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New technologies and customer choices are driving fundamental changes in electric power systems.

Companies that produce, deliver, and sell electricity find it necessary to adapt to these changes; create new systems, services, and product offerings; and perform traditional functions and services in innovative ways. At EPRI we focus on the power system as it is today, the system in transition, and a transformed system that effectively integrates new technologies, systems, and services.

EPRI’s State of the Technology Report highlights these challenges and shows how R&D contributes to progress.

**ADAPT**

Develop systems, methods, technologies, and tools through which power systems and their operators can effectively adapt to change.

- For baseload power generation, the mission profile is changing, requiring many to ramp production up and down at different times to many different levels. Our work examines effects on materials, enhancing environmental performance, operations and maintenance strategies, and providing forums to share critical experience and expertise.
- Research is casting new light on ecosystem services and the water-energy nexus.
- Our Regional Economy, Greenhouse Gas, and Energy model is helping electricity sector leaders anticipate how shifting industry operating and environmental variables will interact with the economy and policy.
- EPRI is expanding the application of probabilistic assessments. We see as many as 60 types of events for which the nuclear power industry must understand probabilities in assessing and managing risks.

**CREATE**

Support the development and deployment of new technologies, applications, and systems to advance the ongoing performance and long-term transformation of the power system.

- New transmission system sensors will become the never-sleeping eyes and ears of system operators throughout the grid, equipping companies to do timely, preventive maintenance, and moving us toward a more reliable, resilient grid.
- Advanced sensors that can detect torsional vibration in turbine-generator shafts are poised to make a big contribution to plant reliability.
- A seal for nuclear reactor coolant pumps can address small leaks by changing shape, and may be applied in other industries in which small leaks call for close scrutiny.
- Technology for inspecting rotating wind turbine blades from the ground are especially impressive when considering that blade tips move at 150–200 miles per hour.
- The Integrated Threat Analysis Framework can integrate data and information from grid events, potential cyber attacks, and potential physical attacks to support timely, effective response to events.

**PERFORM**

Focus resources on physical assets, the workforce, and customers to reach new benchmarks in the safe, reliable, affordable, and environmentally responsible delivery of products and services.

- The nuclear fleet’s performance requires EPRI’s continued focus on materials degradation and providing essential findings in this area for nuclear plants.
- How the grid will perform as it becomes more diverse, decentralized, and dynamic is still an open question as distributed resources come on-line. We are making significant strides in answering this with EPRI software supporting the development of communication among many different devices.
- The grid’s environmental performance and its impact on other sectors get fresh insights from EPRI’s study examining electric transportation, which could inform everyone from car buyers to policymakers.

As you review this report, consider how we address fundamentally new challenges alongside traditional ones. Ultimately we measure our performance by charting the progress in EPRI’s work, in the electricity sector, and in the lives of the public worldwide.
EPRI’s Performance Demonstration Lab in Charlotte, NC, provides the test materials and protocols necessary for certifying nondestructive evaluation techniques, personnel, and procedures for nuclear power plant inspections. EPRI President and CEO Mike Howard is pictured with some of the lab’s inventory of testing samples.
As the world of electricity generation undergoes profound changes, flexibility is key to surviving, says Tom Alley, EPRI Vice President of Generation. And EPRI is helping electric utilities find cost-effective ways to adapt and transform as the power system evolves.

“We see the mission of generating plants changing,” said Alley. Fossil plants designed for baseload service are expected to operate more flexibly to support variable renewable resources and shifting customer demand. Emissions controls designed to operate at full power are now challenged to remove more pollutants at reduced output.

One clear trend is the system’s shift to natural gas, Alley said. Generators are building more natural gas plants and running them more of the time. But coal-fired generation continues to have a significant share of the power system’s asset portfolio and is critically important to the system’s functioning, he said. New and pending environmental regulations are impacting coal generation assets, requiring major modifications at the same time the plants are being asked to vary their loads seasonally, weekly, or daily. EPRI research is helping optimize emission control systems to be more flexible while increasing rates of pollutant removal. “EPRI research provides information, technologies, and processes that members can use to help reduce emissions and keep valuable assets operating,” Alley said.

Some plants make most of their revenues by operating for short periods when demand is high, Alley said, and that requires thinking through operations and maintenance in whole new ways. “Nobody wants to spend money all year so a plant can run just three weeks in winter and three weeks in summer, but if those are must-run weeks, how much capital and O&M expenditure is justified? How do you train, and retain, your staff for that kind of operation?” he asked. Cost control is paramount as utilities seek to spend limited budgets in the most effective ways, he added.

Wind and solar facilities also are aging. Federal tax credits will expire, manufacturer’s warranties will end, and owners will be faced with as-yet-undetermined operating and maintenance costs. “We have to look down the road and research how to assess these facilities’ conditions and what maintenance they will need if we’re to ensure their reliability into the future,” Alley said.

Alley ranks water high among coming challenges. Utilities will need to minimize freshwater withdrawals as competition increases for supplies. More water quality regulations are on the horizon, and liquid waste streams pose new treatment challenges because they contain more pollutants stripped from air emissions. EPRI research can lead the search for new alternatives, he said.

All the challenges generators face require research and innovation so utilities can choose their best options and adapt, Alley said, adding, “All the equations are changing, and it really comes down to flexibility.”
EPRI Working Groups to Pool Expertise as Missions Change for Generator Assets

“Every plant that’s running in a way it wasn’t designed is an experiment,” said EPRI Senior Technical Executive Norris Hirota.

EPRI is organizing five Mission Profile Working Groups in 2015 to focus on hydroelectric plants and the four main types of fossil generating plants—subcritical and supercritical pulverized coal, natural gas boilers, and simple and combined-cycle combustion turbines. Each group will bring expertise specific to the plant type from operators, materials specialists, chemistry staff, and environmental controls experts. The working groups are built on pilot projects conducted at coal, gas, and hydro plants facing lower or variable demand that challenged operating parameters and, at the fossil plants, environmental controls.

Hirota said the pilot projects’ insights came from multi-disciplinary “deep dives,” bringing together operations and maintenance staff, technical support staff, and corporate executives. “They’re not normally in the same room,” he said. “Each learned how what they did impacted other parts of the plant.” The pilots clearly showed the nexus among environmental compliance, operations, and maintenance. For many older plants, environmental controls are being modified to further reduce emissions. “It can be done in the short term, but the challenge is to sustain the improved performance,” he said. “For operators and maintenance staff, there’s more to do, at the same time the plant is operating at lower or variable loads.”

The pilot projects showed that, in evaluating technology changes, it is at least as important to evaluate the impact on plant staff as to assess the technology itself.

The EPRI working groups will pool information on their plant types and make it available to all EPRI Generation Sector members. Hirota notes that the information will be no substitute for each utility’s plant-specific evaluation, but the EPRI work will mean “they don’t have to start from scratch.” Key for the working groups will be getting electric utilities’ staffs to share their experiences and resolutions to emerging issues. “This project is to be a vehicle for sharing institutional knowledge,” he said. “The working groups will try to get the whole industry up to speed quickly on what it means to operate in this new regime from a plant-wide perspective.”

“Nobody wants to find out the hard way that a solution in one area caused a problem in another part of the plant,” he added.
The turbine-generators that convert high-pressure steam into electricity at coal and nuclear plants must be designed to withstand the stresses that build as their blades spin at high speeds and to avoid vibration that can cause component fatigue and, potentially, lead to turbine failure. One known issue for turbine-generators is shaft torsional vibration, which can occur when grid disturbances feed back along the generator shaft to the turbine sections. If one of the shaft system’s natural vibration frequencies is close to twice the electric system’s frequency, the shaft vibrations can be amplified and the turbine damaged. Testing of turbine-generators at the beginning of their service lives, or after modifications are made, is often required to ensure that their natural frequencies are sufficiently separated from twice the grid frequency. EPRI researchers sought more advanced and less costly ways of testing, and their new sensor technology is being demonstrated in operating plants in 2015.

“Our development goal was to achieve long-term reliability of the sensor system with minimal impact on plant operations,” said EPRI Program Manager Steve Hesler. “We wanted to improve measurement sensitivity and sensor operating life.”

All turbine-generators are designed to avoid the vibration range around twice the electrical system frequency—120 hertz in the United States; 100 Hz in other parts of the world. Because the loss of a turbine-generator is extremely expensive, insurers increasingly call for in-plant tests to confirm that the equipment has sufficient safety margins. Different technologies are used for these in-plant tests, and some methods require several days of unit shutdown for instrumentation to be removed after testing, adding to testing cost.

Hesler said a major challenge was designing a reliable way to attach the instrumentation to the turbine shaft that was both easy to install and didn’t affect operations, eliminating the need to remove it post-testing. The other big challenge, he said, was designing a way to power the instrument without using a battery, which requires periodic replacement. To meet those challenges, EPRI designed a small wireless strain-gauge sensor in a telemetry module, powered wirelessly from a 900 MHz radio frequency (RF) transmitter positioned up to one meter away. Demonstration units installed at two operating coal-fired units have functioned well for several months.

With the EPRI design, Hesler said, utilities could choose to monitor for torsional vibration during operation, as they do now for bearing vibration. Torsional vibration usually stems from small grid disturbances, which may become more frequent as more variable renewable generators come on line. Sensors could detect anomalies early, before turbine damage occurs.

Building on the success of the prototype, Hesler sees the potential for applying EPRI’s sensor technology on other rotating equipment. “We’re already having discussions about possible monitoring applications on combustion turbines and hydro generators,” he said.
“This plant is the flagship of the fleet; don’t you dare break it.”

That was the order EPRI Senior Project Manager Merrill Quintrell received from the assistant plant manager at a large coal-fired plant where his team was about to test its strategy for reducing load to levels lower than anyone thought feasible. It was not an idle request. Most fossil plants were designed to produce baseload power, running flat-out and around the clock, and adapting them to emerging grid demands for flexible generation challenges the safety parameters of major plant equipment. Because fossil generating plant economics increasingly depend on flexibility, EPRI is developing approaches to safely adapt plants to more flexible operations—making them able to run when needed and at a wide variety of power levels.

