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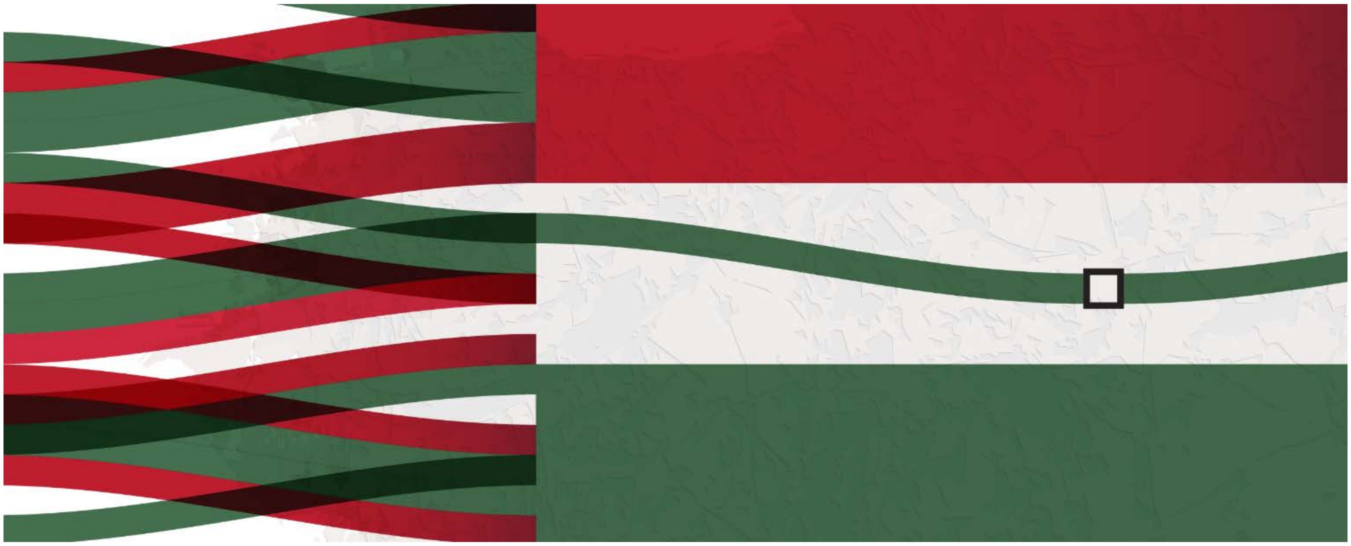


By Brent Barker

Paks Nuclear Power Plant in Hungary joined EPRI's Nuclear Program in 2015 at a significant juncture in the nation's power system. The government had just granted life extensions to two of the four 500-megawatt VVER nuclear reactors at the site, about 130 kilometers south of Budapest on the Danube River. Paks was also in the initial planning stages to add in the 2020s two 1000-megawatt VVER units with a more advanced design—a move that could double Hungary's nuclear capacity.

In 2005, Hungary's National Assembly, recognizing nuclear power's central role in the nation's economy, passed a resolution to support life extension of its nuclear fleet, which was originally scheduled for a 30-year operation. In 2012, Paks Unit 1—online since 1982—was granted an extension to 2032. In 2014, Unit 2 was extended to 2034. Units 3 and 4, far along in the review process, are applying for a 20-year extension. The four nuclear units represent 51% of domestic electricity production. Coal accounts for 21%, gas 18%, and renewables just under 10% (see graphic).

"By joining as a full member of EPRI's nuclear power sector, Paks is able to tap into the complete range of our research related to long-term operations, aging management, fuel reliability, waste management, radiation protection, and risk and safety," said Neil Wilmshurst, EPRI vice president and chief nuclear officer.

Benefits of Membership

"The Paks staff has long known about EPRI and its nuclear programs and had been in touch for many years before joining," said Vaclav Vyskocil, EPRI International's country manager for Central Europe and Scandinavia. "One key inducement was that they operate the same VVER 440 reactors as CEZ, a Czech Republic power company that has benefited greatly from its five years of membership in EPRI's nuclear program."

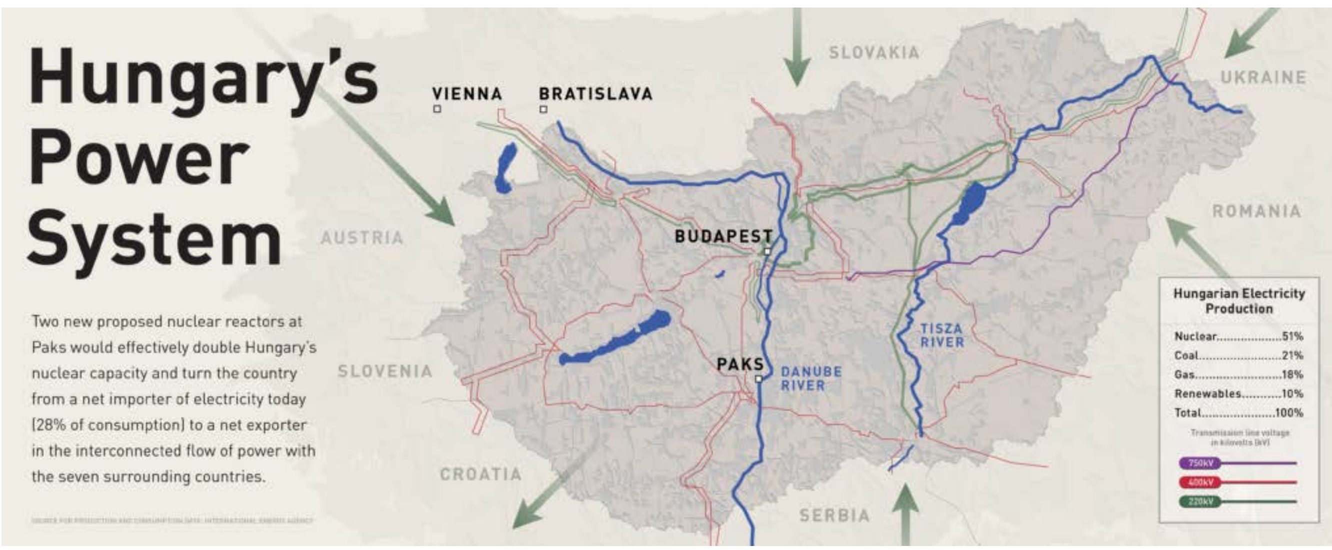
"Within weeks of joining, Paks staff became active participants," said J. P. Sursock, senior technical executive with EPRI International. "They participated in meetings, asked questions, downloaded reports, and were eager to interface with us in a number of fields—especially fuel reliability and life extension. And they have been very interested in talking with their counterparts in the West. EPRI offered them an opportunity to increase their interactions with the larger global nuclear community and further integrate their technical knowledge and operating experience."

Maintenance practices were of particular interest. Following a site visit to Paks by EPRI’s lead maintenance program manager, the Paks staff are applying EPRI software and methods originally developed to support U.S. utilities in implementing the Maintenance Rule. This is part of ongoing work to apply similar rules in Hungary, which requires rigorous routine maintenance and continuous monitoring.

“Paks staff participated in EPRI-organized workshops in the U.S. as well as Europe,” said Vyskocil. “They were active in the Equipment Reliability Workshop in Luhacovice, Czech Republic, in September 2015 and recently at Senec, Slovakia; the Fuel Reliability International Meeting in Prague in November 2015; and the annual Maintenance Rule Users Group in Charlotte, North Carolina. They became active participants in the Nuclear Power Council meetings, benefiting from personal contacts and technical exchanges with other members.”

