EPRI | ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INNOVATION

LOOKING TO THE FUTURE, TODAY

PROSPECTUS 2019

EPRI'S TECHNOLOGY INNOVATION PROGRAM

Looking to the future, today

Driving thought leadership and advanced R&D, along with technology scouting and incubation, to maintain a full pipeline of new solutions for the future Integrated Energy Network.

"The Technology Innovation program provides a key part of the value we get from EPRI membership by maintaining a line of sight on potentially disruptive and longer-range industry developments. The program's focus on early-stage technologies and research gives us insights at a depth and breadth that would be difficult to get elsewhere, especially from a single source."

Chico Hunter, Manager of Research and Development, Salt River Project

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The Technology Innovation (TI) program is building the knowledge and technology foundation for the energy future.

EPRI's TI program surveys the energy landscape, explores technology frontiers, and leverages a global R&D network to inform strategic decision-making and accelerate electricity-based innovation.

Broadly, the TI program is charged with ensuring progress toward the future Integrated Energy Network (IEN), in which consumers are empowered, and clean energy and other lifeline services are available for all. Within EPRI, the TI program maintains a full pipeline of new solutions for application-oriented development by EPRI's Energy & Environment, Generation, Nuclear, and Power Delivery & Utilization R&D sectors.

Approach

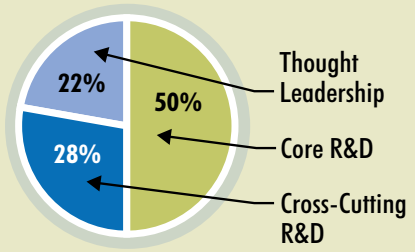
EPRI's member organizations fund the TI program as a strategic, industry-wide investment in producing, integrating, and using cleaner energy along the IEN pathway. Direction and oversight are provided by EPRI's **Research Advisory Committee**, which includes senior executives from U.S. and international utilities.

The TI R&D portfolio is developed in collaboration with EPRI's sectors and members serving on the **Technology Innovation Committee**. Experts throughout EPRI manage individual TI projects, leveraging the resources of technology developers, universities, national laboratories, and innovation ecosystems worldwide to enhance EPRI's capacity to transform promising concepts into real-world applications.

Focus Areas

In 2019, EPRI TI funding totals $32 million, allocated among the following program components:

- **Thought Leadership** includes strategic analysis, modeling, scouting, and incubation focused on emerging issues and high-value opportunities;
- **Core R&D** involves multi-year programs to advance early-stage innovations aligned with the IEN pathway and the technology roadmaps of EPRI's sectors; and
- **Cross-Cutting R&D** builds multidisciplinary knowledge and pushes technology frontiers in project sets and initiatives supporting a broad spectrum of utility applications.



2019 EPRI TI Budget Allocation

Thought Leadership fosters visionary thinking and focuses technology scouting to help lead the electric sector in new directions. Strategic planning, integrated modeling, and other analyses illuminate emerging issues and developments. Scouting involves a global search for—and robust assessment of—new and innovative concepts across all stages of the technology development cycle, with an eye toward business, policy, market, and other factors that will shape commercial potential. In 2019, the TI program is launching an innovation engine through EPRI's Incubatenergy® Network to connect entrepreneurs with utilities and accelerate high-impact demonstrations of new technologies and business ideas.

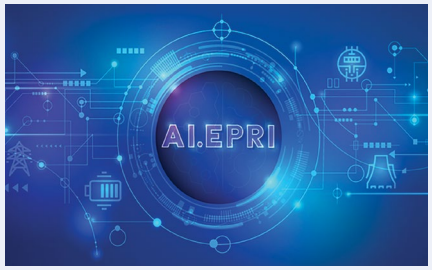
Core R&D and **Cross-Cutting R&D** advance promising early-stage innovations through exploratory research, proof-of-concept testing, validation studies, and pilot demonstrations. Core R&D continues in the areas of advanced renewable, nuclear, and fossil power; energy storage; grid modernization; and efficient electrification. Cross-cutting R&D addresses artificial intelligence, communications, cyber security, modeling and analysis, nondestructive evaluation, unmanned aerial systems, and the water-energy nexus. The remainder of this brochure highlights recent accomplishments and 2019 activities.