The EPRI test was successful. “We took very good care of her, and we didn’t break a thing,” Quintrell said. Maintaining stable operation at lower output has proven to be a significant engineering challenge, however, and because few plants are exactly alike, solutions that work at one plant may not work at another. EPRI is tackling this issue with operational flexibility case studies, applying EPRI expertise to help individual plants maximize their turndown capability.

“The problems are always unique—no two are the same,” said Quintrell. “We can’t go to every plant, so our goal is to do enough projects to create a library of successful techniques that project members can consult and apply.”

The EPRI team’s first success came at a plant where management wanted to be able to return a unit from hot shutdown to full load in one hour, but condensed steam in the steam turbine was forcing operators to completely depressurize the steam generator, adding two hours to each plant start. Researchers identified where the condensation was occurring and developed procedures to drain the condensation without venting the whole system.

Another case study involved Tennessee Valley Authority’s Cumberland Power Plant, home to two 1,300-megawatt (MW) coal units. TVA believed that the minimum load the units could sustain was 800 MW, but grid operators often needed less. EPRI engineers took a holistic approach to the plant, identifying phenomena such as uneven heating in steam turbines and boilers, reductions in flue gas temperatures that affected selective catalytic reduction (SCR) emissions controls performance, and thermal variations in turbine rotors. EPRI devised solutions for each issue and demonstrated that the units could be safely brought down to 500 MW while still meeting air emissions standards. Innovative solutions included intentionally fouling boiler waterwall surfaces to retain higher temperatures required for the SCR and maintaining full pressure inside the boiler to alleviate uneven heating flow in boiler tubes, while throttling pressure at the turbine outlet.

Quintrell said that as demand for flexible generation grows, it’s vital that utilities find ways to make full use of a plant’s capabilities. “There is a lot of potential flexibility left in fossil plants,” he said.
Selective catalytic reduction (SCR) technology is widely used to lower nitrogen oxide (NOx) emissions from coal-burning power plants, and with new environmental regulations requiring additional reductions of elements such as mercury, electric utilities are depending on SCR technology as part of their compliance plans. That’s made it urgent to understand how different catalysts react with flue gases in the field, where coal quality and effluent content can vary. EPRI has developed a portable testing facility that can assess catalyst performance at a coal plant site, while the unit is operating.

“This facility is unique in that it is portable,” said EPRI Senior Technical Leader Tom Martz. “It takes just a couple of days to set up on-site. Depending on the scope of testing, we can run the tests and remove the facility in one to two weeks.” The facility also can be left in place for a longer testing program, he noted.

Martz said SCR technology has gained importance because of the federal mercury rule that took effect this year. Researchers found that mercury can be oxidized in the SCR process, which facilitates mercury removal downstream by existing flue gas scrubbers. Maximizing this co-benefit of SCR depends on both coal quality and catalysts used. “This facility lets us test how well a system removes pollutants with different coals at different plants,” he said.

Martz said the system allows researchers to test the results of varying operating parameters without altering the power plant’s operating status. The facility works by diverting a small part of the flue gas slipstream through the testing apparatus. That means that the flue gas stream includes fly ash, Martz noted. Laboratory testing is done on clean effluent, so it is difficult to see the impact of fly ash—a normal component of flue gas—on catalysts. The test loops give researchers the option to simulate burning different coals by altering the proportions of trace elements in the diverted gas. Researchers also can lower gas temperatures to simulate plant conditions when grid dispatchers require load-following or low-load operation. “We can look at the impacts of cycling with no risk to the system,” he said.

EPRI has built two test facilities to enable comparison of catalysts while a plant is operating. In September, the two will be used at DTE Energy’s Monroe Unit 4 coal plant to test the performance of regenerated catalysts. Those are less expensive than fresh catalysts, but more independent data are needed on their performance, Martz said. Other catalysts are said to increase mercury oxidation, and the EPRI devices will allow independent verification of those claims.

Martz points to growing interest in using the portable facilities, in the United States and overseas, for both coal and biomass plants. “We want to get data to help end users make catalyst management decisions,” he said, “and we want to collaborate with vendors and with end users to help this technology move forward.”
As they face diminishing supplies and competing demands for freshwater, along with new requirements to clean up water discharged from generating plants, utilities are searching for technologies that can reliably and efficiently make wastewater and degraded water cleaner, for both discharge and reuse. To support this search, EPRI has launched a wide-ranging project to develop and test advanced membrane technologies for applications at generating plants.

“We see a variety of advanced membrane technologies playing roles in multiple areas,” said EPRI Project Manager Jeffery Preece. “One technology is not the solution for all requirements.” Utilities have used membrane technologies for years to produce ultraclean water for cycle-loss makeup, he said, but recently membranes have shown capability to deal with a variety of plant wastewaters as well. Typical wastewater streams come from flue gas desulfurization (FGD), cooling tower blowdown, landfill leachate, and evaporation surface impoundments. Degraded water sources that can be used in generating plants may include treated municipal wastewater, brackish water, or industrial or processed wastewater. Among the technologies EPRI is evaluating are forward osmosis, membrane distillation, membrane bioreactor, anti-fouling nanofiltration and ultrafiltration, and vibratory membranes.

The biggest stimulus for membrane research is water quality-based effluent limits (WQBELs), federal limits based on water quality standards for the receiving body of water, said Preece. Those limits can require removing chemicals such as mercury, selenium, halogens, and metalloids that aren’t reduced sufficiently by traditional wastewater treatment. FGD wastewater treatment, in particular, is complicated by variations in waste streams that occur with changes in types of coal, upstream additives to meet air emission rules, and plant operating regimes. A few plants have had to evaporate wastewater because they had no other way of meeting the limits. “These technologies have a lot of maintenance and operational implications,” said Preece. “We think there’s got to be something better.”

EPRI Senior Project Manager Richard Breckenridge said researchers are working with utilities, vendors, and national laboratories to test both new and modified membrane materials. For instance, he said, materials impregnated with carbon nanotubes have shown promise in removing salts from high-salinity sources. Preece added that membrane technologies may be automated and monitored online, simplifying operation.

EPRI researchers also are reaching out to other industries that use membrane filtration for potential utility applications. One goal for oil and natural gas producers using hydraulic fracturing is to reuse water, and Preece said utilities increasingly are looking at whether membrane technology can help them recycle water. Some membrane technologies such as forward osmosis and membrane distillation require heat, and EPRI is looking at coupling power plant waste heat with advanced membranes. As water quality rules and competing water needs alter wastewater treatment requirements, it’s urgent to take a holistic approach, Preece said, noting, “We need to evaluate solutions that incorporate all power plant waste and wastewater treatment needs.”
Wind turbines often tower more than 20 stories above prairies and mountain crests, and individual blades on the largest modern generators may exceed 200 feet in length. Inspecting blades for flaws that could lead to destructive failures has involved stopping operations so maintenance workers can rappel down from the nacelle or be hoisted in hydraulic lifts to check blades visually—a process that is risky to workers and costly to owners. Moreover, modern turbine blades are made of laminated advanced composites, making invisible any internal lamination flaws that could expand under stress. As more electricity comes from wind, turbine reliability is becoming an urgent concern for utilities, and EPRI researchers have responded with innovative technology for in-service nondestructive evaluation (NDE) of turbine blades.

“We have been working with EPRI’s Nuclear NDE sector,” said EPRI Program Manager Stan Rosinski, noting that nuclear plants routinely use a range of NDE techniques to verify the integrity of various equipment. “The holy grail for us was a technology that allows utilities to inspect wind turbine blades from the ground, while the blades are rotating.”

EPRI is demonstrating a process that meets those criteria. Wind turbine blades may sustain invisible internal damage during manufacture, transportation, and installation, Rosinski said, and blade exteriors may be damaged by lightning or other degradation during service. The EPRI team, led by Program Manager John Lindberg, initially experimented with laser shearography, in which lasers were used to detect irregularities in the laminates—but the system wasn’t sufficiently portable. So the team turned to infrared detection. Initially investigated as a screening tool for the laser technology, the infrared equipment proved light enough to be mounted on a sport utility vehicle and capable of detecting internal structural anomalies.

EPRI worked with NDE contractor Digital Wind Systems, Inc., to implement the SABRE™ system, which was initially demonstrated in 2014 at Duke Energy’s Los Vientos wind farm in Texas. It has since been demonstrated at wind farms in three other states. A long-wave infrared camera detects structural anomalies in rotating blades, and acoustic spectral analysis technology is used to detect surface irregularities like lightning strike holes. “Inspections that used to take days can now be done in a matter of minutes for all three blades,” said Rosinski.

Turbine operators then analyze results and decide whether structural anomalies need to be addressed immediately or are located in low-stress areas where they pose no threat to blade integrity. For instance, the demonstration at Los Vientos identified anomalies in an area where a blade had been repaired, and direct inspection found that repair bolts had broken.

“If these big blades get significantly out of balance, it can cause the whole structure to fail,” Rosinski said. “It’s critical for operating companies to detect defects when they can be managed.”
To manage increased variability in both supply and demand, electric power grids are calling on some gas turbines to stop and start more frequently, and that cycling adds to stresses on key components—especially rotors. Manufacturers typically define rotor design life in terms of hours of service and start-stop cycles, and they recommend replacement at specific intervals. Until now, the only way to ascertain rotors’ material condition has been to take the turbine out of service, disassemble it, and ship components off-site for nondestructive testing (NDT).

EPRI’s Gas Turbine Rotor Life Project has developed procedures and technical bases for utilities to evaluate the condition of their gas turbine rotors.

“EPRI has been building this technical knowledge and experience base in extending the life of gas turbine rotors for many years,” said EPRI Program Manager Robert Steele.

EPRI’s rotor life project consists of two major tasks: developing the Rotor Life Inspection and Evaluation Guideline and evaluating degradation mechanisms in components for a range of turbine models. The project has produced component life prediction procedures for individual designs, based on analysis and testing of retired components. The guideline provides a technical foundation for utilities to evaluate rotor condition and decide whether a rotor can continue in operation. It includes sections on rotor design alloys and properties, rotor damage mechanisms, in-service material degradation mechanisms, NDT, and material sampling and testing. The guideline was developed in conjunction with EPRI’s rotor materials database, which compiles years of experience with rotors from a range of gas turbines.