During Paks’ first year of membership, EPRI conducted meetings on site to familiarize their staff with various EPRI products and programs, including equipment reliability, nondestructive evaluation, and risk-informed in-service inspection.

When offered the opportunity, Paks eagerly agreed to host EPRI’s International Nuclear Power Council meeting in Budapest in June 2017, to be followed by a visit to the Paks facility.



EPRI’s Growing Fleet of VVERs

The benefits of Paks’ membership flow in both directions. The nuclear facility is strategically important to EPRI as it continues to diversify the operating experience of its members worldwide. EPRI members now represent 327 reactors. With Paks’ four reactors, EPRI’s collaborative R&D now covers 14 VVERs. CEZ was the first VVER operator to join EPRI, with four 500-megawatt units at Dukovany and two 1000-megawatt units at Temelin. The Slovakian Electric Company, a member of EPRI’s nuclear maintenance and engineering programs, operates four VVER 440 units.

“The Paks membership means more VVER members with the same technology and therefore more VVER research funding,” said Vyskocil. “It enables us to marshal resources and build a more effective collaboration with our VVER members.”

The most common design is the VVER 440 and the VVER 1000 used in Hungary, the Czech Republic, and Slovakia. These reactors operate throughout Russia and in Ukraine, Finland, and Bulgaria. Newer, larger VVER plants are expected to come online in Turkey, India, and China.

"The VVER has many similarities to the U.S. and European-designed pressurized water reactors [PWRs]," said Sursock. "These include the basic heat cycle and safety features with several barriers for defense-in-depth—cladding for the fuel, the reactor vessel itself, and the containment to prevent release of radioactive material into the environment in case of a severe accident. But they also have significant differences, including major component design, construction, materials, and chemistry."

Key differences include:

- **Steam generators**. The most common VVER designs (500-megawatt units) have six primary coolant loops, each with a horizontal steam generator. The newer designs (1000-megawatt units) have four such loops. In contrast, western PWRs have two to four primary coolant loops with vertical steam generators. This leads to substantial differences in the operation, maintenance, inspection, surveillance, and repair procedures for these components relative to their western counterparts.
- **Fuel assemblies**. VVER fuel assemblies feature a hexagonal geometry and a core arranged like a honeycomb while western PWR assemblies have a square pattern and a square core with clipped corners. Fuel enrichment is typically lower relative to western fuels, but Paks recently implemented higher enrichment fuel designs to enable 15-month fuel cycles.
- **Safety features**. VVER designs incorporate interesting safety features not present in western PWRs. For example, a high-volume pressurizer creates a large thermal inertia in the primary circuit for additional safety margin.

Differences in water chemistry offer opportunities for beneficial R&D. Research related to primary system pH control is important for mitigating corrosion, maintaining good fuel performance, and minimizing plant radiation fields. While western PWRs use lithium hydroxide enriched in lithium 7 isotope (to greater than 99.99% lithium-7), VVERs use naturally abundant potassium hydroxide, which offers the advantages of a more readily available global supply and a substantially lower cost.

"Potassium use in primary water chemistry should be as effective as lithium in controlling pH, and may offer additional benefits for both materials corrosion and fuel performance," said Sursock. "Enriched lithium is currently produced only in China and Russia, and that could make western PWR operators vulnerable to a shortage if production were affected or global demand were significantly increased. Because of this vulnerability and the potential benefits of using potassium hydroxide, EPRI is conducting research on potassium so that western nuclear operators could be ready to implement that option if warranted."

While both VVERs and western PWRs use ferritic steels for the reactor pressure vessel, the steels used in VVER reactors have a higher nickel content. For reactor internals, both use various austenitic stainless steels, but VVER steels contain titanium while western PWR steels contain niobium.

"We are not as familiar with VVER materials as we are with steels used in western PWRs," said Sursock. "But we are actively working with Paks, CEZ, and the Nuclear Research Institute at Rez, near Prague, to expand our knowledge of the degradation and aging mechanisms of these materials and to develop mitigation approaches. We'll build on the methodology that has been developed for western PWRs."

Adapting EPRI Research for VVER Technology

To account for these differences, EPRI has modified some of its research products. For example, EPRI extended its Materials Degradation Matrix to include specific degradation mechanisms affecting materials used in primary circuit components in VVERs, along with recommendations relevant to long-term VVER operations. Two expert panels met in Prague in 2014 and 2015 to work on the Materials Degradation Matrix and related Issue Management Tables for VVER 440 and VVER 1000 plants. The panels included Paks, CEZ, various materials specialists, UJV Rez (Nuclear Research Institute of the Czech Republic), and EPRI staff.

Another important aspect of the cooperation between EPRI and VVER operators is safety analysis, such as the simulation of hypothetical accidents leading to core melt and their consequences (so-called “severe accidents”). EPRI’s Modular Accident Analysis Program, which simulates such accidents in western PWRs and other light water reactors, has been particularly useful in analyzing the Fukushima accident, understanding the unfolding of events inside the reactor, and developing guidance to help operators avoid or mitigate accidents. EPRI is completing a version of MAAP that incorporates VVER safety design features as part of developing accident guidelines for VVER operators.

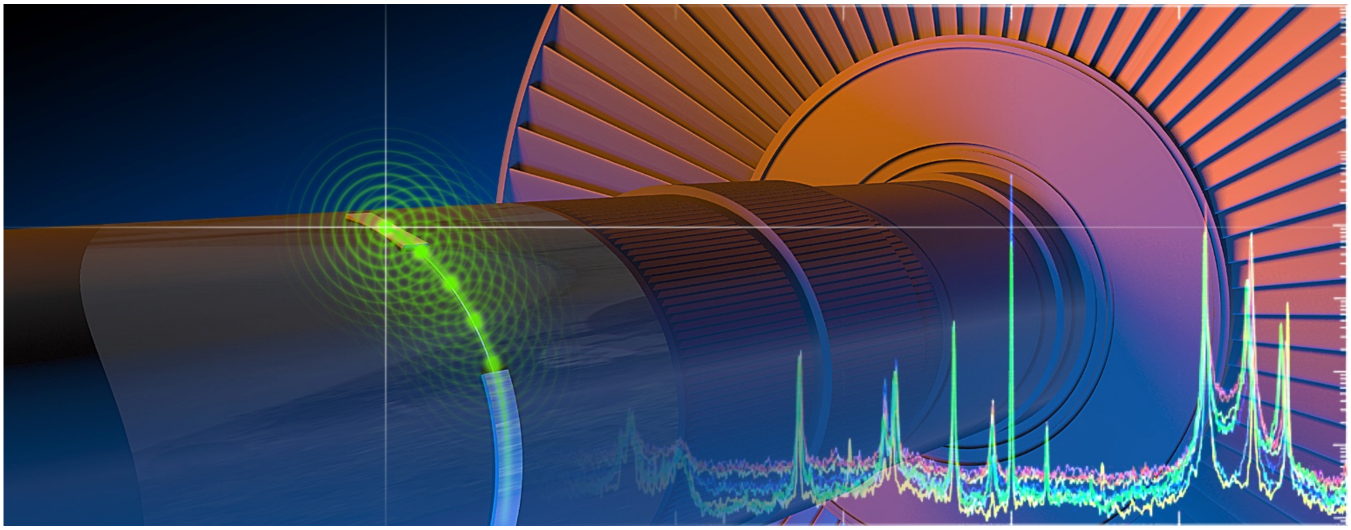
To expand EPRI technical staff’s knowledge of VVER reactors, the Nuclear Sector in 2016 convened seminars in Palo Alto and Charlotte. “We brought in VVER specialists to explain the differences between VVER and western reactors with respect to design, materials, chemistry, and operations. Our technical staff are incorporating this knowledge into their research programs so that we will be more conscious of the specific needs of our members in Hungary, the Czech Republic, and Slovakia,” said Sursock.

