manufacturers. Aligning with these and other strategic technology partners is important in helping us shape and adapt to the future business environment.

First Person—"Super System" to Coordinate Electricity, Gas, Other Utilities

The Story in Brief

Amy Ericson's executive perspective on the electricity sector is grounded in technological development, the emergence of big data, and the opportunities it presents. She also points to the need for effective collaboration, demonstration programs, and coordination with utilities providing diverse services and products, including water and natural gas.

Editor's Note: When this interview was conducted in 2015, Amy Ericson was U.S. country president of Alstom, a grid/power technology provider and rail transit infrastructure company. After GE acquired Alstom's grid/power business in November 2015, Ericson joined GE's Water & Process Technologies team.

EJ: New technologies are transforming the grid, and no one at this point can project exactly what it will look like in the future. How do you guide and plan your business during such a transformation?

Amy Ericson

Ericson: If you look at the grid now, advances in IT and telecommunications have enabled not only two-way energy flow and more engaged consumers, but also a lot more speed. A lot more data is coming in, and quicker. When we put today's grid in the framework of affordability, sustainability, and reliability, it has put our focus on integrating distributed resources and renewables and hardening the grid.

Demonstration projects are essential. We recently completed a five-year smart grid demonstration project in the Pacific Northwest with the U.S. Department of Energy, Battelle, and several other technology companies, including IBM. It involved 11 utilities and 60,000 metered customers. A main focus was transactive control. In the final report, there were a list of things that were considered successful, and a list of things that were identified as 'we need to do better'. That naturally points to what they need to work on next. I see a need for more of these demonstrations.

EJ: What role can collaborative R&D play in doing more demonstration projects?

Ericson: There's something very special about the industry we're in. We provide electricity. It's a uniquely public endeavor. That makes collaborative research and public-private partnerships critical. You can say, 'I developed a new toothpaste. Let's try it out on the market.' But you can't do that in the power industry. It's got to be game-ready by the time it's deployed widely. We can't take chances.

It's to our nation's benefit if we begin coordinating across sectors, with the common core being electricity. This is something I would like to see EPRI tackle.

EJ: What types of demonstrations do we need?

Ericson: One is applying advanced IT and software technologies from the transmission to the distribution level. For example, synchrophasors in the transmission system transmit data 100 times faster than they did 10–15 years ago. The associated data analytics provide visibility into the status of the system. With all the demands now being placed on the distribution network, it could benefit immensely from this ability to collect data faster and to have that real-time situational awareness. That's going to require basic research and demonstration.

Energy storage is also important. A lot is happening with batteries, but they're still far from utility-scale, and we don't know the capacity limits for the different types of batteries. There are other, larger utility-scale types of storage—pumped hydro storage and compressed air. I'd like to see EPRI help us answer the basic question: How much energy storage are we going to need to optimize our electric system? It's a great modeling question that EPRI could handle well [*see box at end of article*]. This could help us figure out whether we can optimize the system with batteries, or whether we need the larger utility-scale options.

If the electric industry is able to achieve better situational awareness—knowing what's wrong instantaneously—with faster data and data analytics, wouldn't the other utilities benefit from them, too?

EJ: What other critical R&D needs do you see?

Ericson: Electricity is the cornerstone for a lot of other utilities in some places—water, gas, and transportation. These are major services that are required in populations around the world. They need to be coordinated and optimized with electricity. Discussion in the electric industry should not just be about the electric system. It should also be about the systems that electricity supports. It's to our nation's benefit if we begin coordinating across sectors, with the common core being electricity. This is something I would like to see EPRI tackle.

For example, a tremendous amount of electricity is required to pump water. We talk about optimizing the load on the electricity grid. What if you now bring the water systems into that discussion? What is the best time to pump the water? It's a larger optimization equation. It involves the same concepts that deal with traffic congestion. America needs to be the first to do this on a big scale. We're doing a microgrid demonstration at the former Naval Yard in Philadelphia, again with many partners. What's interesting is that both the water and the electric utility of Philadelphia are involved.

All the other systems that are naturally coordinated with electricity can give you a bigger picture to optimize your overall energy system, and that's even more powerful. Big data and analytics can be applied to all of these. If the electric industry is able to achieve better situational awareness—knowing what's wrong instantaneously—with faster data and data analytics, wouldn't the other utilities benefit from them, too?