Recently, EPRI helped European utility Enel develop a rotor life extension program that is allowing up to 60% more lifetime start-stop cycles. It included on-site NDT and focused on turbines that were used for peak loads and spinning reserve, resulting in several starts and stops daily. The manufacturer had set the lifetime limit at 5,000 starts.

EPRI researchers analyzed out-of-service rotors and developed stress analysis models. Material testing helped establish baseline properties and lifetime thresholds. EPRI performed a root cause analysis on the cracking determined to be the first failure indicator and verified an NDT method, in situ ultrasonic phased array, that could detect crack initiation in that area without disassembling the rotor.

Using the project’s findings, Enel extended the rotor life to 8,000 starts, based on actual rotor condition.

“Our knowledge of the rotor designs allowed us to focus in on the problem areas” when working with Enel, Steele said. “We could look very specifically at those key points.

Steele characterizes the work as “a breakthrough,” adding that EPRI plans to demonstrate its system on other turbine models as it continues to refine its rotor guideline and database.

“Our knowledge of the rotor designs allowed us to focus in on the problem areas.”
Taking care of the environment goes beyond compliance, says Anda Ray, EPRI’s Vice President of Environment and Chief Sustainability Officer. Way beyond.

“Environmental stewardship calls for critical, strategic activity integrated into every aspect of creating and operating a sustainable electric power system,” said Ray. “Increasingly, industry leaders’ thinking is driven by factors tied to sustainability, which goes well beyond an environmental compliance focus. They seek to drive improved corporate performance in risk management, capital productivity, and technology innovation and growth. They know there is a correlation between sustainable electric companies and their financial performance.”

Moreover, she said, “Sustainable actions are a strong component of the new relationship with customers, who are driving changes in the market because they want a cleaner, financially viable, and socially responsible future.” The bottom line, says Ray: “You invest in environmental science and technology because it’s just plain smart business.”

Environmental research has often been pursued in response to compliance challenges, as power utilities have sought the best options for complying with specific environmental regulations. Ray insists that environment is not just another “compliance box to check,” and environmental issues can be more cost-effectively handled before, rather than after, technologies are widely deployed. For example, she said, while solar panels and lithium storage batteries are promoted for their benefits to the environment, both contain potentially hazardous materials, and research has just begun with respect to their recycling or disposal. “We need—now—the life cycle assessments of the technologies that will be part of a new transformed power system,” Ray said. “We need science to inform policy way before any regulation is proposed. We can’t start when the rule rolls out.”

The breadth of environmental issues being explored at EPRI is gaining increased interest from top-level executives who see opportunities to create value and strengthen their business foundations for long-term growth. To capture the expanding role of these issues, EPRI’s Environment sector has laid out six “roadmaps” to align their research across all of EPRI’s research sectors. The roadmaps address generation environmental science, energy delivery and utilization environmental science, occupational health and safety, strategic analysis and technology assessments, renewables, and sustainability.

“As long as there are humans on this planet, there will be increasing value put on the air we breathe, the land that feeds us, and the water that sustains us,” said Ray. “Looking through the lens of sustainability gives companies much sharper focus on potential risk exposures and potential opportunities in the future. Many environmental challenges are foreseeable, and investment in the research and technology is a key component of surviving and succeeding. Let’s not kick the can down the road.”

“You invest in environmental science and technology because it’s just plain smart business.”
Ecosystem resources—water, air, wetlands, biodiversity, climate—benefit everyone but often are treated as both free and limitless. Today, with some ecosystems strained and regional shortages emerging, power companies worldwide increasingly recognize how ecosystems benefit their businesses and seek to manage the bottom-line risks posed by potential ecosystem constraints.

“Power companies rely on functioning natural services—such as water for cooling, or predictable climate—for their own well-being,” said EPRI Program Manager, Jessica Fox. “Companies need to account for these ‘free’ services, and recognize they may not be provided that way in perpetuity.”

The concept of attributing monetary value to natural resources was initially developed in academia, largely by environmentalists. But increasingly, says Fox, identifying the business value of ecosystems is no longer an academic discussion as power utilities seek sustainable operations and regulatory agencies in effect put prices on clean air and clean water, with limitations on water withdrawals, tighter air quality standards, and greenhouse gas regulations.

For more than a decade, EPRI’s ecosystem services research has developed methods and tools to identify the business value that environmental resources contribute to power utility operations, and to incorporate those values into risk analyses and the bottom line. Ecosystem services include naturally occurring functions such as storing and cycling carbon, nitrogen, and other key elements; enriching soils; retaining sediments; filtering and retaining storm and runoff water; and sustaining diverse biota to fill specific ecological niches. Power utilities own and maintain extensive land holdings that perform these ecological functions, Fox said, but they have not had any systematic way to recognize the value these lands create. EPRI’s analytic approach can help put a business value on those functions, giving companies a more accurate asset valuation and improving their risk management strategy.

One significant result of this research is EPRI’s Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model, a spatially based tool that can model and map the delivery, distribution, and economic value of ecosystem services over time. InVEST analyses can be used to optimize location of facilities on utility land, to support management of natural resources such as pollinator habitat, and to refine and enhance traditional land management strategies. American Electric Power (AEP) successfully applied InVEST to determine the optimal location for well pads for natural gas exploration on 60,000 acres of reclaimed land in Ohio. Previously strip-mined for coal, the land was restored as a public recreation area, and the InVEST analysis enabled AEP to ensure that the wells had minimal impacts on the functioning of restored ecosystems.

The EPRI research has been published in a peer-reviewed journal (Keller et al. 2015, Journal of Environmental Management) and can be applied beyond the United States. “This research shows how to take an academic model and apply it to corporate decision making,” said Fox. “EPRI continues to assess the piece missing from the academic agenda: the corporate business case.”
Conventional steam electric generating plants require water for cooling; hydroelectric plants need water for generation. Public water supplies require energy to treat and pump freshwater and wastewater. That’s the energy-water nexus: “You can’t address one without addressing the other,” says EPRI Senior Program Manager Kent Zammit. With increasing competition for water supplies from other economic sectors, and with some U.S. regions already experiencing droughts, EPRI has embarked on multifaceted research into energy options for a water-constrained future.

There’s growing realization that there is no region of the United States that isn’t vulnerable,” said EPRI Senior Technical Executive Robert Goldstein.

U.S. electric utilities withdraw about 40% of all fresh water taken annually from lakes, rivers, and aquifers—more than any other industrial sector and slightly more than agriculture, said Zammit, and most of that water is used in cooling systems. However, the electric power industry consumes only about a twentieth of what it withdraws, through evaporation, and returns the remaining 95% to the ecosystem. But having such volumes of water available is crucial because water is far more efficient for cooling than the main alternative, air.

EPRI research in the energy-water nexus is targeted to improving existing technologies and demonstrating innovations to ready them for commercialization. Projects include promising innovations in reducing water used for cooling, reducing energy needed for water treatment, and facilitating increased use of wastewater effluents—or “gray water”—for cooling.

For the longer term, EPRI is researching methodologies to enable utilities to assess regional water resources, needs, and sustainability, and developing tools to support stakeholder decision making. EPRI is revising its economic model of energy flows (US-REGEN, Regional Economy, Greenhouse Gas, and Energy) to include water use data for power plants.

Researchers can then use it to examine impacts of adding various renewable technologies, and assess how droughts may disrupt electricity generation and delivery. Researchers are also developing EPRI’s Water Prism, which can model regional water resource availability and needs from all sectors of a region’s economy with results reaching out 30–50 years, the expected life of a utility asset. This modeling supports utility collaboration with stakeholders to consider regional water and energy needs and alternatives, including possible climate variation. Researchers are also investigating how advanced water treatment could facilitate moving to zero liquid discharges at energy facilities and novel ways of integrating energy and water resources as more non-utility distributed generation comes online.

Ultimately, EPRI’s energy-water nexus research supports corporate stewardship goals, said Goldstein. As utilities consider long-term capital expenditures, their stockholders, lenders, and customers all want assurance that the options chosen are economically and environmentally sustainable. Energy-water nexus research and modeling are developing the metrics and tools utilities need to manage the complex long-term risks they face.
The electric power system is evolving in unprecedented ways, with innovative technologies straining century-old business paradigms and requiring unprecedented flexibility to accommodate such technologies in all facets of operations. These new dynamics are challenging analytic models the power industry has long relied on for system planning. With change in every corner of the industry, EPRI has framed a "research imperative" for developing a modeling framework that integrates the power system and the environment.

"We have never had so much non-dispatchable generation, and the expected trend is for this component to be extremely significant," said Bill Gould, EPRI director of Strategic Analysis and Technology Assessments. "Electricity consumers have never been so empowered to do things that are difficult to forecast. Market structures are shifting. Modeling needs to reflect these new dynamics, with their associated risks and uncertainties." Resource planners need analytic tools to optimize generating assets, distributed resources, interactive customers, and the grid into an integrated, dynamic power system.

"The point is not to build a supermodel," Gould said, but to alter the process of modeling. That process needs to be "more iterative and cross-informing," with new influences found in one area of research routinely communicated to and woven into all related areas.

Models need to increase in both stochastic and dynamic abilities to integrate the new factors, he said, because traditional divisions like generation, transmission, and distribution are now fluid, with changes in one area shifting fundamental variables in another. For instance, Gould said, modelers were long able to use a predictable correlation between gross domestic product and energy consumption. With increasing distributed generation and technologies that let consumers control when they use power, that correlation has become a moving target. In transmission and distribution planning, weather variables have been key for forecasting, but expansion of customer-sited solar and non-dispatchable wind generation has significantly complicated those calculations. "It’s hard to forecast decisions people make to install solar panels," he said. "We are just beginning to understand how to do that."

Environmental considerations are interwoven virtually everywhere, Gould noted. Altering wind turbine operations to protect endangered bats, for instance, or adding the as-yet unknown cost of solar panel disposal to system economics fundamentally shifts their long-term viability. Environmental requirements are evolving, with uncertainties ranging from international climate negotiations to local customer demands for sustainable operations. Environmental regulations may have widespread effects outside traditional compliance, Gould said, citing the U.S. Environmental Protection Agency’s (EPA’s) recent state-by-state proposals to reduce carbon emissions from existing power plants. EPA modeled the proposals’ results for emissions, but did not rigorously model effects on system reliability, which are potentially huge. "Impacts on reliability and environmental compliance cannot be addressed separately," he said.