“With EPRI membership, Paks gains access to products, technology, and best practices to help them successfully navigate life extension and enhance equipment reliability,” said Vyskocil. “It provides the Paks staff with access to PWR operators around the world and brings their expertise to bear on EPRI’s growing interest in VVER technology. EPRI’s entire global nuclear collaborative also benefits from a larger international engagement.”

Key EPRI Technical Experts

J.P. Sursock, Vaclav Vyskocil

A Real-Time Eye on Turbines



EPRI's Wireless Sensors Continuously Monitor Vibration to Help Prevent Failures

By Matthew Hirsch

One evening in September 2008, the control operator at American Electric Power's Donald C. Cook Nuclear Generating Station Unit 1 in Michigan recorded strong vibrations and felt severe rumbling. The operator shut down the reactor, quickly sending the turbine-generator from 1,800 revolutions per minute to a standstill. Three turbine blades dislodged from the rotor, and two blades fractured. This created a severe imbalance on the rotor, damaged a hydrogen seal in the main generator as well as other connected systems, and led to a small fire in the turbine building. Altogether, repairs and lost power output from the turbine failure and fire cost $468 million.

At the time of this event, there were very few commercial systems available for continuous monitoring of turbine shafts for torsional vibration, leaving many turbines unmonitored. These systems are now readily available. Spurred by a new nuclear industry insurance standard, EPRI engaged New Hampshire–based Suprock Technologies to develop a system that continuously measures how turbine shafts twist and shake while spinning at high speed. The system, successfully demonstrated at several power plants and now commercialized, provides real-time information to plant staff, enabling early detection of conditions that cause turbine blades and other rotor elements to fail.

Widespread deployment of torsional vibration sensing will also provide the power industry with some of the data needed to assist in determining the root cause of turbine-generator rotor cracking. Indeed, the cause of the Cook Unit 1 event in 2008 remains unknown. Unconfirmed possibilities include torsional vibration of the turbine shaft, a defect in turbine blade material, workmanship, and vibrations due to blade interaction with the steam flow.

"About 80 percent of power in the U.S. comes from a turbine driving a generator," said EPRI Project Manager Stephen Hesler. "Until now, there hasn't been a commercially available sensor for continuous monitoring that you could put on the turbine shaft to easily acquire and process vibration data."

From Periodic to Continuous Monitoring

When a single manufacturer designs all the components of a new turbine-generator—including the turbines, the generator, and the exciter—the supplier has the design data needed to assess shaft vibration and risk of cracking from fatigue. But because plant operators often procure replacement components from different vendors, the integrated rotor design data can be more difficult to obtain, and the risk increases for unexpected vibration. In this situation, plants can use sensors to test periodically for vibration as an early sign of component failure. But vibrating components can fatigue in a matter of hours—too quickly for this approach to be effective. Over the past 30 years, the industry has experienced several catastrophic failures similar to the one at Cook Unit 1 (see box at end of article).

Recent advances in sensor technology created an opportunity for plant operators to improve monitoring and analysis of turbine shaft vibrations. When Nuclear Electric Insurance Ltd. (a mutual insurance carrier for electric utilities) revised its standards in 2013, it provided plant operators with criteria to determine when it is appropriate to use available technology to test for torsional vibration on the turbine-generator shaft instead of relying on computer algorithms to analyze and predict susceptibility to such vibrations. Some manufacturing industries were using continuous monitoring sensors on rotating shafts in machine tools, but the power generation industry had not yet adopted the technology.

The EPRI-Suprock torsional monitoring system: The thin yellow strip on this turbine shaft is an epoxy-infused fabric that keeps electrical devices bonded in place when the shaft is spinning. Sensors and antennas are concealed under this strip.

That same year, EPRI contracted with Suprock Technologies to develop the concept for a small, sensitive, and energy-efficient sensor to perform reliably for unlimited operation on a turbine-generator. It uses transceivers that continuously measure strain and acceleration on the turbine shaft and wirelessly transmit data, stationary receivers that capture the data, and a computer to archive them.

During prototype development and field demonstration, three key improvements advanced the use of telemetry in power generation:

1. Use of Radio Frequency for Power and Data Transmission: Because turbine-generators stop producing power when the turbine shaft stops spinning, plant operators use every precaution to keep them running as long as possible—stopping them for critical maintenance only. For sensors used in periodic testing, batteries must be replaced about every three days. Adding energy storage to the sensors would result in more bulk for equipment already constrained by space. The solution is to reduce energy consumption. With the EPRI-Suprock system, stationary radio frequency transmitters located about one meter from the shaft send power to the rotating sensors. Consuming 50 milliwatts of energy, or less than half a percent of the energy used by a single LED lightbulb, the sensors stream data to stationary receivers.

2. One Device to Measure Strain and Acceleration: The conventional approach to wireless monitoring on a rotating shaft is to place sensors in locations specified to collect strain and acceleration data. Because the strain and acceleration sensors in the EPRI-Suprock system are so small, they can be installed just millimeters apart—in effect, the same location on a shaft. This results in significant savings in installation costs for the plant operator. “The technical advantages of the EPRI-Suprock system have lowered overall testing costs considerably compared to existing shaft-mounted sensor options,” said Chris Suprock, principal investigator of Suprock Technologies.

3. Epoxy and Fabric Attachment: While power generation engineers typically employ hardware to attach sensors, EPRI and Suprock decided to use an epoxy-infused Kevlar and carbon-fiber fabric for attaching the device to turbine shafts. With this adhesive, there is no need to wrap the fabric around the shaft's full circumference, saving installation time while reducing the system's size and weight. "People build airplanes out of epoxy and carbon fiber now," said Hesler. "It's a viable method for building structural elements." EPRI has demonstrated its ability to withstand operating temperatures of 150–250°F and sustain superior bond strength at the shaft's full speed, where centrifugal acceleration increases the weight of attached sensors by a factor of 6,000. Field testing has shown that the epoxy performs as well as conventional attachment methods.

Field Demonstrations

In spring 2015, EPRI and Suprock Technologies installed the first torsional monitoring system for field testing at Duke Energy's Marshall Steam Station. Researchers found that it provided more detail than conventional sensors, enabling them to identify strong vibrations and their causes before turbine failures occur. After more than a year and a half of operation at the Marshall Steam Station, there have been no failures with the installed EPRI-Suprock system.

Later in 2015 at Salt River Project's Navajo Generating Station Unit 3, a side-by-side comparison with a conventional battery-powered torsional monitoring device highlighted two main advantages of the EPRI-Suprock system. First, Salt River Project was able to order all the parts of the EPRI-Suprock system and install them in three days. Second, the EPRI-Suprock system continues to collect a stream of data after operating more than a year while the other system ran out of power and stopped collecting data after three days. Changing batteries on the other system would require shutting down the plant for 36–48 hours.

In spring 2016, Salt River Project installed a version of the EPRI-Suprock system with the telemetry components repackaged in a more compact, field-ready enclosure and the user interface more than 100 feet away from the turbine. "Smaller equipment makes a speedy installation possible," said Colsen Jim, a senior mechanical engineer at Salt River Project. "There are a lot more places on the shaft where you can install it."