EJ: There could be one super system that optimizes all the sectors.

Ericson: That's what I'm talking about.

What Is the Optimal Amount of Energy Storage for the Grid? The Answer: Not So Simple

"I've been asked this question a lot over the last decade," said Haresh Kamath, EPRI's program manager for energy storage. "It's a natural question: Storage developers want to know the market size for storage, and utility managers want to estimate how much they will have to pay. However, finding an answer is not trivial."

To begin with, the meaning of *optimal* can change depending on the context, especially in view of the many tradeoffs in grid design. "Deploying a significant amount of storage may allow more renewable penetration on the grid, but may also make the grid significantly more expensive," said Kamath. "The goals have to be identified before we can define what 'optimal' really means."

Even after the goals are decided, it is still possible that there are easier or more cost-effective ways of achieving them than storage. "The choice isn't simply whether we use storage or not," said Kamath. "In some cases, we have to choose a technology from a portfolio of options, and in other cases, we have to choose a combination of technologies. Finding the best answer can be extremely difficult."

These answers can be explored through appropriate modeling. But it takes significant time and effort to build models sophisticated enough to accurately estimate optimal energy storage deployments across the grid, factoring in all possible storage technologies and applications, and ranking them against non-storage solutions to the same problems. Such models have to be updated continuously as new technologies are introduced, and as costs and features of other technologies change.

According to Kamath, other investigators have published storage market size estimates based on tenuous analyses. "Every so often, you will hear someone make a statement estimating the storage market to be worth $3 billion, or $30 billion, or $300 billion," he said. "The variation in the values is a red flag that the studies lack rigor."

In a 2009 analysis, EPRI estimated the overall market size of storage by evaluating its value for various types of projects and calculating how many of those projects are possible in a given service territory at a given cost.

"We have not updated the estimate because we have focused our research on the economics of individual projects, which we believe is more important and immediately actionable than general market projections," said Kamath. EPRI has recently developed models that can analyze project costs and benefits, helping utilities and regulators decide whether to invest in storage. These include the Energy Storage Valuation Tool and its successor, the Storage Value Estimation Tool, expected to be available in late 2016. The former was used in 2013 to inform stakeholders involved with a California Public Utility Commission regulatory proceeding on the cost-effectiveness of storage.

For more information, contact techexpert@eprijournal.com.

First Person—Flexible, Connected, Resilient

Trio of White Papers Explores Power System Transformation

The power system is rapidly changing into a highly integrated network of power generation, delivery systems, and customer-sited distributed energy resources such as solar, energy storage, and grid-interactive appliances. Based on examination of these trends, EPRI and electricity sector stakeholders determined that the future power system needs to be more flexible, connected, and resilient. EPRI kicked off 2016 with the release of three white papers on these characteristics.

Learn about the motivation for producing these white papers from EPRI Senior Vice President of Research and Development Arshad Mansoor.

Flexibility

Power system flexibility is the ability to adapt to changing conditions while providing safe, reliable, affordable, and environmentally responsible electricity. EPRI's white paper on flexibility describes technologies that EPRI and electricity sector stakeholders are developing and applying to address the challenge of flexibility.

Connectivity

Connectivity refers to the widespread deployment of grid communications, providing access to data streams and functions that inform decisions and behaviors from the power plant to the end consumer. As the electric power system transforms from a one-way power flow network to one that enables intelligent and interactive two-way power and information flow, connectivity will be paramount. EPRI's connectivity white paper discusses challenges and opportunities with emerging technology innovations to improve grid communications.

Resiliency

Resiliency is the ability to harden the grid against—and quickly recover from—extreme weather and other high-impact, low-frequency events. EPRI's resiliency white paper discusses the three key elements of a resilient grid—damage protection, recovery, and survivability—and related technologies under development.

In Development

Ready for Service

EPRI Guidance Helps Operators Bring Fossil Plants Online and Offline Safely and Reliably

By Chris Warren

For power plant operators and grid operators these days, a fossil-fueled plant is like a backup quarterback in the NFL. When the grid operator needs that plant in the lineup, the plant operator and the plant must be able to respond quickly, reliably, and effectively. Like a backup quarterback, the plant has to be ready to perform, no matter how long it has been inactive.