"People appreciate there is a connection" among the changing technologies, environmental rules, and shifting economics, said Gould, "but they often don’t see how tight the connection is. This is why we believe this research is truly imperative.”
EPRI Researching Environmental Risks in Managing Coal Combustion Products

“We want to provide utilities with tools to determine if the option to close will reduce environmental risk or create a bigger problem.”

The U.S. power industry generates more than 100 million tons of coal combustion products (CCPs) each year. Changing environmental regulations are fundamentally affecting the way U.S. coal plant operators manage CCPs, the ash from coal burning, and the solids from flue gas desulfurization (FGD) systems. For decades, CCPs have been stored in ponds and landfills, but environmental and safety concerns are spurring operators to devise new management strategies, and EPRI research is supporting the development of scientifically sound, cost-effective approaches.

Federal disposal guidelines published by the U.S. Environmental Protection Agency (EPA) impose strict new requirements on landfills and ponds, including location restrictions, design and operating requirements, and groundwater monitoring and corrective action. The expected result is the eventual closing of most ponds.

Since 2012, EPRI research in its Pond Closure project has assisted in this anticipated transition, including the development of guidelines for closing CCR ponds and building landfills over ponds, as well as detailed evaluation of geotechnical characteristics of CCRs and conditions that could potentially lead to pond failure.

The goal is to create “an organized way to develop predictive and preventive analysis,” said EPRI Technical Executive Ken Ladwig. That requires research into CCR stability under different loading conditions, ash flow potential in the event of a pond wall failure, and integrated corrective actions. Starting next year, research will delve deeper into potential seismic effects on pond stability and long-term environmental management.

Two recent large-scale releases from operating ash ponds have brought intense scrutiny from regulators and the public, including demands that ponds be closed immediately or even, in some cases, removed altogether to another site. EPRI is developing a relative risk model that can compare the environmental and worker safety risks of pond closure options, ranging from on-site remediation to removing a pond’s contents to a landfill. “We want to provide utilities with tools to determine if the option to close will reduce environmental risk or create a bigger problem,” Ladwig said.

To support the increased reliance on landfills, EPRI is researching the compatibility of various CCP leachates with natural clay and geosynthetic clay liners, leachate collection and management, fugitive dust mitigation, and alternative covers. Groundwater research focuses on new monitoring requirements and site assessment tools; remediation technologies are also being explored.

Nearly half of CCRs are being beneficially used in a variety of applications, and Ladwig believes that the percentage could grow. EPRI research played a key role in EPA’s 2014 decision that fly ash used in concrete and FGD gypsum used in wallboard were environmentally safe. “Many CCP uses are exempt from federal disposal requirements, creating an opportunity to increase beneficial use for proven applications,” Ladwig said. EPRI research is addressing uses in agriculture, asphalt, waste stabilization, and road base, as well as innovative concrete technologies, and research is planned to examine applications such as mine reclamation and engineered fills.
Federal wildlife agencies have committed to clearing lengthy backlogs of candidate species for listing as threatened or endangered, and the electric power industry, with assets that literally criss-cross the country, has deep interests in ensuring that listing decisions are scientifically sound. In response, EPRI is working with the industry and regulators to develop constructive, collaborative approaches to collecting scientific data and advancing research on at-risk species and their habitats.

“The electric power sector is in a period of restructuring, and there’s concern about how new species listings might impact both existing operations and changes in the transmission grid and generation sources,” said EPRI Senior Technical Executive Robert Goldstein. “EPRI is developing the knowledge base to support technically sound decision making and conservation plans.”

EPRI researchers are working to cooperate with the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS), the agencies charged with decisions on listing species as endangered on land and in coastal waters, respectively. “EPRI is not interested in contesting agency decisions,” said Goldstein. Rather, the number of species up for consideration has challenged agency resources. EPRI is collaborating to identify research gaps, particularly for candidate species whose habitats are affected by electric utility facilities and operations, and to compile existing scientific data on candidate species that are most relevant to EPRI members.

EPRI is evaluating one approach called “Candidate Conservation Agreements with Assurances (CCAs).” These negotiated agreements may preclude the need for formal listing, and lower the costs for species’ protection, by creating plans to manage an ecosystem to benefit multiple species. EPRI also is examining the concept of critical habitat and its application. Though the law requires the agencies to identify each endangered species’ critical habitat and bars degradation of such habitats, more than half of all species already listed don’t yet have a formal critical habitat designation. Many candidate species are, almost by definition, extremely rare, so some research is being considered to identify surrogate species—similar animals and plants that can be studied to augment data on the rarer species. Goldstein said research involves developing scientific methodologies for identifying potentially endangered species and their habitats.

A key goal of EPRI’s work is to develop a collaborative forum in which federal agencies and stakeholders can discuss both critical challenges and opportunities for cooperative actions prior to listing decisions. Workshops with federal officials, Goldstein said, have helped EPRI identify areas in which research can provide scientific data that federal agencies need for their decisions.

Goldstein expects such cooperative approaches to become increasingly important. The Environmental Protection Agency (EPA) issued guidance indicating that it will consult with FWS and NMFS on water intake and discharge permits for generating plants. “Basically we are going to see a whole new level of FWS involvement,” Goldstein said.
It’s axiomatic that safety is integral to all electric utility operations, so it’s no surprise that safety is an aspect in much of EPRI’s research. But awareness of safety is so ubiquitous in the industry that its role sometimes gets taken for granted. EPRI’s Safety Center of Excellence aims to remedy that, highlighting worker safety issues that cross traditional fields of operation and helping EPRI research teams share information on projects that bear on safety in multiple areas.

“Safety is a top-down, corporate-wide issue,” said EPRI Senior Program Manager Chris Melhorn. “The center will help us do justice to safety issues through better coordination of safety research within EPRI.”

EPRI research traditionally works in areas that mirror members’ operations: Generation, Power Distribution & Utilization, Nuclear, and Environment. EPRI research in each of its four sectors has tended to proceed independently, so safety issues raised in one area may not be communicated in a timely way to other areas.

“The Safety Center will help bring everything related to safety to the top,” said Melhorn. The Safety Center will look at research across the Institute, identify projects with safety significance, and mark them with a ‘safety stamp,’ Melhorn said. “EPRI members will be able to see easily which projects have safety impacts.”

Melhorn also anticipates that research on worker safety issues in multiple fields of operation can be conducted much like projects under Technology Innovation, EPRI’s cross-disciplinary program that accelerates early-stage scientific research and development of breakthrough technologies.

Melhorn points to diverse examples of operational research that affects worker safety. He cited work on concrete crawlers, wall-crawling robots that carry sophisticated concrete inspection devices up the fronts of hydroelectric dams or similar walls to inspect for material flaws. The devices could replace hazardous work on scaffolding or in safety harnesses. Another example is protective clothing for line workers on transmission and distribution systems, Melhorn said. Researchers devised clothing to protect against fires and power arcs, but did not consider the clothing’s impact on worker heat stress. Other research has found that exposure to blue light at night may impact worker health, a finding with safety implications wherever workers staff 24-hour operations. Recent research indicates that worker hearing loss may occur at sound levels lower than the federal daily permissible exposure limit, which could impact a variety of operations. Federal safety agencies recently lowered the exposure limit for hexavalent chromium, a by-product of welding, and for crystalline silica, which can be found in fly ash and concrete. In both areas, without proper engineering controls, workers can be exposed to harmful levels that can cause lung diseases, including cancer. Utilities need options for future compliance across operational fields.

Melhorn said that EPRI members have been enthusiastic about the Safety Center’s cross-sector approach, and he hopes to see it begin operating in 2016.
As the energy industry undergoes fundamental changes around the world, EPRI is adapting its Regional Economy, Greenhouse Gas, and Energy (REGEN) model to help electric utility leaders anticipate how shifting industry operating and environmental variables will interact with the larger economy and government policy in coming years. “Despite fundamental differences among nations, we see similar things happening worldwide,” said EPRI Senior Program Manager Tom Wilson. “With REGEN, we don’t predict the future, we try to understand it.”

Demand patterns are changing as more customers generate some of their own electricity and manage the timing of their demand. Simultaneously, utilities are integrating into their systems more non-dispatchable renewables such as wind and solar. U.S. utilities are shuttering as much as 20% of coal-fired generating capacity due to increasing environmental restrictions, competition from natural gas, and age. More shutdowns and shifts in operating patterns may be coming if the federal government limits carbon emissions from power production.

EPRI developed REGEN for the United States and currently models 48 distinct state-level regions, said Wilson, a capability necessary because state and regional energy policies and resources vary widely. The model has provided key analytic support as EPRI and its members responded to the Environmental Protection Agency’s proposals for state-by-state reductions in carbon emissions.

But the model also is proving useful in Europe, and EPRI researchers are hoping to expand it to Canada and Mexico, said Wilson. This year, the first EU-REGEN will be unveiled. The joint effort with Germany’s IFO Institute for Economic Research is sponsored by the Bavarian state government to explore issues critical to the European Union electric sector. An early study examines impacts of Germany’s national energy policy, replacing nuclear power with wind and solar. The growth of solar has flattened the daytime price for electricity, said Wilson, creating economic challenges for baseload generators well beyond nuclear plants. “These issues are emerging in the U.S. as well,” he said. “The U.S. work is informing the work in Europe, and vice versa.”

In 2015, EPRI begins REGEN modeling work with Mexico’s state electricity supplier as the government begins to open Mexico’s energy business to competition and fundamentally change the market dynamics. EPRI is also considering a Canadian REGEN, said Wilson. The countries share close ties: more than 90% of Canada’s energy trade is with the U.S., and its regions share more pipelines and high-voltage transmission lines with the U.S. than with one another.

Globally, the electricity sector is undergoing rapid change as the cost of renewable energy plummets, efforts to reduce carbon emissions gain traction, and shifts in revenue patterns challenge electricity market designs. Wilson said that REGEN can explore these emerging issues to help companies, policymakers, and society make better-informed decisions in this high-stakes environment.

“With REGEN, we don’t predict the future, we try to understand it.”
In coming years, transmission and distribution systems will still have wires, and they’ll still connect consumers and suppliers. But the power system of the future will function in ways never imagined when those wires were strung, say Rob Manning, EPRI Vice President, Transmission, and Mark McGranaghan, Vice President, Distribution, Energy Utilization, Information, and Communications Technology.