Other Applications of Torsional Monitoring

Applications of the torsional monitoring device go beyond nuclear and fossil plant turbines to include any components with a rotating shaft, such as hydropower and combustion turbines. As with steam turbines, hydro turbines can be expensive to operate and maintain, and monitoring provides considerable savings potential. Hydropower turbines have little instrumentation, and the industry has limited understanding of turbine cracking. Insurance carriers are not creating a need as they have in the nuclear industry, but hydropower operators are motivated by the potential to enhance long-term system health.

In fall 2016, AEP installed the EPRI-Suprock system during its retrofit of Cook Unit 2's turbine-generator. In Unit 1, AEP used a torsional monitor from a different vendor that must be attached around the full circumference of the shaft. An off-the-shelf version wasn't available for Unit 2's larger shaft size, and the vendor could not prove that its product could withstand the centrifugal force on the shaft.

According to Greg Smith, lead project engineer at AEP, the utility supported the other vendor's attempts to produce a torsional vibration sensor for Unit 2, but a suitable product was never delivered. The EPRI-Suprock system's dynamic monitoring and communication system captured AEP's attention. "We were all-in when we realized that the design could withstand the centrifugal force," Smith said.

At the Cook plant, EPRI added multiple sets of transmitters and receivers so the system will continue operating even if one set fails.

Commercialization and Growing Importance of Monitoring

In three years, the EPRI-Suprock system has advanced from concept to prototype to demonstration to commercialization, making it one of the fastest development efforts in which Hesler has been involved at EPRI. Suprock Technologies will manufacture the commercial product—the Turbine Dynamics Monitoring System—and sell the equipment and installation service to plant operators.

Torsional monitoring at conventional plants will increase in importance as the grid responds to the change in mix of generation assets. For example, the increase in wind and solar generation is expected to produce more frequency excursions on the grid. These events can increase the torsional response of turbine-generator shafts and result in more fatigue damage.

Hesler emphasizes that the power industry is still learning how to recognize the role of torsional vibration in turbine-generator reliability and that this system can help to fill this gap.

"Until a turbine-generator's torsional vibration characteristics are measured, there is risk of damaging vibrations that can occur without operator knowledge," said Hesler. "The EPRI-Suprock system can significantly reduce this risk."

Landmark Turbine Failures Caused by Torsional Vibration

In 2005, EPRI published a report on torsional vibrations and fatigue, including a review of major failures and their causes. Here are some examples.

Dresden Generating Station (Chicago, Illinois metropolitan area)
In 2004, inspectors discovered a 13-inch crack in the generator shaft of Dresden Generating Station's Unit 3 turbine-generator and a slightly smaller crack at the same location of Unit 2. Both units experienced a steady increase in lateral vibration at the generator bearings after their rated capacity was increased from 810 to 912 megawatts in 2002. The root cause of the shaft cracks: intermittent oscillating torsional loads on the generator rotor.

South Texas Project (Houston, Texas metropolitan area)
In 2002, shortly after the 1,300-megawatt South Texas Project Electric Generating Station restarted following a refueling outage, numerous cracked blades were discovered in a low-power turbine. The following year, the unit was restarted and then shut down again due to excessive torsional vibration that caused another set of cracked blades in the low-power turbines.

Maanshan Nuclear Power Plant (South Bay, Taiwan)
In 1985, a 952-megawatt turbine-generator unit at the Maanshan Nuclear Power Plant tripped from high load with no warning. The lateral vibration at the bearings increased, a fire occurred under the generator, and the machine stopped abruptly. Eight turbine blades had fractured, and 12 blades had cracked attachment fingers. Unbalance forces that arose from the blade fractures may have been the cause of further fracturing on a turbine shaft. The turbine-generator also experienced fire damage and abrasion. Testing confirmed that the cause of the blade fractures was shaft torsional vibration resulting from large grid frequency excursions.

Key EPRI Technical Experts

Steve Hesler

First Person—Nuclear Power and the Climate Equation

The Story in Brief

"The climate math simply does not work without nuclear energy," says Marv Fertel, president and chief executive officer of the Nuclear Energy Institute. Fertel speaks with *EPRI Journal* about insights from his 35-year career in the nuclear industry, nuclear power's future role in U.S. and global electric power, the importance of nuclear in decarbonization, and critical research and development (R&D) needs.

EJ: You've worked in the nuclear industry for more than three decades. What are the top three insights from your career that can inform industry priorities for the next decade?

Marv Fertel

Fertel: First, beyond the technologies, the strength of our industry is the women and men who operate and support the operations of our facilities. We have the best operating plants in the world and the strongest, most effective safety culture. This includes the broad nuclear community—academia, operating companies, suppliers, regulators, and others. We need to ensure current and future pipelines for our people and recognize that the millennial generation is motivated by factors—such as varied career paths and digital technology interactions—that differ from the key motivators of my generation or even those of the Gen X-ers. Our industry is already committed to the workforce as a priority, and that's good.

My second insight: Let's focus on getting more prepared for the future, which I believe is very good. Our nation and the world will need more clean electricity, potable water, and other services and products that nuclear technologies can provide. We need to develop the best business models for continued deployment of large advanced light water reactors, small modular reactors, and advanced Generation IV reactors. New business models should include appropriate and defensible financing mechanisms. We will also need efficient, effective, appropriate regulatory licensing processes, and support from policymakers, opinion leaders, energy and environmental thought leaders, and business leaders.

"Any nation committed to a credible carbon emissions reduction program cannot succeed without nuclear energy."

My third insight is that this industry has always made a significant commitment to necessary research and development, whether for new technologies or for addressing aging and other challenges with existing technologies. We also invest heavily and appropriately in developing our people and providing them with the support they need to perform at exceptional levels. We work cooperatively and effectively to address significant topics such as the Fukushima accident and other technical and regulatory issues. Where we may need more resource commitment is in our public advocacy programs. This is an area that NEI has been working on and that my successor will take to a new and more effective level. I encourage industry leaders to advance advocacy campaigns that achieve the policy outcomes to support our existing plants and provide the foundation for the future.

EJ: What role do you envision nuclear power playing in the U.S. generation portfolio and power system over the next decade? What's your vision for its global role?

Fertel: Nuclear energy facilities will remain the key component of our nation's low-carbon electricity portfolio for many years to come—the next decade at a bare minimum. Nuclear power plants operating in 30 states generate more than 60% of the carbon-free electricity supply in the United States, and the overwhelming majority of them hold renewed operating licenses from the U.S. Nuclear Regulatory Commission that will allow them to continue generating electricity beyond 2030. Globally, more than 60 reactors are under construction. Global interest in nuclear energy will continue to grow as nations strive to expand their economies, provide electricity to increasing populations—including the more than one billion people who don't currently have electricity—and do this with a commitment to reduce greenhouse gas emissions. Any nation committed to a credible carbon emissions reduction program cannot succeed without nuclear energy.

EJ: Dominion Virginia Power recently announced its intent for a second nuclear license renewal, and other U.S. nuclear operators are likely to follow with similar announcements. Why is extended nuclear operations beyond 60 years important for the U.S. power sector?

Fertel: Yes, others will follow. Both Surry and Peach Bottom are the lead plants for obtaining a second license renewal to operate up to 80 years. Based on the experience of the 83 reactors that already have achieved license renewal to operate to 60 years, the U.S. Nuclear Regulatory Commission made the decision in 2015 that no change to its existing regulations was necessary to renew the licenses to 80 years. We expect that the licensing process can be achieved in 18 months.