For fossil plants, this requires a well-executed layup. Plant staff must take effective measures, such as adding nitrogen and certain chemicals to protect equipment from corrosion, leakage, and other mechanical problems that could delay a prompt return to operation.

A layup lasts longer than a routine shutdown. "With a shutdown, you keep the temperature in the boiler the same as when it's generating because you're anticipating the need to be online in the next 24 to 48 hours," said EPRI Senior Technical Leader Mike Ruszkowski. "Layup is longer term, usually weeks or months. But if you're in layup and several other plants trip offline, you have to be available to come online quickly."

More Layups with a Changing Grid

As the grid incorporates more natural gas and renewables and as demand management increases, coal-fired units increasingly are used only during periods of high electricity demand, such as hot summer and cold winter periods, with layups scheduled between them. Because these plants were designed to operate continuously at full load, operators need to take measures to protect generation equipment when they are cycled frequently online and offline or operated at low loads for short periods.

EPRI has developed guidelines to help plant operators successfully manage the increased frequency and complexity of layups. This work is part of EPRI's Changing Mission Profile initiative to help operators manage flexible operations of baseload plants.

Required: Communication, Vigilance, Planning

According to George Verib, a FirstEnergy senior consultant for water and steam chemistry, a major challenge with layups and shutdowns is a lack of clarity about their duration. "There have been times when a shutdown would last for two or three weeks, and managers couldn't take protective layup measures because the plant was always on 24-hour notice to come back online," said Verib.

Ray Chambers, an EPRI technical executive who worked on the layup guidelines, points to communication as the most important factor, because independent system operators and plant operators don't have the same priorities. "Reliability of generation equipment is a guiding principle for plant operators, while system operators are looking for the lowest cost of generation over the next few hours," said Chambers. "Therefore, it's essential to communicate with your independent system operator or dispatcher—and if possible, get agreements with them—so that you know when you're going to be offline and for how long." This enables plant operators to choose the proper layup techniques and assemble the appropriate materials, equipment, and workers to execute them.

Also important: Keep a consistent maintenance schedule. “A three-month layup should not translate into ignoring the plant for two-and-a-half months,” said Ruszkowski. “Crews need to stick to a schedule and regularly complete tasks such as checking pump and motor oil levels and testing fans. If equipment problems arise, you need time to address them.”

A well-executed layup requires a plan to get back online. This should detail timing of tasks—such as draining off protective chemicals—and ensuring that the right personnel are on-site during the restart. “There’s nothing worse than having to call a plant manager at three in the morning to let him know that the plant cannot start up on time because of equipment problems and a lack of maintenance staff on-site,” said Ruszkowski.

Key EPRI Technical Experts

Mike Ruszkowski, Ray Chambers

Innovation

New Models for a New Era

By Garrett Hering

Until recently, the electric power industry was an exception to the old adage, “It is difficult to make predictions—especially about the future.” Most electric utilities were able to forecast power supply and demand with relative confidence.

“In most places until about 2008, electric demand growth mirrored the trajectory of gross domestic product. Load was forecastable, generation was dispatchable, and electrons flowed in one direction,” said Bill Gould, EPRI director of strategic analysis and technology assessments. “Resource and system planning was much more predictable than it is today.”

Utility resource planners now face many more variables. For instance, the U.S. Energy Information Administration expects non-hydro utility-scale renewable generation to account for nearly 9% of total U.S. power supply next year, led by intermittent wind power. Non-hydro utility-scale renewables accounted for 7.1% in 2015 and 3.1% in 2008. States such as California, Vermont, and Hawaii are calling for 50–100% renewable energy in power portfolios. Increasing variable generation from customer-owned photovoltaic systems and other distributed resources tests the limits of local distribution circuits. The U.S. Environmental Protection Agency’s Clean Power Plan mandates states to limit electric sector carbon emissions.

These and other developments introduce uncertainties into utility planning and operations. How will more intermittent generation impact system reliability? How will conventional power plants, designed for baseload operation, perform as they operate more flexibly to accommodate solar and wind? How will environmental impacts of solar and wind power plants affect their operation? How will consumers interact with the new generation mix?

Traditional forecasting models are based largely on one-way electricity flow, dispatchable generation, and economic growth estimates—and they cannot account for these new developments.

“The grid is more dynamic than ever before, and the modeling methodology needs to reflect this,” Gould said.