The distinctions between electricity suppliers and electricity consumers will blur as distributed energy sources like solar panels, wind turbines, electric vehicles, and microgrids require an integrated grid to manage and optimize increasingly dynamic electron traffic. Manning and McGranaghan are leading EPRI to enable effective application of advanced technologies that are making grid integration feasible.

“EPRI works with the industry to identify opportunities,” Manning said. “We scout technology advances, test things out till we find combinations that work.” Power delivery systems are already changing with renewables integration, he said, and technology has advanced to permit penetration of variable renewables greater than that thought possible even five years ago. In the past, the industry valued generating assets that could stay online reliably, but with more renewables, he said, “we want conventional generating assets to be there when we need them, and be gone when we don’t.”

“Changes are occurring so rapidly,” said Manning. “Technology is vital because it can be implemented faster than building new assets. And it’s overlay technology, utilizing existing assets.” New sensor technology, for instance, is being applied both on long-distance transmission lines and on distribution systems, giving grid operators significantly more real-time data on their delivery systems’ status. Operators in the future, he said, “will need to understand what is happening everywhere on their system.”

EPRI is working with vendors on the Open Application Platform, a common software platform for “smart” devices such as advanced meters, breakers, and controllers. The platform, McGranaghan said, will allow third parties to develop new applications that could enable innovative customer services and improved grid operation. In effect, he said, EPRI is facilitating turning grid-connected devices into smart phones. EPRI also is developing interface requirements for information exchanges between transmission and distribution systems, and developing the basis for the “next-generation customer model.” The customer of the future, he said, “is a dynamic control system with smart appliances, energy storage, local generation, and home energy management systems. It’s a big change for the industry.”

McGranaghan said that creating the integrated grid will require more than technology. Industry standards and guidelines must be established and optimized to ensure interoperability of the new technologies. “One of EPRI’s roles is to make sure that new technologies can be applied effectively on the integrated power system,” he said. “Our challenge in the integrated grid is to make ‘customer energy optimization’ part of ‘global energy optimization.”

“Our challenge in the integrated grid is to make ‘customer energy optimization’ part of ‘global energy optimization.”
The electric system increasingly depends on a resilient grid—a grid that can withstand or quickly recover from extreme events such as Superstorm Sandy, emerging challenges such as geomagnetic storms, and physical and cyber security attacks as well as more common events such as fires and floods. But most grids were built decades ago, and enabling them to support these diverse, dynamic new demands means utilities need real-time information about their condition. To meet that need, EPRI is developing a suite of sensors for transmission assets so maintenance can be optimized and unplanned outages avoided.

“We are developing a tool box of sensors for a variety of components, to transmit just the information utilities need to make informed decisions,” said Andrew Phillips, EPRI director of Transmission and Substations.

Underway for a decade, the project is working to develop low-cost sensors, independently powered, that transmit essential information by radio frequency. The sensors are designed to alert utilities to incipient faults and provide situational information so maintenance activities can shift from reactive to preventive. For instance, sensors can measure contamination on insulators, alerting maintenance staff to wash them so they don’t fail, or can give the exact location of a power interruption to maintenance crews. Other sensors are in development or demonstration for substation components including insulators, surge arresters, and transformers. For overhead lines, sensors are being developed to detect excessive line movement, conductor breaks, lightning strikes, and geomagnetically induced currents. Other sets of sensors will detect problems in underground installations, such as excessive cable movement, and potential sabotage of transmission structures and transformers, including bullet strikes.

One challenge for all sensors is devising a reliable power source. EPRI’s sensors either harvest electromagnetic current from power lines or use extended-life batteries. Phillips said the sensors require only tiny amounts of current and can be paired with very high-density advanced batteries that will last a decade or more. The effort has resulted in many patents for EPRI and some early sensors are already licensed for commercial use. More patents are pending. Developing sensors robust enough for electric utility operations requires multiple rounds of lab and field testing, said Phillips, noting, “There are about 30 sites now hosting either pilot or demonstration projects with hundreds of sensors installed.”

Determining what types of information are meaningful for each component requires an understanding of each part’s functions and failure modes. The development effort has involved collaboration with more than a dozen electric utilities, but Phillips said that the breadth of experience within EPRI has enabled researchers to draw together the precise expertise needed for each project. “Whether we need subject matter experts, sensor experts, electronics experts, transmission experts, or data integration experts, we can reach inside the organization and out to members and draw all of that together,” he said.
Realizing the full value of intermittent and distributed energy resources (DER) such as solar photovoltaic (PV), wind, and demand response technologies will require their full integration into the power grid—and into grid policies and planning. EPRI’s Integrated Grid framework gives electric utilities, grid operators, and regulators tools to analyze the benefits and costs of integrating new technologies, policies, and services with existing sources of generation. EPRI is initiating a series of pilot programs to test this analytic framework on a variety of resources under a variety of operating conditions.

“EPRI is providing a scientific methodology to holistically account for the many variables in the new energy equation. This can inform the direction of new resource integration, policy, and investment,” said David Porter, EPRI director of U.S. Strategic Accounts. “We need an objective, consistent, and repeatable method for evaluating new technologies and investment against the backdrop of reliability and affordability mandates. This approach provides a credible scientific basis for decisions.”

Porter said understanding the benefits and the costs of adding DER to the grid required understanding the engineering impacts and then developing a benefit-cost methodology framework. EPRI’s goal, he said, is to enable utilities to evaluate future business models for integrating distributed resources into the grid system, regardless of who owns them. Grid operators must prepare for the real effects of DER in order to maximize benefits to all stakeholders, he said.

In developing its benefit-cost framework, EPRI sought out comments from stakeholders. Since its release in 2015, the framework has been praised by environmental advocates as well as industry. “EPRI stressed the importance of making it freely and publicly available,” Porter said.

As the next step, EPRI is using integrated grid pilot projects to work with operators to test the model’s analytic tools in the field. Three projects were underway by mid-2015, with a half-dozen more in negotiation. They are projected to take one to three years. “These are not quick studies,” Porter said. “We are talking about significant impacts on the electric system.” Just collecting base performance data could take up to two years on some projects.

EPRI is seeking to test the framework with six technologies: utility-scale PV systems with energy storage, utility-scale PV systems without storage, distributed energy storage, microgrids, electric vehicle (EV) charging infrastructure, and customer-sided technologies such as combined heat and power systems. Modeling will look at effects down to individual circuits, said Porter, so utilities can see, for instance, where additional capacity is needed in the distribution system and where customer resources might make additions unnecessary.

“We’re going to test our integrated grid model with real, live data and adjust it, and get reaction from utilities, technical providers, and regulators,” Porter said.

“This approach provides a credible scientific basis for decisions.”
An alarm rings at a utility security center signaling that a fence may have been cut at a substation. Another alarm rings at corporate cyber security offices, indicating an unauthorized attempt to access control equipment at the same substation. A third alarm at a grid dispatch center indicates that a transformer at the substation has failed. In most cases, each alarm would be handled separately, by personnel who have no way of knowing the larger picture that the three alarms could present if analyzed together. EPRI’s Integrated Threat Analysis Framework (ITAF) would change that, analyzing the different alarms to create a comprehensive threat assessment for security personnel.

“EPRI had been researching how utilities can establish Integrated Security Operations Centers, or ISOCs, pulling together physical and cyber security events from various domains of operations,” said EPRI Senior Program Manager Galen Rasche. “After the Metcalf incident, we began asking whether we could include events from grid operations in the ISOC.”

In April 2013, saboteurs attacked the Metcalf, California, substation of Pacific Gas & Electric Co. They cut telephone cables and began shooting. It took 10 minutes for operators in a nearby building to realize what was happening and call for help. In 19 minutes, saboteurs knocked out 17 transformers and escaped. While grid operators rerouted power and avoided any blackouts, it took PG&E 27 days to restore service at the substation.

That event led to the ITAF, said Rasche. “Other utilities looked at how long it took for personnel to get a clear idea of what was happening, and asked if they could do better. Not many could. Metcalf was the catalyst for this project.”

The ITAF project is identifying barriers to integrating data from grid events with data from physical and cyber security events. A major challenge is developing an automated system that can evaluate the data from power system sensors and detect which patterns represent threat scenarios. “We need to have a very intelligent, analytic system,” said EPRI Principal Technical Leader Ralph King. Researchers must work closely with operations staff to achieve a solid understanding of grid operations, and then develop algorithms to recognize and analyze anomalies across multiple domains. The system must be aware of things such as maintenance schedules so that false alarms can be minimized. “Raw power system data don’t integrate very well into existing security platforms. We have to transform the data into something useful,” he said.

The project will test its event analysis frameworks in the laboratory and in real-world settings. Rasche said several utilities are building or planning ISOCs, and they see the ITAF project as “a logical progression.” Adding the transmission system to the larger security mission requires broadening security concepts, he said. “We have defense in depth. Now we need defense in breadth.”
U.S. distribution systems have significantly more assets than transmission systems, with poles and wires stretched over thousands of miles, from mountains to marshes, remote towns to crowded metropolises. That’s the heart of the asset management challenge for electric utilities: the sheer magnitude of this part of the electricity delivery system. EPRI has undertaken a series of initiatives to understand better how distribution system components fail and to apply advanced data analytics to support proactive and preventive maintenance programs for these systems.

“EPRI’s goal is to give utilities the tools to create proactive maintenance programs anchored in credible data on component and equipment performance, with metrics that can justify capital investments and operating and maintenance budgets. Researchers have sought lessons in the airline industry’s successful preventive maintenance programs, but the fit is not exact. “We just have so much more infrastructure to track,” Olearczyk said. Collecting data on failure modes has been a major challenge by itself. Researchers at EPRI’s Lenox, Massachusetts, laboratory are testing a range of equipment that has been in service for varying periods to determine degradation modes and root causes of failure. With better understanding of how a component fails, researchers can select or design sensors to detect imminent problems. Historically, a principal challenge arises from the cost of collecting and analyzing huge volumes of system-wide data. Today sensors cost less, and advances in data analytics are enabling algorithms to derive information that’s useful for decisions.