Moving forward with second license renewals for up to an additional 20 years is important because by 2040, half of the nation's nuclear power plants will have operated for 60 years. By 2030, the United States could experience electricity shortages if a significant number of nuclear plants are retired in a short period. Also, meeting our greenhouse gas reduction targets without the continued operation of a large portion of the current fleet will be impossible. EPRI and the U.S. Department of Energy have conducted scientific research to understand the technical issues associated with long-term operation of nuclear power plants. This research shows that there are no generic technical issues that would prevent a well-maintained nuclear plant from operating safely during the second license renewal period.

> "We need to ensure current and future pipelines for our people and recognize that the millennial generation is motivated by factors—such as varied career paths and digital technology interactions—that differ from the key motivators of my generation or even those of the Gen X-ers."

EJ: What role do you expect small modular reactors to play in the nuclear industry in the United States and globally over the next decade?

Fertel: Given the very low electricity demand growth in the United States, increasing penetration of intermittent renewable technologies, and growing global demand for clean energy generation sources, small modular light water reactors have become a very important complement to our larger advanced light water reactors. They are designed to capitalize on the benefits of modular construction, ease of transportation, and reduced financing, making them a good option for areas where large reactors are not needed. Thinking globally, because of their small size—300 megawatts or less compared to a typical nuclear plant of 1,000 megawatts—they can generate electricity in remote locations where there is little or no access to the main power grid or provide process heat to industrial applications. Progress is being made to deploy the first wave of small modular reactors, which are anticipated to begin operating around 2025. These reactors will benefit from the industry's history of incremental safety improvements through design. The short-term challenge is to solidify and expand the public-private partnerships that can accelerate their commercial development and to establish a Nuclear Regulatory Commission licensing regime that is appropriate to the safety enhancements that these new reactors will boast.

EJ: How can nuclear plants cut operating costs to make them more competitive without jeopardizing safety?

Fertel: Last year, the industry—working with EPRI, Institute of Nuclear Power Operations, NEI, and organized labor—initiated the program we call Delivering the Nuclear Promise. This is an industrywide, multi-year initiative to identify efficiency measures and adopt best practices and technology to improve operations, reduce electric generating costs, and help prevent premature reactor closures. Industry teams led by chief nuclear officers are identifying improvements to programs such as work management, security, and engineering to achieve efficiencies while either maintaining or enhancing our commitment to excellence in safety. To date, this initiative has yielded about 30 separate "efficiency bulletins" sent to plant sites for implementation. For example, a recent bulletin focuses on timely, cost-effective processing of all workers by standardizing key training modules across the nuclear fleet. This eliminates the need for repeat trainings when workers move from one site to another, saving the industry as much as $30 million to $60 million annually.

> "By 2030, the United States could experience electricity shortages if a significant number of nuclear plants are retired in a short period."

EJ: Why is nuclear generation needed in addition to wind and solar to achieve domestic and international climate goals? What unique attributes and services does it provide?

Fertel: The climate math simply does not work without nuclear energy. More specifically, without the nuclear energy facilities that operate in 30 states, carbon emissions from the U.S. electric sector would be approximately 25% higher. Meanwhile, the U.S. Energy Information Administration reports that worldwide emissions of carbon dioxide will roughly double between 1990 and 2040. Renewables, hydropower, shifting from coal to gas generation, and existing and new nuclear are all essential to meet the nation's goal of an 80% reduction in carbon by 2050. Because nuclear energy is the only unlimited deployable baseload electricity source that doesn't emit greenhouse gases, continued operations of existing nuclear facilities and construction of new plants are essential to achieve that target. Our nuclear plants provide electricity 24/7 safely and reliably, with price stability, electric grid support in the form of voltage support and frequency response, and carbon reduction and compliance for all other criteria air pollutants.

EJ: What do you see as the most effective policy pathways in the United States to expand nuclear's role in decarbonization?

Fertel: There is no single pathway. Many states should move quickly to address policy challenges before more nuclear plants shut down prematurely, as we saw recently with the adoption of a Clean Energy Standard in New York to help upstate nuclear plants continue operations. States can evolve their renewable portfolio standards into clean energy and carbon-free standards that rely on nuclear and hydropower in addition to other non-emitting sources, making them more economical for customers and more effective for carbon reduction. We need the Federal Energy Regulatory Commission (FERC) and the regional transmission organizations to demonstrate a greater sense of urgency and consider all the factors that constitute a robust, resilient, sustainable market. For markets to function effectively long term and yield the optimum mix of electric generating resources, practices that distort price signals or suppress energy market prices must be corrected. We also need FERC to complete the work on price formation that started about two years ago and has languished for no apparent reason. Congress can exercise more oversight over FERC to achieve greater transparency in its deliberations and ensure some semblance of discipline with respect to rulemaking schedules. The Executive Branch can do more as well via executive orders and presidential memoranda instructing federal agencies on procurement of carbon-free energy.

> "Without the nuclear energy facilities that operate in 30 states, carbon emissions from the U.S. electric sector would be approximately 25% higher."

EJ: What R&D is needed to support safe, reliable nuclear power globally?

Fertel: R&D has been and will continue to be a cornerstone of nuclear power development. In addition, it is essential to demonstrate and commercialize new technologies. One important R&D area is ongoing work to support extension of operating licenses from 60 to 80 years, with a focus on material aging issues. Also significant is research done in collaboration with industry, EPRI, and the Department of Energy on extended storage of high-burnup used fuel. Another key area is enhanced accident tolerant fuel designs that could increase the time available to mitigate a loss-of-coolant accident before significant reactor damage occurs. These designs could also eliminate the potential for hydrogen generation resulting from oxidation of the zirconium cladding of fuel rods. I would also like to highlight the Generation IV reactors. There are a number of private companies and national laboratories doing research in support of new designs, including pebble bed high-temperature gas reactors, liquid metal fast reactors, and molten salt reactors. Experimental work is ongoing to analyze material properties and design and qualify fuel for future non-light water reactors. Finally, important research occurs on a daily basis at nuclear plants to identify new, innovative tools and techniques that support more efficient operations. These and other efforts by industry, EPRI, and the Department of Energy are essential to the continued viability and advancement of nuclear power generation.

In Development

EPRI Explores Air Quality Impacts of Fossil Distributed Generation

By Garrett Hering

At the dawn of the Electric Age in the late 1800s, small, local fossil-powered generators provided power to businesses and homes. In the early 1900s, large plants replaced these distributed generation (DG) resources, and most of the plants (and their emissions) were moved away from population centers.

In the 21st century, distributed generation—fossil and renewable—is making a comeback. Until now, the air quality impacts of these modern fossil DG facilities have not been examined rigorously.

In 2016, EPRI began releasing the results of a three-year research project to shed light on fossil DG deployment and its air quality impacts. Researchers developed atmospheric models to simulate how fossil DG air pollutants affect local and regional air quality. They also used EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model to explore how DG penetration scenarios based on other economic models would affect the overall generation portfolio.

"There is a concern that rising levels of fossil distributed generation will deteriorate air quality. Our research explores local and regional air pollution from these facilities to inform stakeholders and to assist in the development of air quality management plans," said EPRI Principal Technical Leader Eladio Knipping.