Modeling: A Research Imperative

Gould is leading EPRI’s “research imperative” to improve understanding of the changing power system and identify modeling gaps.

The effort is detailing key certainties and uncertainties integral to grid planning and operations, then addressing them in EPRI’s models, and providing key insights to enhance modeling industry-wide. EPRI is creating a roadmap for incremental changes to existing models and for developing methodologies that factor nontraditional variables such as customer behavior.

For instance, EPRI is modifying its U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to help better understand how changing supply, new transmission and distribution technologies, and more active customers could interact with various economic and policy scenarios. The electric demand side of US-REGEN will examine in greater detail the interactions between end-use efficiency, demand response, and the competitiveness of electricity in the broader energy system. On the electric supply side of the model, EPRI is investigating ways to incorporate more operational realities—the moment-by-moment technical options for balancing electricity supply and demand—when creating multidecadal scenarios.

Another major step will be to link planning for transmission and distribution, which have historically been loosely connected. As part of this, EPRI is working with the New York Power Authority and the Advanced Grid Innovation Laboratory for Energy to develop, test, and validate new modeling and assessment practices.

Aligned with EPRI's Integrated Grid concept, these efforts to improve, enhance, and integrate industry forecasting models can help equip the industry to tap the full potential of distributed energy resources by incorporating them into grid planning and operations.

"Rather than build one supermodel, we're going to assemble a connected set of tools to address the many new uncertainties," Gould said. "Each tool will be useful on its own and even more useful as we link them in a consistent approach for thinking about the future."

Key EPRI Technical Experts

Bill Gould, Tom Wilson

Technology At Work

Seeing What Good Looks Like

EPRI Videos Help Power Plant Workers Make Best Practices Second Nature

By Robert Ito

At the H.F. Lee Energy Complex in North Carolina, an engineer radios to a technician to switch to "Pump Alpha" in the power plant's steam turbine generator. Because of the plant's deafening whine, the technician hears "Pump Bravo" and repeats that to the engineer. "No sir, that's not correct," the engineer replies. After another exchange, the technician correctly repeats "Pump Alpha." Such word-for-word repetition of instructions, known in the power industry as three-way communication, avoids a potential crisis from deploying the wrong pump.

This scene was captured on video by a team of filmmakers led by EPRI's Operations Management and Technology Program. It is typical of daily interactions at power plants across the country, and it is now part of a video series: *What Does_____Look Like*. EPRI is producing the videos to illustrate best practices in power plants. Ranging from 3 to 5 minutes long, they are shot at EPRI member sites to supplement and distill knowledge from thousands of pages of EPRI technical manuals.

Learning by Seeing

Neva Espinoza, EPRI's Director for Power Plant Components and Processes, saw the need for the videos during a two-week power plant assessment, when she and her team were discussing best practices with plant personnel. "I realized that many early-career workers just starting out in power plants have only a rough sense of what certain practices are supposed to look like and could benefit from visual examples of these practices performed well," she said. Veteran workers are retiring, she noted, and new workers—more accustomed to learning from tablets or other digital devices—have to get up to speed quickly.

Espinoza's team chose the video topics based on EPRI member interest, with each video strictly adhering to power plant best practices described in EPRI's written guidelines. Power plant operations and maintenance personnel created the scripts, ensuring that the scenes and dialogue were technically accurate, understandable, and applicable to plant operations nationwide.

"Seeing what something looks like is very different from reading a hundred-page technical report on what it looks like," said Espinoza. "New workers often lack the experience needed to absorb all the information in reports, and they rarely have the opportunity to travel to sites where they can observe best practices in use. After they watch the videos, these practices can become second nature. It's a very effective way to transfer our R&D to our members."

The videos cover topics such as having a questioning attitude and conducting a pre-job brief (see box at end of article). In one video, the narrator explains the STAR method (stop, think, act, review) for self-checks. After the narration, a worker demonstrates the procedure, saying each step out loud as he does it. When a coworker interrupts him, he restarts the procedure as best practices dictate.

"I was an operator before coming to EPRI, and I know that sometimes you feel silly doing these procedures," said Espinoza. "But they have a huge impact on successful power plant operations if you implement them well."

Some plant managers have incorporated the videos into their initial and requalification training sessions, while others have posted them online so that their staff can learn from them at their own pace.