Another hurdle has been the lack of an industry-wide distribution systems failure database that would help utilities compare components and equipment. EPRI has such databases for transmission and substation equipment, but data have not been systematically collected for distribution system components. Part of the problem in assembling a database is that system designs vary by utility, said Olearczyk, so operating environments are not exactly the same for all components—nor are the weather conditions to which they are exposed. EPRI’s research also aims at enabling life extension of components, where changes in maintenance could allow longer service lives. “We want to make age an input, not a determinant,” Olearczyk said. “We don’t have an exact calculus for failures yet, but predictive data analytics are beginning to yield tangible results.”
If distributed energy resources are to realize their commercial and operational value in an integrated grid, information on their status and performance will have to be available as routinely and transparently as information on traditional central generating stations. That requires two-way communication between these dispersed resources and the grid’s operators, said EPRI Technical Executive Walt Johnson. EPRI’s Automated Demand Response (ADR) and Ancillary Services Demonstration Project are showing how open-source implementations of ADR can advance distributed resources.

“We’ve had considerable success,” said Johnson. “Our freely available software has been downloaded more than 5,000 times around the world.”

New sensor technology is being added to the distribution system, giving grid operators more precise information on power flows, and EPRI foresees a coming “integrated grid” that can optimize resources on all sides using this new intelligence. Electric utilities have been using demand-side management programs for decades, Johnson said, but grid dispatchers have had no way of monitoring customers’ response to requests to reduce load. This takes on new urgency with the surge in customer-side energy resources. “We are starting to face the fact that we can’t just have everyone doing their own thing,” he said. “The grid is not designed for that.”

Lawrence Berkeley National Laboratory developed the first open protocol for two-way communications among grid operators, energy consumers, and energy providers. Those energy providers vary from industrial operations that reduce load in times of peak demand, to automated home air conditioning and smart appliances that respond to power prices, to electric vehicles (EVs) whose batteries can be both consumers and providers of electricity. The OpenADR Alliance, an industry consortium in which EPRI participates, has issued open specifications based on that protocol, which vendors can use to design interoperable products.

Based on those specifications, EPRI researchers developed software to demonstrate how those communications work. Johnson said the challenges of managing communications across multiple operators and vendors proved more time-consuming than expected, as did moving from the specification to the commercialization phase. EPRI has now demonstrated the concept of exchanging signals and feedback regardless of equipment type—EV, air conditioner, or industrial boiler—on a common communications platform, he said.

EPRI’s ADR work has already had an impact in the industry, as open availability of its software supports faster development of commercial ADR products, Johnson said. The next step will be to demonstrate that ADR can function as an economic resource to deliver ancillary services to grids, so that ADR can be aggregated and bid into grid operators’ growing markets for short-term support services. Johnson said the project aligns with EPRI’s Integrated Grid initiative and other efforts to enable integration of advanced technology into the power system. Utilities “can’t just completely rebuild the grid,” he said. “The only alternative is to manage it in an optimized and integrated way.”

“Our freely available software has been downloaded more than 5,000 times around the world.”
The electric grid is changing from a one-way system that takes power from central generating stations to consumers into a multi-dimensional set of connections linking diverse and dynamic sources of both supply and demand. Fundamental shifts in grid operations are changing the role of electric utilities in ensuring that sufficient capacity is maintained to serve the grid’s loads. To give stakeholders in industry, government, and the public a factual basis for confronting the economic and policy issues raised by these changes, an EPRI team has created a public whitepaper that lays out the physical realities facing utilities and identifies emerging—and missing—connections.

“We wanted to frame the discussion,” said EPRI Engineer Ben York. “Capacity costs are significant for utilities. So what are the key attributes of capacity? What does it mean to have availability? Reliability? Flexibility?”

EPRI defined capacity broadly, as the capability to supply and deliver electricity at any point in time, taking into account ancillary services such as frequency regulation and load following needed to maintain grid stability. The paper built on other EPRI work on integrated grids, York said, and aimed to bring together all elements that provide capacity on the changing grid—from solar panels to nuclear plants. New technology means “there are a lot of new players in the industry,” he said, from thousands of homeowners with rooftop solar panels to third-party aggregators for both supply and demand. “We have to take a hard look at assumptions that have been generally accepted for a long time, and consider the potential for lots of changes, all at once,” he said. “We have to find new ways to keep these systems reliable and affordable with an increasingly different set of resources.”

The study team focused on particular gaps in knowledge. For instance, they examined how wholesale markets are defining and planning for capacity, and compared the ways utilities and regulators account for capacity at the retail level. Capacity markets look ahead just three to four years and tend to be volatile, the team found, leading to a growing sense that capacity mechanisms may need to provide longer-term price signals.

Among the team’s key findings is that variable resources such as wind and solar supply energy but little capacity, because their availability is irregular. A utility therefore must maintain other capacity to serve customers when variable resources aren’t available, and the cost of maintaining that backup capacity may be significant. And while more energy-efficient appliances, such as residential home heat pumps, are reducing total electrical load, they aren’t reducing peak loads—and peak loads determine the amount of capacity required. Capacity issues extend to many aspects of the power system, including economics, the environment, and social equity. EPRI is “trying to highlight how the physics work” to give stakeholders a basis for policy and regulatory discussions, said York. “We’re trying to show the connective tissue in a balanced way.”

“We have to find new ways to keep these systems reliable and affordable with an increasingly different set of resources.”
That’s the headline from EPRI’s latest study on the environmental footprint of electric transportation, said Dan Bowemaster, EPRI manager of electric transportation. “The grid is getting cleaner across the country,” he said. “It’s all good news.”

The study, undertaken jointly with the Natural Resources Defense Council (NRDC), updates a 2009 joint study that examined grid operations and the resulting environmental footprint for EVs. The update is coming in at 400 pages of text, charts, and graphs, Bowemaster said, but the upshot is simple: “Electric vehicles are great for the environment.”

Other studies have made headlines by claiming that emissions from the electric system mean EVs are no better for the environment than petroleum-fueled vehicles. Those studies are generally using data about electric system emissions that are several years old, Bowemaster said. “Grid emissions peaked in 2007, and in the last eight years or so, they’ve declined, largely due to lower cost, cleaner alternative power sources.” He cited increased use of natural gas for electricity generation, technology advances allowing better integration of renewable energy sources such as wind and solar, and more stringent air quality regulations.

EPRI wanted an authoritative study that policymakers could use as a base for decisions, he said. “We spent a lot of time with the NRDC experts, making sure the work was academically rigorous and 100% sound on the science.”

Sources of electricity vary significantly around the country, from systems using significant amounts of coal in the Southeast to those in the Northwest powered largely by federal hydroelectric dams. Though EVs have no emissions on the road, their environmental footprint depends on how their charging power supply is generated. Bowemaster said that the study’s model accounts for regional differences, but shows that overall emissions from the electricity system are declining. “Nothing is emissions-free,” he said, “But this study shows the direction the grid is going.”

Key variables for electric system emissions going forward include the relative share produced by today’s largest sources of emissions-free generation: nuclear and hydro. Another open question is whether and where drought may reduce the potential of hydroelectric stations, as well as thermal plants that depend on water for cooling. Hydropower is used in some areas to balance variable wind generation, so a drought could mean that the grid can support fewer renewables as well.

The study teams stated clearly what they knew, what they didn’t, and the basis for the study’s assumptions, Bowemaster said. The study has been peer-reviewed, and the overall conclusion is clear: The 2009 study “has been held up as a gold standard,” he said. “Our goal was to make this the updated gold standard, a study stakeholders can depend on.”
The global nuclear industry is diverging into three different paths, says EPRI Vice President Neil Wilmshurst, and EPRI’s challenge is to maintain the appropriate balance of research to meet the industry’s emerging needs. Some operators are planning for their plants’ end of life, and their concern is safely managing the units into decommissioning. Other operators are aiming to extend the life of their reactors, so they want to manage their plants for long-term safety, reliability, and cost-effective operation. A third group is building new reactors and wants to integrate the lessons of 40-plus years of commercial reactor operation worldwide.

“I view EPRI’s role as having a virtual crystal ball, so we can take the time to look at the entirety of the industry and see what is coming over the horizon,” said Wilmshurst. “We pull the issues together, prioritize them, and then work with our members. We tell them, ‘This is what we think you need to pay attention to.’”

About half of EPRI’s nuclear research funding now comes from members outside the U.S., he noted, and EPRI has been expanding its research to encompass reactor designs such as Canada’s CANDU and Russia’s VVER. “The metal alloys used in nuclear reactors don’t care which country they are in when they crack,” Wilmshurst said. “We always have an eye out for the common issues, the ones that cut across different designs.”

Safety—for both workers and the public—is a cross-cutting issue for all of EPRI’s nuclear work, he said. “At some level, everything we do is driven by safety and ensuring the reliability of nuclear plants,” he said.

If EPRI were not taking the role it does in international nuclear research, Wilmshurst doesn’t see who else would do it. Vendors need to see commercial potential where they pursue research, and national laboratories must balance multiple demands on their resources. Only EPRI is able to look into that crystal ball and act on it, he said, adding, “This is the sweet spot of EPRI.”

“I view EPRI’s role as having a virtual crystal ball, so we can take the time to look at the entirety of the industry and see what is coming over the horizon.”
Researchers Try to Pin Down Suspected Low-Dose Radiation Risk to Workers’ Eyes

Worker safety is an imperative in nuclear power, so recent research indicating that standards for protecting workers’ eyes might not be adequate drew quick attention from the industry and from EPRI.

“It has been well known that certain levels of exposure to the eye’s lens could result in cataracts,” said EPRI Program Manager Phung Tran, but the annual dose safety limit for the eye—set years ago at 15 rem—is far higher than the limit for workers’ whole body exposure, which is 5 rem in the United States. Rem is a measure of absorbed radiation dose, and worker dose limits are set to minimize their risks for long-term health effects.

Recent research indicated that lens opacity could result from doses lower than previously thought, and the International Commission on Radiation Protection (ICRP) recommended lowering the annual lens-of-the-eye dose limit to an average of 2 rem. The U.S. Nuclear Regulatory Commission (NRC) is considering a limit of 5 rem, but effects of small doses over long periods are typically difficult to pin down, and there is still scientific dispute regarding the ICRP’s conclusion. So in 2013, EPRI initiated a review of all available research and quantified the risks, using meta-analysis to synthesize findings and identify research gaps.