New Initiative: AI.EPRI

In 2019, EPRI is launching a strategic, multi-year initiative to enable and accelerate the development, application, and adoption of artificial intelligence (AI) across the electric sector. AI.EPRI objectives include:

- **Developing a collaborative R&D roadmap:** Based on input from utility executives and leading AI vendors, EPRI is defining R&D priorities and opportunities across power generation, delivery, and customer use.
- **Collecting and curating industry data:** To support R&D, EPRI experts and utility practitioners are collaborating to identify, collect, and provide secure access to the 10 highest-value data sets—the "EPRI10."
- **Educating the R&D and utility communities**: EPRI U workshops will educate industry professionals on AI technologies and applications, plus AI developers on power system physics and EPRI10 use cases.
- **Creating a hub for R&D and objective analysis**: Collaborative AI work will center on EPRI10 use cases, rigorous and independent technology assessments, and mitigation of security issues and risks.

Pilot AI.EPRI projects involve the mining and analysis of decades of utility data and imagery to support diverse AI use cases in asset operations, maintenance, and advanced metering infrastructure.



"Electric industry innovation is built on a foundation of vision, thought leadership, and collaboration. EPRI's Technology Innovation program provides all three – informed perspectives on the industry, insights on what we will need in the near and long terms, and knowledge and practical expertise from its staff and members."

Gary Brinkworth, Director of Enterprise Research & Technology Innovation, Tennessee Valley Authority

Trends, Signposts, and Trajectories

Building on recent scenario planning and roadmapping exercises involving leaders from industry, academia, and government, EPRI is identifying inflection points and milestones indicating the timing and other characteristics of anticipated transformations—such as mass-market adoption of electric vehicles (EV)—along the IEN pathway. Insights with major implications for individual companies and the broader electric sector will be applied to align EPRI's strategic technology and R&D trajectories with industry-driven R&D needs and opportunities.

Integrated Energy Network Planning (IEN-P)

Following on a 2018 white paper characterizing 10 critical integrated resource planning challenges that are emerging today and expected to grow in scope and complexity over time, EPRI published an initial set of case studies in early 2019 documenting how several U.S. utilities are responding. Learnings and insights span IEN-P applications such as assessing the ancillary services required for managing solar variability at high penetration levels, coordinating planning between generators and system operators, and engaging multi-level stakeholders in integrated planning processes. A second case study compendium is under development.

Shared Integrated Grid

Based on EPRI's leadership over the last 5 years, the Integrated Grid is emerging to position distributed energy resources (DER) as complements to conventional infrastructure in delivering reliable and affordable electricity. The Shared Integrated Grid takes the concept one step further, in which customer assets—traditional DER plus appliances, buildings, vehicles, and more—become flexible solutions that leverage internet-of-things (IoT) connectivity to enhance value for all. With EPRI support, Dartmouth University completed a book-length exploration of the myriad technical and business transformations that will be enabled by smart devices with distributed sensing, decision-making, and actuation capabilities. *eIoT: The Development of the Energy Internet of Things in Energy Infrastructure* was published in early 2019.

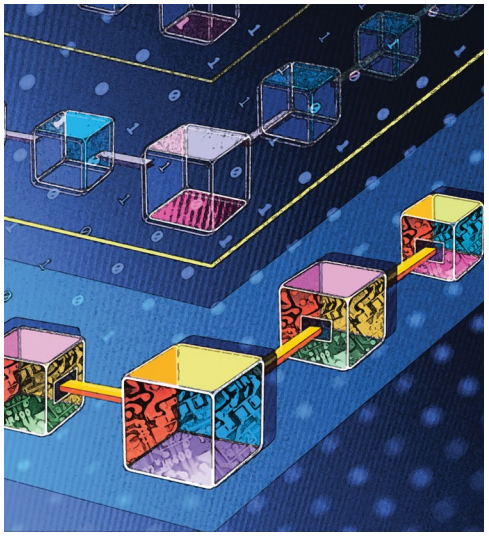
Blockchain and Utilities

The Utility Blockchain Interest Group (UBIG), organized by EPRI in 2018, provides a collaborative forum for accelerating industry learning—especially on high-value applications, beyond transactive energy—by bringing together utility representatives and domain experts from around the world to exchange information and develop best practices. UBIG participation features monthly webcasts with guest speakers addressing utility use cases and lessons learned, periodic in-person events, and access to a growing resource library and vendor community. A 2019 white paper details U.S. and European utility experiences, highlighting continued exploration, some proof-of-concept tests and pilots, and the need for technology maturation. For 2020, a global utility pilot database and market intelligence newsletter are planned.