Fossil DG Inventory

Principal Technical Leader Stephanie Shaw and Knipping discovered a lack of information on fossil DG capacity in the United States. They consolidated data from national, state, and local databases to create the first comprehensive inventory of U.S. fossil DG, defined as behind-the-meter generators with a capacity of less than 25 megawatts.

The total U.S. capacity in 2014 was about 14,500 megawatts. Three categories account for all but about 200 megawatts:

- Internal combustion engines (primarily diesel-fueled backup generators): 6,300 megawatts
- Combustion and steam turbines (mostly natural gas–fueled combined heat and power units): 7,500 megawatts
- Combined-cycle plants: 500 megawatts

Combined heat and power systems, usually powered by cleaner burning natural gas, produce relatively low emissions. Diesel-powered backup generators produce higher emissions but are used primarily during emergencies and planned outages.

Modeling Air Quality

In a separate 2016 study, EPRI and the Houston Advanced Research Center developed a model to simulate local air quality effects of fossil DG units in Houston, Texas. The team focused on early afternoon of a typical summer day.

"The goal was to assess the immediate near-source impacts of different types of distributed generators in an urban environment," said Shaw, who leads the fossil DG air quality research.

Researchers examined three hypothetical generators commonly used, each with two operational scenarios: a 25-megawatt natural gas turbine operating in simple-cycle or combined heat and power mode; a 25-megawatt natural gas turbine in a cold startup with moderate or high formaldehyde emissions; and a datacenter with 10 megawatts of either diesel- or natural gas–fueled backup power. Simulations of formaldehyde, ozone, particulate matter, and nitrogen dioxide emissions assumed a single generation unit operating for two hours.

Only one of the six scenarios generated significant air pollution: the diesel backup generator for the datacenter boosted ambient nitrogen-dioxide emissions by 10–50 billion parts per million by volume (ppbv) within 2 kilometers downwind of the source. Just one scenario modeled for natural gas turbines increased emissions by more than 1 ppbv for any gases other than ozone. This indicates that many fossil DG units can be quite clean on their own.

However, substantial increases in air pollution can result when individual units are aggregated regionally. In regional modeling of the continental United States, researchers developed fossil DG deployment scenarios for 2050 ranging from 14 to 40 gigawatts, with the Pacific Coast and Northwest showing the most economic potential. EPRI then modeled the potential air quality impacts of these scenarios.

Preliminary results, to be published in a peer-reviewed manuscript in late 2016, indicate measureable impacts in the vicinity and downwind of the sources—for example, an increase by several ppbv of ozone. “Such impacts can affect efforts to attain air quality standards,” said Knipping.

“We found that within a few kilometers of natural gas units, single-source impacts are usually very small,” Knipping said. “But there can be significant regional increases in emissions and concentrations of ozone and particulate matter when there is broad market adoption. The size of those increases depends on the type of technology, application, and location.”

Key EPRI Technical Experts

Eladio Knipping, Stephanie Shaw

In the Field

Thinking Big in New York

EPRI, NYPA, and Central Hudson Gas & Electric Collaborate to Contribute In-the-Field Lessons to the Empire State's Energy Transformation

By Chris Warren

EPRI, the New York Power Authority (NYPA), and Central Hudson Gas & Electric are collaborating on research examining how best to integrate distributed energy resources (DER) into the grid.

The research is one of EPRI's 20 Integrated Grid Pilots worldwide and involves a 117-kilowatt photovoltaic (PV) system atop the Sojourner Truth Library at the State University of New York-New Paltz as well as a 101-kilowatt PV array and 200 kilowatt-hour battery energy storage system at the school's Elting Gymnasium. The projects will be connected to a distribution feeder operated by Central Hudson Gas & Electric.

EPRI will conduct several analyses:

- **Distribution feeder impacts**: EPRI will analyze the effects of the solar PV systems on grid voltage and power quality and determine how much PV can be installed on the feeder without requiring grid upgrades to maintain reliability.
- **Optimizing solar and storage**: EPRI will determine the settings for smart inverters and energy storage that maximize the benefits of distributed solar and minimize negative impacts. For example, smart inverters can help control voltage fluctuations common with PV generation, and energy storage can provide increased output during peak load.
- **Economic analysis**: EPRI will look at the costs and economic benefits resulting from integration of various types and levels of DER at SUNY-New Paltz. For example, if Central Hudson Gas & Electric has to install circuit breakers, sensors, and capacitors to accommodate new DER, how do the costs of the new equipment compare with the benefits provided by the DER in terms of increased capacity and grid resiliency?
- **Microgrid analysis**: EPRI will evaluate the technical feasibility and financial viability of using solar and batteries to establish a microgrid at the SUNY-New Paltz campus. The investigation will examine microgrid design and required size of solar PV and energy storage. Interest in microgrids to enhance grid resiliency and reliability has grown following the extensive power outages in New York as a result of Superstorm Sandy.

The research will inform New York's Reforming the Energy Vision (REV), launched in 2014 to create a more resilient, affordable, and low-carbon grid, with a target of generating 50% of electricity from renewable sources by 2030. DER is expected to serve an integral function.

While NYPA is a generation and transmission utility and doesn't connect DER to its high-voltage grid, it is also a quasi-governmental agency committed to advancing the knowledge that will make Reforming the Energy Vision a success. "We want to advance renewables, lower the costs and barriers to DER interconnection, and make sure the grid remains as reliable as possible," said Charles Hermann, a senior engineer at NYPA.

The New York project plans to communicate lessons and insights to the many stakeholders involved, including the state's Public Service Commission, policymakers, utilities, nongovernmental organizations, and the public.

By providing data generated from solar and battery systems in real-world operating conditions on distribution feeders, the analyses will inform distribution company decisions about where to site DER.

“Some locations are prime for DER as a result of grid design and a lack of capacity,” said Becky Wingenroth, EPRI principal technical leader. “This study will help utilities better understand grid impacts of DER siting, additional equipment needed to maintain grid reliability, and the costs of these technologies.”

“Utilities are responsible for the delivery of reliable service to all customers,” said Wingenroth. “So while they want to encourage DER, they are still accountable to make sure it doesn’t negatively impact service to other customers from both a reliability and safety perspective.”

Key EPRI Technical Experts

Becky Wingenroth

Shaping the Future

Hydrogen Revisited

EPRI, Other Industry Stakeholders Examine Hydrogen's Potential to Support Grid and Power Plant Operators

By Brent Barker

Grand visions of hydrogen for power generation come and go. A turn-of-the-century surge was epitomized by Jeremy Rifkin's 2002 best seller, *The Hydrogen Economy*, which highlighted hydrogen's revolutionary potential, without a clear-eyed view of the obstacles. Momentum in the 2000s met strong headwinds with the Great Recession and subsequent budget battles.

The latest resurgence of interest in hydrogen arrives with a more practical approach to its role in energy's future.

"Researchers are taking another look at hydrogen," said Brittany Westlake, energy scientist in EPRI's Energy Storage and Distributed Generation Program. "The U.S. Department of Energy's National Laboratories are assessing hydrogen on the scale of the energy system as a whole, primarily as a storage vehicle to help balance the grid. There is traction in Europe, especially as storage to complement renewables, and Asian automakers are investing in the early stages of commercialization of fuel cell electric vehicles."

Why Hydrogen?

The vision and potential remain appealing. Hydrogen is the most abundant element in the universe, but it doesn't exist naturally on earth as a free-form gas. It is bound with oxygen as water and with carbon as hydrocarbons. The practical issues remain: how to produce or extract it economically and safely, store it, distribute it, and use it. Environmental benefit is hydrogen's great allure: when either burned or oxidized through a fuel cell, the only emission is water.