Upcoming Video Projects

In 2015 at South Carolina Electric & Gas facilities, EPRI filmed a video series focusing on “lockout/tagout” safety procedures to ensure that potentially hazardous machines and power sources are properly turned off. The films are in production, including Spanish-subtitled versions. Discussions are underway for a third film series in 2016. “As long as EPRI members are getting value out of these videos, we’ll continue to build this video library,” said Espinoza.

Key EPRI Technical Experts

Neva Espinoza

Shaping the Future

From Data-Chasing to Master Data

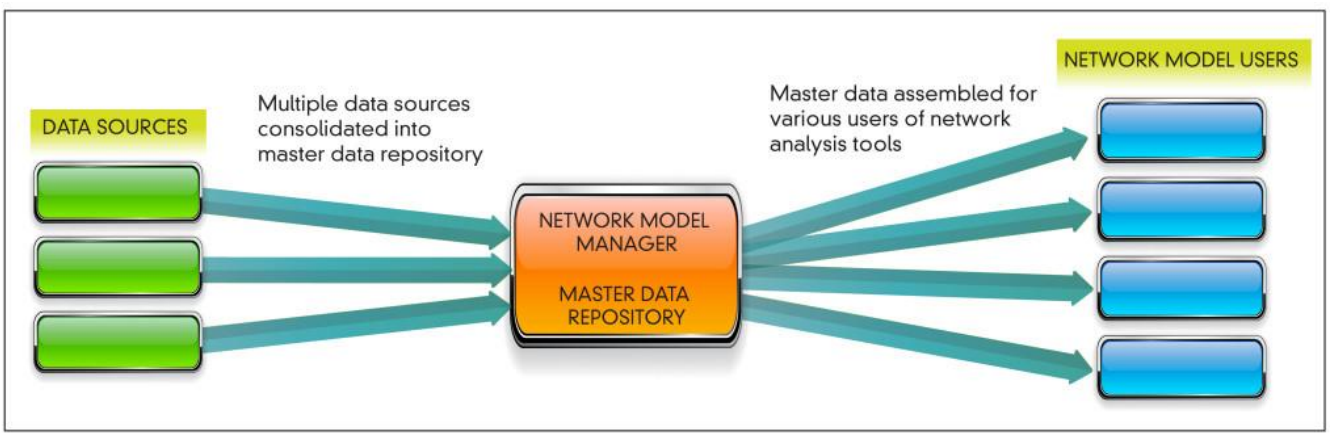
A New Approach to Eliminate Conflicting Data and Support Accurate Grid Analyses

By Robert Ito

Utilities rely on network analysis tools for transmission grid planning, design, and operation. These tools are only as good as the network models that support them, and network models are only as accurate as the data that feeds into them.

Consider this scenario: One network analysis tool indicates that a grid component is at risk of overload. According to another, it's not. If the first tool is correct, operators will need to shift load near term, and system upgrades will be needed longer term. "All that work could end up as a waste of time and money if they're trying to solve a problem that doesn't exist," said John Moseley, a network model engineer at the Electric Reliability Council of Texas. The alternative, however, is also costly: Utility engineers spend valuable time "data-chasing" to figure out whether such discrepancies are the result of an erroneous network model, faulty assumptions about system conditions, or differences in tool algorithms.

Since 2011, EPRI researchers have been exploring the concept of a "network model manager" to store and manage "master" data and assemble it for use by network analysis tools in various utility divisions. A network model manager can eliminate data conflicts that lead to incorrect decisions with negative impacts on grid operations and planning. It can also save significant hours spent entering, synchronizing, and correcting information from multiple sources. Accurate network analyses enabled by a network model manager are especially important today as power companies integrate more renewable generation and distributed energy resources.



How a network model manager works

Breaking Down Silos

Over many decades, more utility domains—such as operations, planning, protection, and markets—have deployed increasingly sophisticated network analysis tools. Because each tool typically has its own users and data managers, silos have developed. For example, employees in operations (concerned with real-time grid monitoring and control) and planning (focused on future grid issues) use different network analysis tools, modeling philosophies, and processes. Combine that with inconsistent data among models, and inefficiencies abound. Engineers spend time wrangling data instead of analyzing the grid, and errors occur that affect the quality of models and network analyses.