“We modeled our approach on the one used by EPA [U.S. Environmental Protection Agency] to evaluate chemical carcinogens,” said Tran. Researchers found that there were many studies, but they were difficult to reconcile. They varied on such basics as whether they used measured doses or doses imputed from work functions, and even the best designed studies had significant uncertainties. Few studies quantified the risks in a way that was suitable for a meta-analysis, and many were extrapolated from outcomes of substantially higher exposures.

The meta-analysis exposed significant gaps in research. While some studies “do suggest that effects to the eye appear to be occurring at exposures lower than previously thought,” said Tran, further research is needed to identify what level of exposure actually creates risks. Further work is also needed on the biology of the eye to identify the mechanisms of cataract formation.

In addition, research is needed on the actual exposure mechanisms at nuclear power plants, Tran said, asking, “Does anyone get this exposure now?” Dosimeters typically are worn on the chest and don’t measure eye lens dose directly, and plant workers routinely wear eye protectors for industrial safety. Their potential for radiation protection has not been fully explored.

EPRI researchers are providing input to a pending report of the National Council on Radiation Protection & Measurements to the NRC and are hoping their work prompts further scientific research on worker eye safety. Tran said EPRI researchers plan to assess further potential non-cancer health risks related to radiation exposures, starting with cardiovascular risks.

“Even the best designed studies had uncertainties, and EPRI’s meta-analysis identified research gaps.”
Controllable Pump Seal Could Reduce Nuclear Plant Outages

When nuclear reactor coolant pump seals leak beyond an acceptable minimum, the typical repair costs half a million dollars, requires a week-long plant outage, and exposes workers to radiation. EPRI researchers are working with Georgia Institute of Technology scientists on an innovative pump seal design that could dramatically cut RCP seal leakage repairs—if they can overcome manufacturing challenges.

“This is a ‘way out there’ project,” EPRI Project Manager Gary Boles said. “We are trying to push the envelope.”

Reactor coolant pumps are designed with three seals on a system that progressively steps down reactor primary system pressure as part of normal coolant circulation. These mechanical seals are characterized by a small amount of leakage, which the system is designed to manage. But if leakage exceeds certain specifications, safety requires taking the reactor offline to fix it.

EPRI has worked over the years with engineers at nuclear power plants to develop operational measures, such as changing pressure in the volume control tank, that often reduced leakage at least temporarily, but it was not clear why these measures worked. A few years ago, the industry identified this seal leakage as a persistent issue that warranted focused research.

Boles said Georgia Tech’s Dr. Richard Salant had been researching pump seal faces embedded with piezoelectric elements that would signal sections of the faces to deform by a few microns as needed to re-establish a seal. EPRI researchers felt systems run by electric current would not be practical in the coolant system, so they set about working with Georgia Tech to adapt the design to a system activated by hydraulic pressure.

“The seal has hollow sections in its face that can be minutely reshaped to improve its sealing capabilities,” said Boles. The EPRI team then wanted to test the innovative design but couldn’t find a manufacturer who could make the seal using conventional methods.

EPRI is working with Oak Ridge National Laboratory to make a test seal from advanced carbon fiber using 3-D printing technology. If the seal cannot be made as a single component, Boles said, researchers will try to bond graphite subcomponents so they can withstand the temperatures, pressures, and radiation of the reactor coolant pump operating environment. EPRI plans to test the seal on a seal manufacturer’s full-scale test rig.

EPRI and Georgia Tech have applied for a patent on the design. While aiming initially to develop a product for the nuclear industry, Boles said the seal design could be adapted for use in other hazardous industrial environments such as petrochemical plants.
Nuclear plant operators must continually monitor the integrity of the systems that keep their plants running safely, so EPRI has worked for years with light water reactor (LWR) operators to develop a risk-informed in-service inspection methodology that identifies where inspections are most critical, supporting continued safe operation and efficient allocation of inspection resources. Recently, encouraged by the LWR experience, operators of CANDUs—a Canadian heavy water reactor—turned to EPRI to adapt that methodology to their plant design.

The result was a successful pilot test of the methodology at Ontario Power Generation’s (OPG’s) Darlington Unit 2. The Canadian Standards Association (CSA) is now incorporating the methodology into its standards for nuclear plant inspections.

“Operators can focus their resources on the right areas for the right reasons,” said EPRI Project Manager Patrick O’Regan, noting the methodology provides technical justification for exerting greater effort on those components and systems with higher vulnerabilities.

The project had two phases. Starting in 2010, EPRI worked with CANDU Owners Group (COG) to adapt the risk-informed inspection methodology to primary systems, creating a “best fit” for evaluating the relative risks of system piping welds. Also, with rising industry concern about the effect of balance-of-plant systems on nuclear safety, the project was extended beyond primary systems to all pressure-retaining components and elements, such as tanks, vessels, pumps, and valves.

“This initiative was the first large-scale extension of the methodology to such a wide range of systems and components,” said OPG Senior Technical Engineer Mehdi Rezaie-Manesh.

In 2014, EPRI and OPG piloted the updated methodology at Darlington Unit 2. “There were 168 systems,” said O’Regan, “so we developed a prescreening process to eliminate systems that presented low risk” and focus on the systems, or portions of them, presenting the higher risks to safety. Inspection resources could then be reallocated to ensure appropriate attention was given to each area, depending on its safety risk.

The pilot project demonstrated that the methodology could be adapted to the CANDU technology and could be used efficiently to prioritize plant systems and components needing inspection and monitoring, O’Regan said. The CSA standard for balance-of-plant inspections will be incorporated into Canadian plants’ licensing bases during their periodic license updates.
Nuclear reactor operators must be confident that, when they call on plant safety equipment, it’s ready to operate with an assured power supply. That imperative makes single-phase open-circuit faults in electrical transformers particularly dangerous. Until now, operators have been unable to detect whether a fault exists and whether the transformer will operate when needed.

“It’s a pernicious fault,” said EPRI Senior Project Manager Wayne Johnson.

“You can’t tell the plant is vulnerable,” said EPRI Senior Project Manager Bob Arritt.

Several U.S. nuclear plant incidents had already shown that open-phase faults could exist for weeks without being detected, but in 2012, Exelon’s Byron Unit 2 scrambled due to a cascade of events set off by a single-phase open-circuit fault. Faced with mounting industry concern and to tackle the problem, EPRI launched a joint research initiative of its Nuclear and Power Delivery & Utilization sectors, led by Johnson and Arritt, respectively.

“This is really an example of the industry tackling an issue,” Arritt said.

“Bob’s group did the heavy lifting on circuit modeling,” said Johnson, “and we modeled a nuclear plant similar to Byron so we could better understand the impact of an open-phase fault.” Once the team understood the failure better, researchers began designing approaches for instrumentation to alert operators to open-phase faults on common types of grounded wye transformers under no-load and light-load conditions. In those situations, plant operators may find themselves unable to start up key safety equipment, or the motors may overheat and quit unexpectedly.

By early 2013, researchers had chosen an engineering approach, which they tested and verified in the laboratory. The team took care to use only commercially available, off-the-shelf parts to minimize cost and maintenance. The resulting Open-Phase Detection (OPD) System measures changes that occur when a transducer sends signals to a transformer circuit’s neutral phase, said Johnson. Researchers found that measurements from the OPD System gave clear indications when the circuit was faulted, said Arritt.

By spring 2014, the team was ready for a full-scale field test, and in May demonstrated the Open-Phase Detection System successfully on a high-voltage transformer at the Tennessee Valley Authority’s Bellefonte nuclear plant. Observers from the U.S. Nuclear Regulatory Commission and the industry’s Institute of Nuclear Power Operations were among those witnessing the test.

In total, noted Arritt, the team has published five technical reports. The team’s lab work was done in parallel with a patent application, and the system design has been licensed to a commercial firm, which is manufacturing it for the power industry.

“The technology has been licensed to a commercial firm, which is manufacturing it for the power industry.”
To ensure nuclear power reactors continue to perform safely and reliably as they age, EPRI has worked for more than a decade with light water reactor (LWR) operators to identify both the behavior of reactor materials over time and the research needed to effectively manage aging mechanisms. EPRI’s resulting Materials Degradation Matrix has proven a productive approach to aging management that has been expanded to Canadian CANDU-design pressurized heavy water reactors (PHWRs) and is now being extended to Russian-design VVER reactors.

The matrix, together with the Issue Management Tables that help prioritize research, are reference documents that support “proactive self-regulation” by reactor operators, said EPRI Program Manager Tiangan Lian. “We provide operators with a structure to address materials degradation issues in a systematic way.” The matrix involves a comprehensive survey of the materials and operating parameters in the reactor primary system—the crucial system that contains the nuclear fuel. The matrix identifies potential degradation mechanisms that may affect system performance and evaluates the state of knowledge about how those mechanisms work and how they may be mitigated.

“The Materials Degradation Matrix identifies research needed to address basic vulnerabilities,” Lian said. “We don’t just identify the degradation mechanisms. We try to understand the state of knowledge, and what more we need to know.” The matrix can show linkages between degradation in different systems, giving operators a solid basis for additional research. Lian said the matrix and the Issue Management Tables together support near-term and long-term research planning for materials and component reliability programs.

Initially developed in 2005 for LWRs, the matrix was revised twice before the 2013 revision, when EPRI worked with CANDU operators to expand it to cover the Canadian-design PHWRs. Some new aging mechanisms were identified for unique CANDU components, such as the horizontal fuel channels, moderator system, and primary heat transfer system.

Now, EPRI researchers are working with operators in the Czech Republic to expand the Materials Degradation Matrix to cover VVER reactors. Czech utility CEZ operates six units at Dukovany and Temelin. Lian said EPRI has been working with CEZ and Czech nuclear research institute UJV on a comprehensive survey of the materials in the VVER primary systems and of the conditions—such as temperature, pressure, and radiation—under which the systems operate. In recent months, the VVER operator in Hungary, Paks, has also joined this collaborative effort.

“EPRI brings the structure, while CEZ brings the experience in operations,” said Lian. He expects that in 2015, EPRI and CEZ will be able to establish the Materials Degradation Matrix framework for VVER reactors and to finalize a draft document that operators can use to systematically approach primary system aging management.