Additional 2019 Priorities

Complementing the thought leadership activities highlighted above, EPRI also is monitoring developments and scouting innovations in the following areas:

- **Artificial Intelligence:** Framing EPRI-wide collaborative R&D objectives, identifying the highest-value industry data sets, and developing guidance on specific AI technologies and methods.
- **Hydrogen:** Monitoring hydrogen production and utilization demonstrations worldwide and exploring hydrogen synthesis pilots at U.S. nuclear power plants.
- **Mobility:** Evaluating how the rapid evolution of transportation technologies and methods will impact customer choice and future needs for electricity infrastructure.
- **Synthetic Biology:** Exploring and assessing the potential of powerful genetic engineering tools (including CRISPR) for enhancing biofuel production and other energy applications.



Thought Leadership Resources

The resources listed below, with sample topics, are designed to inform utility decision-makers at all levels and industry stakeholders of all kinds:

EPRI Unplugged: Podcasts featuring insights on power industry transformation and innovation from technical experts across EPRI:

- Shifting Energy Across Time and Space
- Hopping on a Hyperloop

Quick Insight Briefs: Executive-level briefings that analyze recent developments to address strategic questions facing the electric sector:

- Hydrogen's Role in Decarbonizing Heat
- Solar + Storage Offtake Agreements

Landscape Reports: Technology overviews summarizing performance characteristics, applications and markets, costs, readiness levels, R&D, and policy/regulation:

- Advanced Nuclear Reactor Technology
- Energy Storage Technology

Emerging Tech Reports: Technical reviews of the current status and strategic value of emerging technologies and ongoing R&D:

- Assessing Economic Impact of Geological Variability in Subsurface CO_2 Storage
- Renewable Ammonia Production and Use for the Transportation Sector

Scouting Updates: Technical briefings that frame technologies in terms of performance, applications, and milestones:

- DistribuTECH 2019: Innovations in Smart Homes and Street Lights
- Augmented and Mixed Reality for Space and Energy Applications

Infographics and Fact Sheets: Introductory briefings that make technical information accessible to a general audience:

- Extreme Cold Impacts on Power Systems
- Residential Battery Energy Storage

Incubatenergy® – EPRI's Innovation Engine

With funding from U.S. Department of Energy (DOE), EPRI engaged leading incubators and accelerators in the United States and Europe in creating a highly effective network of organizations having a proven record in the clean energy space and supporting a combined portfolio of more than 500 early-stage companies. In 2018, EPRI assumed leadership of the Incubatenergy® Network to build on its success in facilitating collaborations among startups, utilities, and other stakeholders—ranging from investment to involvement in validation, scale-up demonstration, and early deployment projects. In 2019, a series of Incubatenergy® Innovation Challenges is being launched to identify early-stage companies aligned with specific utility-defined interests and to accelerate their paths to demonstration. Additionally, EPRI is increasing international outreach to strengthen connections among incubators, accelerators, and energy providers in Europe and Asia.

TechPortal – EPRI's Innovation Database

EPRI's TechPortal, launched in 2018, is an online, curated, and fully searchable database of hundreds of innovative technologies and concepts of interest to electric utilities and the broader energy sector. The database is regularly updated based on scouting by experts across EPRI, including targeted outreach through Incubatenergy® and to universities, national labs, R&D institutes, and other high-technology industries. For each entry, the TechPortal includes baseline information as well as EPRI's assessment of technology readiness level, timeline to commercialization, and potential business impact—from minimal to evolutionary to revolutionary.

Startup Engagements

Fiber-Optic Transformer Monitoring
An experimental transformer manufactured by integrating a continuous optical fiber sensing system while wrapping its winding and core is undergoing laboratory validation by EPRI for low-cost, real-time temperature and strain monitoring. By 2020, this innovation—developed by Hyperion Sensors and cultivated through the Ameren Accelerator, an Incubatenergy® member—is expected to be ready for pilot demonstration in a transformer prototype with IoT-enabled capability for optimizing thermal loading and detecting incipient failure modes.

Phase-Change Cold Storage
Pilot testing of phase-change thermal energy storage technologies developed by Viking Cold Solutions and Axiom Exergy—startups supported by Incubatenergy® members Prospect Silicon Valley and Cleantech Open, respectively—is under way in collaboration with Salt River Project and the Tennessee Valley Authority. Load shifting and demand response capabilities are being documented for storage units and controllers deployed at commercial buildings with large refrigeration, cooler, and freezer systems.