"With an effective network model management tool, you can have one source of data, you can point to the place where particular data came from, and everybody can use it," said EPRI Technical Leader Pat Brown. "This makes network models more accurate and reduces labor costs. Instead of having ten different engineers entering the same data, you have one engineer entering it, and ten engineers using it."

To improve network model management in the power industry, Brown has launched projects to assess existing practices and provide guidance to utilities on solutions. EPRI also led a consortium of eight utilities and two vendors to define industry requirements for a network model manager tool. The effort educated utilities on its value and provided guidance to vendors in developing robust tools.

"We're pointing out that there is a pervasive problem in the industry, and there's a tool that can enable a utility to manage its network model data in a more intentional, organized fashion," said Brown.

The impacts of these efforts are apparent. Utilities and grid operators are expressing more interest, vendors are investing in their respective tools, and the Common Information Model standard is being extended to support more network model manager data exchanges. FirstEnergy and American Electric Power, both participants in EPRI research, have launched major network model management improvement projects.

In 2016, EPRI will continue to work with vendors, utilities, standards groups, research organizations, and other stakeholders to advance efficient network model management.

Key EPRI Technical Experts

Pat Brown

In Development

A New Approach to Safeguard "Attack Surfaces"

EPRI Develops Classification Scheme to Help Protect Nuclear Plants from Cyber Attacks

By Margaret L. Ryan

A term of art in cybersecurity is "attack surface analysis," and it's a key to the process that EPRI is developing for nuclear plants to help identify and block entry points for cyber attacks before hackers can find them.

"Attack surface is a more precise way to talk about the types of holes or doors into your device," said EPRI Senior Technical Leader Matt Gibson.

The U.S. Department of Homeland Security logged more than 256 industrial cyber security incidents in 2013, more than half of them in the energy sector. Targets included power plants and critical grid infrastructure. Power plants historically operated with isolated, proprietary control systems, but with the advent of regional power pools and smart grids, they're increasingly connected to the outside world. Cyber attackers can potentially exploit hundreds of digital components. These range from simple switches and measuring devices to complex computerized systems that monitor and balance electricity flow to and from the plants. All of these create myriad electronic pathways that must be properly secured.

According to Gibson, nuclear power plants already have significant cyber security. The most sensitive control equipment, which monitors, manages, and protects plant process systems, is not connected to the Internet. However, the attack surface includes interfaces where patches and updates are added from portable storage media, and those surfaces must be digitally secured.

"While nuclear plant owners have committed significant resources to cyber security, the industry always takes a 'belt and suspenders' approach to safety," said Gibson. "Nuclear operators wanted EPRI to provide a systematic way to verify that potential vulnerabilities are being identified. They want to confirm that they are at the level of technical detail needed to secure plant systems and allocate security budgets effectively."

Organizing Attack Surfaces into Profiles

EPRI is developing and validating an integrated classification scheme that recognizes when attack surfaces of different plant equipment are the same. Based on the classification, researchers can identify measures to block each potential attack pathway, regardless of the specific device.

"A lot of different devices have the same cyber attack surface," Gibson said. "We are trying to organize those attack surfaces into a set of characteristic profiles so utilities don't have to analyze every single device. If your attack surface matches a profile that will give you things you can do to protect the device."

To classify attack surfaces methodically, researchers began with small, single-function digital devices, which typically have fewer external interfaces. Devices such as valve actuators, valve positioners, and instrument transmitters do not have general purpose network connections or memory cards and other removable media. Researchers are finding that they have smaller attack surfaces.

Nevertheless, it is proving essential to analyze devices individually. "Devices with more complex functions do not necessarily have a larger attack surface," said Gibson. "Complex controllers can have a small attack surface, while functionally simpler devices may have multiple points for potential intrusion. It is challenging analysis."

Expanding the Analysis

EPRI will apply the analysis to progressively more complicated equipment, such as network interfaces and programmable devices, which tend to have larger attack surfaces as a consequence of multiple points of interface with other systems.

The attack surface approach is enabling EPRI to develop a methodology that can be applied consistently across devices, nuclear plants, and the industry. The project's first technical report was issued in 2015. EPRI will test the approach at operating nuclear plants in 2016.

Key EPRI Technical Experts

Matt Gibson

EPRI JOURNAL

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