Two pathways for producing hydrogen gas are reacting steam with natural gas (or gasified coal) and electrolysis (splitting H_2O, or water, with electricity). The first path is well-established in the chemical industry. The second path is about 1.5 times more expensive and is used sparingly. Compression of hydrogen gas to liquid form requires cryogenic processes (at -253°C). Because pure hydrogen embrittles metal, storage tanks are made of composites.

A driving force in the renewed interest in hydrogen is its scalability for bulk storage. Current battery technologies don't lend themselves to bulk storage as do pumped hydroelectric storage or compressed air energy storage, but both of these are capital-intensive. Hydrogen, stored in volume, offers a third alternative for bulk storage.

On a smaller scale, hydrogen storage could smooth the variability of wind and solar generation, using the excess electricity to generate hydrogen. "The same way we refine millions of gallons of gasoline a day, we could potentially produce millions of kilograms of hydrogen from renewable generation," said Westlake.

Also driving hydrogen research is its potential for co-production with fossil or nuclear generation. "Underutilized generation assets could produce hydrogen in off-peak hours, lifting capacity utilization of existing equipment," said Westlake.

Nuclear power plants have historically operated as baseload units as a result of their low fuel costs. With increasing grid variability, some nuclear operators are faced with flexible plant operations. They are interested in studying the feasibility of using electricity generated during periods of low demand to produce hydrogen and minimize cycling.

Prospects in Europe

A recent EPRI report assesses hydrogen's potential in Europe, finding that established, traditional supply chains and surplus industrial hydrogen "could be a key source during the transition to a hydrogen economy." Current production is nearly 7 million tons per year, with more than 99% used for petroleum refining and ammonia production.

With respect to hydrogen use in transportation, the consensus is that it will require sustained, significant R&D investment to improve performance and to reduce the cost of fuel cells. Establishing a fueling infrastructure will be formidable, with only about 100 hydrogen fueling stations in the European Union.

"The outlook for green hydrogen [hydrogen coupled with renewables] in Europe remains highly uncertain," said the report. "With the right conditions in place, green hydrogen could account for 15% of Europe's hydrogen demand by 2030, up from less than 1% today."

Fuel Cell Vehicles in the United States

Asian automakers—notably Toyota and Hyundai—are making a concerted effort to create a global pathway for fuel cell vehicles. Toyota introduced the Mirai in the California market in 2015. It sells for about $65,000, and as an inducement Toyota offers an eight-year/100,000-mile warranty, along with free fuel for three years.

Toyota Mirai fuel cell vehicle

The U.S. Department of Energy estimates that about 300 fuel cell vehicles have been sold in the United States, with 31 public hydrogen fueling stations primarily clustered in the San Francisco Bay Area and Los Angeles.

EPRI's Hydrogen Research

EPRI is pursuing several projects related to hydrogen storage and distributed generation, with its researchers assessing the prospects of polymer electrolyte membrane fuel cells and fuel cell electric vehicles. EPRI's Generation and Nuclear sectors are exploring how hydrogen production and co-production could increase the operational flexibility of new and existing power plants.

"We see great potential for hydrogen, especially as a storage medium supporting renewable generation, and through co-production increasing the operating capacity of fossil plants," said Westlake. "As a bulk storage option, hydrogen could contribute to system flexibility and grid stability. This is one of the reasons utility members have shown growing interest in recent years."

But Westlake cautions that many technical, economic, logistical, and marketing obstacles remain. "We've learned not to promise the moon. Nevertheless, hydrogen has a unique potential, and the U.S. Department of Energy recognizes that this will be a long-term trajectory well worth the R&D investment."

Key EPRI Technical Experts

Brittany Westlake

Innovation

Illuminating the Black Box

EPRI, National Academy of Sciences Provide Greater Scientific Scrutiny of "Social Cost of Carbon" Analyses

By Brent Barker

Imagine trying to estimate the monetary damage of one additional ton of carbon dioxide (CO_2) emitted into the atmosphere in the year 2020, 2030, or 2040. The modeling must be global, look hundreds of years into the future, and account for damages that encompass potential effects on health, agriculture, forestry, sea level rise, extreme weather, water resources, energy consumption, and human migration. It would be necessary to build and run models backed by comprehensive, sophisticated thinking. As impossible as this endeavor might seem, it describes models addressing the Social Cost of Carbon (SCC), which is becoming more integral to development of environmental regulations. To date, more than 60 federal and state rulemakings applied SCC modeling to estimate the costs and benefits of reducing CO_2 emissions.

Despite the widespread use of SCC numbers, the models behind them remain for most people a black box. Most of the nation's scientists, regulators, and policymakers do not know how they are constructed, how they work, or how they differ. In 2015, the National Academy of Sciences (NAS) established a committee to evaluate SCC modeling approaches. Early in 2017, NAS plans to publish a major report with recommendations for improvements, and to reflect certain scientific guidance which has, to date, been lacking.

Origins of the Social Cost of Carbon

How did the SCC emerge? EPRI Technical Executive Steve Rose was there at the beginning. "In 2007, the Ninth U.S. Circuit Court ruled in an environmental lawsuit that the U.S. Department of Transportation (DOT) was arbitrary and capricious in assuming a value of zero for the benefits of reducing CO_2 in its passenger vehicle efficiency standards," said Rose, who at the time was at the U.S. Environmental Protection Agency (EPA) and the only federal employee working on SCC modeling. "The government had to come up with numbers, and three agencies—DOT, EPA, and the U.S. Department of Energy—began working on the problem independently." Rose moved to EPRI in 2008.

In 2010, a new Interagency Group produced the first official U.S. government SCC numbers, which were revised upward by 50–100% in 2013. Since then, minor revisions also used the 2010 methodology. For example, current estimates used in rulemakings value a CO_2 reduction today of one metric ton at $36. Alternative values range from $11 to $105 per metric ton, depending on factors such as discount rates. Expected CO_2 reductions in subsequent years are assigned even higher values.

"The revisions garnered a lot of attention in policy circles, including Congress," said Rose. "Congressional hearings ensued. The White House Office of Management and Budget requested public comments, and this led to a request to the National Academy of Sciences to establish the SCC Committee in 2015." Rose is one of its 13 members.

Three Models, Three Approaches

To calculate the SCC numbers, the Interagency Group integrated results from three models—FUND, PAGE, and DICE—that use distinct analytical approaches to climate change–related damages.

Research by Rose and other EPRI researchers has yielded important insights regarding the three models. With FUND, the major source of damage comes from cooling loads in the developing world as global temperatures rise, particularly air conditioning in China. With PAGE, the greatest damages initially emerge in the developed world, particularly non-economic damages associated with effects such as those on human health and ecosystems. DICE, on the other hand, organizes damage into only two categories—sea level rise and "other."

"DICE covers some of the same types of damage as the other models, but unlike the others they are not explicitly separated into categories," said Rose. "This makes them less transparent and hard to interpret and evaluate."

All three models isolate sea level rise damages providing one point of comparison. "But they differ dramatically in how they approach it," said Rose. "FUND estimates almost no net sea level damages because it assumes that nations mitigate the risk with adaptation measures such as sea wall construction."

The three models come from the academic world. "A handful of prominent researchers at universities such as Yale and Cambridge synthesized all things climate, from emissions to projected temperature responses to induced damages," said Rose. "It is a substantial challenge to build a model that simulates all the world's physical and economic systems for 300 years into the future. You can imagine the uncertainty that somehow needs to be considered."