2019 Incubatenergy® Innovation Challenge

Leveraging EPRI's international network of innovators and utility end users, the first Incubatenergy® Innovation Challenge began with the broadcast of a solicitation addressing five challenge areas:

- **Customer Experience:** Analytics, billing, communications, and new business ideas for providing personalized services.
- **Grid Optimization:** DER, storage, and interoperability solutions for controlling and shifting peaks on a localized basis.
- **Mobility and Electrification:** EV charging and grid integration infrastructure and new business models for accelerating transport electrification.
- **Operations and Maintenance (O&M) Efficiency:** AI, data analytics, and automated and predictive inspection for digitizing O&M tasks.
- **Wildcard:** Novel solutions and disruptive technologies addressing additional industry challenges and opportunities.

In May 2019, EPRI, American Electric Power (AEP), and other participating utilities hosted a one-week boot camp and pitch day leading to the selection of seven startups—from a total pool of 112 applicants—for an intensive, 10-week accelerator program. The chosen entrepreneurs are developing innovations in the areas of augmented reality, fleet electrification, fast charging, satellite imaging, transformer monitoring, automated inspection, and solar and battery adoption.

Representing an expansion of AEP's IlluminationLAB, the accelerator program focuses on establishing the technical feasibility and business viability of real-world utility use cases within the context of broader commercialization strategies. It also connects entrepreneurs with subject matter experts from EPRI and innovation leaders from AEP, Ameren, Consolidated Edison, Nebraska Public Power District, New York Power Authority, Salt River Project, Tokyo Electric Power Company, and Tennessee Valley Authority.

In September 2019, the program concludes with proof-of-concept demonstrations by startups, as well as proposals for future engagement with EPRI and participating utilities. Follow-on pilots and early deployments implemented across multiple service territories are expected to help in accelerating commercial scale-up of the most promising innovations.

"I'm thrilled to see EPRI commit to supporting the Incubatenergy® Network through its TI program and look forward to seeing the impact of greater collaboration between utilities and startups."

Hilary Flynn, Director of Incubation, National Grid

EPRI Core R&D pursues opportunities for improving the life-cycle productivity, reliability, and environmental performance of renewable energy technologies and for positioning utility-scale plants and distributed resources as flexible assets in the future IEN. Strategic R&D topics for 2019 include concentrating solar power (CSP) plant design and materials development, photovoltaic (PV) plant design and end-of-life management, offshore wind cabling and interconnection, and hydro asset valuation and modernization.

Success Story

Developed and demonstrated SABRE™, a ground-based thermal imaging and acoustic analysis system for inspecting the blades of all types of operational wind turbines. Now available through GE Renewable Energy, this innovation can detect and characterize structural anomalies and incipient problems before life-limiting blade damage occurs. Benefits include increased worker safety and avoided downtime during inspections, plus O&M cost reductions from proactive blade management.

2018-19 Highlights

High-Temperature CSP Technology Assessment and Materials Development

Informed by EPRI work documenting utility interests in the flexibility of CSP plants operating above 700°C rather than in a specific high-efficiency Gen 3 configuration, DOE awarded $62 million in 2018 to advance competing particle-, liquid-, and gas-phase heat transfer systems integrating thermal energy storage. Through 2020, an EPRI-led technical advisory committee is supporting R&D teams headed by Sandia National Laboratories, U.S. National Renewable Energy Laboratory (NREL), and Brayton Energy, providing design recommendations and operational testing parameters aligned with utility end-user requirements and grid management needs. In parallel, advanced materials and fabrication methods with potential to reduce the cost of critical CSP plant components by about 30% are being developed by EPRI, drawing on internal expertise with nickel-based alloys for ultrasupercritical coal applications. In follow-on work, DOE plans to choose one Gen 3 configuration for a 3-year, megawatt-scale demonstration and testing project.

Valuation of Pumped Hydro Energy Storage

Recent EPRI assessments of state- and utility-level integrated resource planning studies and operational and market data for pumped storage hydro (PSH) plants in different U.S. regions have illuminated factors influencing the current and potential future use of this bulk storage technology for load balancing and ancillary services. In 2019, EPRI is initiating a DOE-funded exploration of the value of pumped hydro in restructured regions and in vertically integrated service territories having evolving generation mixes, different PSH technology configurations and operating strategies, and diverse market structures.