“The Materials Degradation Matrix identifies research needed to address basic vulnerabilities.”
EPRI researchers are applying probabilistic methodologies to better understand potential extreme external hazards.

Beyond Earthquakes: EPRI Develops New Approaches to Nature’s Threats

Earthquakes, floods, hurricanes, tornados, tsunamis—over their decades of operation, nuclear power plants must be able to safely withstand whatever nature throws at them. Nuclear power plants are engineered to survive a set of extreme external events, specified in each plant’s design basis, but recent events such as 2011’s earthquake and tsunami in Japan emphasize the challenge of preparing for even more severe “beyond design basis” events. EPRI is pursuing a range of research projects to focus on such hazards and the challenges they pose to nuclear plants.

EPRI has long been a leader in seismic research, conducting studies to better characterize the earthquakes that might affect nuclear power plant sites. EPRI Technical Executive Ken Huffman said researchers have learned a great deal about how plants and their equipment react to ground motions caused by earthquakes. In 2009, EPRI had begun to update seismic hazard assessments for U.S. regions and accelerated its seismic research following the Fukushima accident.

Potential risks posed by other external events have also grown on the industry’s radar. In all, said Huffman, based on world-wide information, EPRI has found nuclear operators may need to consider some 60 types of events. One immediate application for EPRI research has been devising a methodology for operators to assess systematically which event types pose the greatest risk to individual plants, equipping operators to focus those that are most relevant. That methodology has been applied in the United States, Canada, the Czech Republic, and France in evaluating events and enhancing plant- and country-specific decision making. Additionally for the U.S. industry, EPRI is systematically monitoring for new data relevant to the more significant hazards, such as seismic, flooding, and extreme temperatures. Changes to existing information and new data are being compiled to support informed decision making.

To guide its research, EPRI has developed a “roadmap” addressing data and analytic improvements needed to develop more realistic risk assessments of seismic events. EPRI also has drawn up a roadmap addressing external hazards that historically have not received the same attention as earthquakes and potential issues inside plants. Emerging topics in this area include flooding and high winds, said Huffman.

For events such as rainfall, wind, and floods, the lack of long-term historical data presents a major challenge. “The records just don’t go back very far, which makes it difficult to use analytic approaches based solely on observed events,” Huffman said, “and thus researchers are applying probabilistic methodologies to better understand potential extreme external hazards.”
Nuclear plants are getting more energy out of their fuel, but that means when fuel assemblies are removed from service, they have been inside the reactor longer than in the past. The industry refers to this fuel as high-burnup fuel, and it’s characterized in terms of gigawatt-days of power produced per metric ton of uranium fuel (GWd/MTU). To ensure that high-burnup fuel can be stored safely for decades at plant sites and then transported safely for eventual permanent disposal, EPRI has embarked on a long-term project to measure the behavior of high-burnup fuel inside dry storage casks.

Previous research has confirmed the safety of cask storage and transport for fuel up to about 45 GWd/MTU, but today more than 450 casks hold fuel with higher burnup levels, some up to 62 GWd/MTU, said EPRI Senior Project Manager Keith Waldrop. The uranium fuel used in nuclear reactors is contained inside hollow fuel rods made of a zirconium metal alloy. The metal rod is referred to as the cladding. Laboratory tests simulating extreme conditions have found cladding can become brittle, threatening the rods’ integrity—and this embrittlement potential starts to increase above about 45 GWd/MTU. “We need to confirm fuel behavior in a real cask with real fuel under real conditions,” Waldrop said.

“We are running a full-scale demonstration to confirm there are no surprises,” said John Kessler, manager of EPRI’s Used Fuel and High-Level Waste Management Program. Stand-alone spent fuel storage installations on plant sites will need to store fuel for decades, he noted, and this project’s results will provide data critical for aging management.

With U.S. Department of Energy funding, and with Dominion Virginia Power hosting the demonstration at its North Anna plant, EPRI will place instrumentation into a Transnuclear TN-32 dry storage cask to monitor the condition of high-burnup fuel over a decade. The cask will contain high-burnup fuel from North Anna with four varieties of cladding. Fuel rods from the fuel assemblies will be tested at U.S. national laboratories to establish the base condition of the fuel both prior to and after the decade-long test, so researchers can measure any changes as the stored rods age.

Waldrop said challenges have included figuring out how to put measuring instruments in the fuel cask and get readings while maintaining the cask’s confinement. Another challenge is fitting the project into North Anna’s operating schedule. Researchers must plan their work so it doesn’t interfere with plant operations. In addition, the U.S. Nuclear Regulatory Commission (NRC) must approve an amendment to North Anna’s spent fuel storage facility license so the test cask can be stored there. Waldrop noted NRC shares the industry’s interest in high-burnup fuel’s long-term behavior because the agency licenses spent fuel storage nationwide.

EPRI researchers plan to ship the test rods to Idaho National Laboratory in early 2016, and, with NRC’s approval, to load the test cask in 2017.

“"We need to confirm fuel behavior in a real cask with real fuel under real conditions."
At a Glance: Some Areas of Focus for EPRI’s 2015 Research Offerings

**Integrated Grid and Integrated Grid Pilot Projects**  EPRI’s Integrated Grid Initiative and Benefit-Cost Framework can equip stakeholders to identify optimal combinations of central and distributed energy resources, based on local circumstances, goals, and interconnections. Integrated Grid pilot projects will establish benefits and costs for utility-scale solar photovoltaic (PV), energy storage, electric vehicle charging infrastructure, smart inverters, advanced controls, and microgrids.

**Environmental Sciences**  Scientific research such as air quality modeling, risk assessments, emissions characterization, and human health effects studies provides a basis for managing the environmental aspects of electricity operations, along with a multimedia approach to human health and environment impacts that includes land and groundwater protection and remediation strategies for transmission and generation facilities.

**Flexibility of the Generation Fleet**  Originally designed for baseload operations, fossil generation assets are undergoing significant changes in operating missions. EPRI is collaborating with its members to compile and share knowledge and best practices, and helping staffs integrate data and apply advanced technologies holistically across plants to improve operational flexibility and maintain safety and reliability.

**Cobalt-Free Operation**  While working in radiation fields is tightly controlled by regulatory bodies and industry principles, achieving and maintaining exposure goals is an ongoing challenge. EPRI is exploring how “big data,” enhanced decision logic, and new technologies can reduce radiation fields at nuclear power plants to further safeguard worker health.

**Energy Analyses**  Insights to support risk-informed decision making to help companies and stakeholders better understand energy and environmental futures and forecasting, technology options and pathways, comparative economics, and environmental and carbon impacts.

**Operational Performance**  New approaches are needed to operate and maintain plant components and improve reliability, economics, and safety and to reduce emissions. EPRI is helping to develop, integrate, and demonstrate holistic, cost-effective strategies such as new, advanced sensors and data for equipment damage mitigation, monitoring, diagnostics, life assessment, maintenance process, and controls as well as greater operator awareness.

**Energy Storage Valuation Tool**  When implemented effectively, energy storage can be key to improving grid flexibility, resiliency, and use of assets. This tool estimates energy storage benefits relative to costs, calculating how an energy system would be dispatched to get maximum value. When used with additional analysis, the tool can indicate the potential effectiveness of storage in particular applications and help prescribe its size, location, and operating regime.

**Inspecting Around Pipe Elbows**  Guided wave technology was developed originally for examining straight runs of piping. Expanding the application of guided wave technology to enable buried pipe inspection around elbows could help ensure pipe integrity and reduce inspection costs by avoiding or reducing the need for excavation.

**Energy Delivery**  Health and environmental research on impacts of energy delivery and use, including transmission and distribution rights-of-way management, remedial approaches to substation spill and cleanup issues, and exposures to electric and magnetic fields and radio frequency.

**Environmental Stewardship**  Power plant emissions controls capture pollutants across a range of fuels and need new technologies including sorbents, materials, updated guidance for reagents, and options for treatment of wastewater to reduce water withdrawal and consumption. EPRI is helping develop new technologies and enhance existing power plant water management systems.

**Health and Safety**  Safety research to help power companies maintain safer, healthier work environments by identifying injury and illness trends, developing cost-effective ergonomic interventions and designs, and addressing critical occupational exposure issues. The research equips companies to anticipate and reduce employee work-related risk.

**Transmission and Distribution Radio Frequency Sensor Suite**  EPRI is developing, demonstrating, and commercializing sensors for overhead lines, substation, and underground lines, enabling users to measure such things as line capacity and asset degradation. This can optimize operations and maintenance budgets without sacrificing reliability.

**Real-Time Welding**  EPRI is advancing nondestructive evaluation (NDE) technologies to enable real-time flaw detection and defect mitigation during welding operations at nuclear power plants. Real-time NDE will provide for quality control immediately after a weld pass, minimizing excavation and subsequent rework.

**Renewable Generation and Advanced Power Cycles**  Renewable energy resources increasingly are being deployed to meet policy standards, provide energy security, and reduce greenhouse gas emissions. EPRI is addressing the economic challenges, technology performance, availability, and cost-effectiveness of wind, solar, and hydropower assets and is evaluating new, more efficient fossil fuel generation methods to reduce CO₂ emissions.

**Sustainability**  Leadership in defining and measuring sustainability for the electric power industry. The research helps define, measure, and strategically manage social, economic, and environmental issues to improve business performance, reduce corporate risk, and support communities.

**Live Working Non-Ceramic Insulators Tool and Robot**  Line workers often evaluate the condition of insulators prior to performing live work on a structure. This tool enables them for the first time to assess an insulator’s condition while lines are energized, reducing the need to deenergize lines prior to work and enhancing safety. A robot in development will automate its operation, reducing workers’ proximity to energized components.

**Severe Accident Analysis**  The Fukushima Daiichi accident prompted numerous efforts to understand the event and assess its global implications. EPRI’s Modular Accident Analysis Program, or MAAP, is providing insights into accident responses regarding coolant injection, reactor depressurization, and other factors.

**Renewables**  Scientific research to address key environmental characteristics of renewable technologies such as impacts to threatened and endangered species and other environmental issues associated with water power, renewable integration, air quality concerns, and land use challenges.
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