EPRI's Role

Rose serves on the NAS committee for several reasons—his pioneering SCC work while at EPA, his standing among specialists and leaders in modeling, and his more recent EPRI work dissecting the SCC models and evaluating how they operate.

"To date, EPRI has been the only organization to bore down into each of the models to examine and directly compare their components," said Rose. "Others have looked at the models as a whole, added features, or varied parameters. Based on our work, we brought a fine-grained understanding of the models' inner workings to the NAS committee to inform its thinking. For instance, our insights regarding the differences in the climate system modeling of the three models—and their implications for projected temperatures—were key inputs into the NAS Phase 1 report that came out in 2016. Our insights regarding socioeconomic projections and the modeling of damages are also proving valuable to the committee."

Beyond the committee, Rose has taken the message about the need for greater understanding and scientific engagement on the road. "I've given more than 25 presentations to stakeholders of all types, including EPRI utility members, trade associations, government agencies, policymakers, environmental groups, academics, and climate scientists. They are all very appreciative of the work, objectivity, and novel insights. EPRI's role is to contribute to the SCC scientific and technical knowledge for more informed discussion and decisions."

Key EPRI Technical Experts

Steve Rose

R&D Quick Hits

The Value of Renewables?

It's Complicated.

What's the value of wind and solar generation?

The answer: It depends on many factors—in particular, installed renewable capacity, variability of output over time and across regions, operational flexibility of fossil and nuclear power plants, regional electricity trade, and energy storage. This conclusion comes from a novel modeling framework developed by EPRI, which was applied to evaluate solar and wind deployment scenarios in California and Texas. The framework can be used to examine other renewable technologies and states.

Researchers analyzed long-term electric sector capacity planning along with various aspects of power market operations, providing a detailed look at the technical and economic impacts of renewable energy integration. A key observation: As renewable energy deployment increases, dispatchable generation may drop dramatically, even when capacity needs stay roughly the same. As a result, it may eventually be necessary to build two different power systems: one renewable system and another dispatchable system to provide backup when renewables cannot meet demand.

Other insights:

- The value of renewable energy decreases with increasing deployment across various technologies and geographic regions.
- Restrictions on transmission and regional coordination among grid operators increase renewable integration costs, pointing to the importance of effective market design and trade.
- Grid-connected energy storage is valuable for balancing supply and demand at high renewable penetration, but revenues diminish with increasing storage deployment.

R&D Quick Hits

Ready for Takeoff: The Bottom Line

EPRI Study: Electrification Can Save Detroit Airport Nearly $16 Million

If deployed at Detroit Metropolitan Wayne County Airport, electric ground support equipment and gate electrification technologies could yield about $16 million in lifetime savings and beneficial reductions in emissions relative to diesel-powered counterparts, according to EPRI research. This assumes that the airport charges the equipment during off-peak times at lower utility rates.

Photo courtesy of Charlatte America

Researchers identified potential to electrify 452 diesel- and gas-powered ground-service units, 19 diesel-powered heating/cooling units, and 38 diesel ground-power units for a 20,000-ton reduction in annual CO_2 emissions.

Other insights based on the study:

- **Airline-airport partnerships can facilitate cost sharing:** Electrification can reduce airlines' diesel and jet fuel costs while increasing the airport's electricity costs.
- **Use a phased approach:** Consider electrifying the most frequently used equipment with shorter payback times first, which would enable the use of cost savings to fund conversion of equipment with longer paybacks.
- **Familiarize employees:** Deploying charging stations for employees' personal plug-in electric vehicles can familiarize them with operation and benefits.

R&D Quick Hits

What Makes a Utility Customer Want an Electric Vehicle?

EPRI Examines How Utilities Can Help Guide Customers in Adopting EVs in Their Service Territories

EPRI in 2017 will survey residential utility customers to examine their stated preferences for electric vehicles (EVs) and identify how utilities may help support EV adoption in diverse service territories.

In a 2014 EPRI survey of more than 4,000 EV owners in 11 states and the District of Columbia, only 5% said that the utility played a role in their purchase decision, and just 4% changed their utility rates after the purchase to lower charging costs. Yet, respondents appeared to envision a significant role for utilities in the EV market:

- 30–40% said that they wanted more guidance on optimizing charging through utility programs, consumer information, and home energy audits.
- 40% saw a role for the utility in installing charging infrastructure at residences and public locations.
- 59% preferred that utilities, rather than third parties, run demand response programs.

To further explore utilities' potential roles, EPRI's 2017 survey will examine customer preferences for various attributes of EVs (such as charging requirements, financial terms, and payback) and EV programs and products (such as incentives, charging-friendly rate structures, commuting benefits, and education) in at least five utility service territories. EPRI anticipates that the results may be used in developing software to help utilities forecast EV adoption in their service territories as a result of specific options.

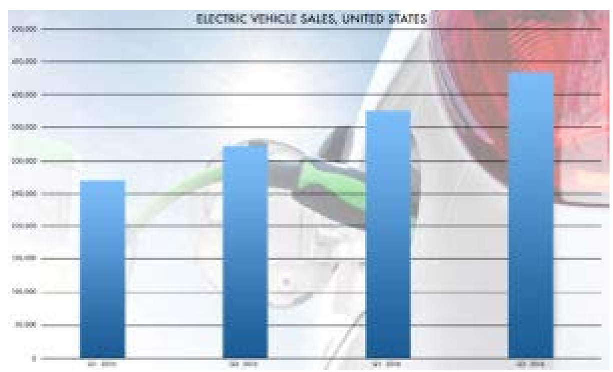


Chart based on EPRI analysis of vehicle registration data

"The EV market is poised for significant growth: While total EV sales in the U.S. since 2010 have been approximately 450,000, there were about 400,000 advance orders of the Tesla Model 3 in just two months this year," said EPRI Engineer/Scientist Jamie Dunckley. "This survey will help to equip utilities with the tools to serve, advance, and prepare for this growth."

R&D Quick Hits

Can Carbon Capture Make Coal Competitive with Natural Gas?

The Answer May Be 'Yes' in Some Cases, According to Retrofit Case Study in Alabama

Retrofitting some existing coal plants with partial post-combustion carbon capture may be competitive with newly constructed natural-gas–combined-cycle plants with respect to CO_2 emissions and economics. This insight comes from an EPRI analysis of a partial capture retrofit of the 773-megawatt coal-fired Plant Barry Unit 5 operated by Southern Company subsidiary Alabama Power.

Photo of Plant Barry carbon capture unit courtesy of Southern Company

The capture system used an amine-based solvent to absorb 45% of the CO_2 from the plant's flue gas, reducing total plant emissions to about 830 pounds per megawatt-hour. This is comparable to an average natural-gas–combined-cycle plant in the U.S. and well below the 1,400 pounds per megawatt-hour limit proposed by the U.S. Environmental Protection Agency for new coal plants.

To minimize the energy penalty, steam from the coal plant was used to regenerate the solvent, and heat from the carbon capture facility was used for feedwater heating.

This is the sixth in a series of EPRI carbon capture retrofit studies at operating coal plants across North America. For all retrofits, initial plant efficiency, air quality control equipment, availability of space for capture equipment, and other factors impacted the plant's levelized cost of electricity.*

*"A Summary of EPRI's Engineering and Economic Studies of Post Combustion Capture Retrofit Applied at Various North American Host Sites" from the Proceedings of the 11th Greenhouse Gas Control Technologies Conference.

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