PV Module End-of-Life Management

EPRI is leading strategic R&D to help PV plant owners understand and mitigate the challenges involved in managing a growing volume of damaged, degraded, and spent PV modules in the decades ahead. In 2018, EPRI completed an experimental module sampling and toxicity testing study and identified novel separation processes for automating recycling steps, increasing the amount and purity of recovered materials such as silver and solar-grade silicon, and minimizing residual volumes and risks. Follow-on applied R&D will improve the technical basis for toxicity testing through sampling and characterization of ex-service modules sourced from utility-owned PV projects. Pilot-scale repowering experiments to be conducted in 2019 at EPRI's SolarTAC test plot in Colorado will explore alternative strategies for replacing damaged or underperforming modules to extend the useful lifetime of existing PV projects. Collectively, these projects support a new EPRI initiative focused on informing end-of-life management approaches being created by utilities, regulators, policymakers, manufacturers, and other stakeholders for PV modules, wind turbine blades, and storage batteries.

EPRI-developed insights for managing spent and damanged modules and aging solar arrays are helping reduce the life-cycle risks of investing in PV assets.

Cross-Cutting R&D: Communications

To enable end-to-end integration of customer-sited renewables and other dispersed resources as grid assets, EPRI is accelerating the emergence of distributed energy resource management systems (DERMS) that will bridge the gap between utility operations and individual device-level controllers by providing aggregation, translation, simplification, and optimization functions. Building on 2018 progress, new customer service interactions, messages, and use cases needed for supporting flexible and dynamic DERMS implementations by utilities and third-party providers are being developed, tested, and communicated to standards committees. These data integration resources will associate customers and devices with utility and other programs and enable DERMS-based management of smart inverters and end-use controllers.

EPRI Core R&D is leading industry engagement in building a technical foundation for high-temperature Gen IV reactors offering a sound value proposition to utilities and other end users and available for post-2030 deployment to serve the future IEN. Strategic R&D topics for 2019 include materials and fabrication methods, safety assessment methods to support design and licensing, tri-structural isotropic (TRISO) fuel qualification, and owner-operator requirements for non-electric missions.

Success Story

Adapted process hazard analysis (PHA) methods developed by the chemicals industry for safety evaluation of Gen IV designs while providing a bridge toward the probabilistic risk assessment (PRA) required for regulatory approvals. Documented in a state-of-knowledge report and being piloted by a reactor developer, the PHA-to-PRA approach enables early hazard identification, event and fault tree development, risk analysis, and system engineering for increasing safety while minimizing cost, scheduling, and licensing impacts.

2018-19 Highlights

Powder Metallurgy Component Fabrication for Small Modular Reactors

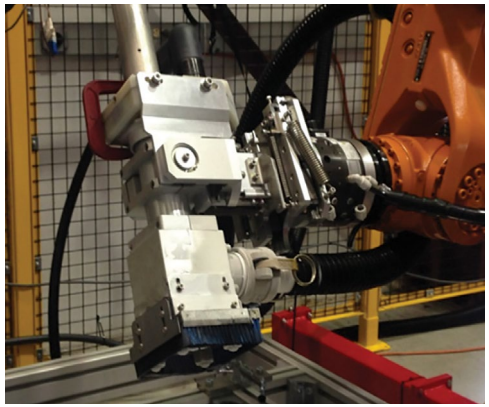
A recent EPRI Technology Transfer award to Rolls-Royce recognized the first commercial applications of nuclear plant components fabricated using powder metallurgy-hot isostatic pressing (PM-HIP) methods developed and qualified on the basis of long-term R&D initiated in 2010. In an ongoing DOE-funded project, PM-HIP, electron-beam welding, and other EPRI-developed innovations are being extended to reduce the cost and lead time required for manufacturing small modular reactor pressure vessels by up to 40%.

Gen IV Reactor Materials

A materials gap analysis being completed during 2019 identifies R&D priorities for enabling future reactors to operate using novel heat transfer fluids under temperature, pressure, and corrosion conditions never before experienced in power generation systems. For specific Gen IV designs and components, EPRI's assessment will characterize the suitability of existing and emerging materials and fabrication methods based on anticipated operating environments and on experimental and commercial experience at nuclear reactor, fossil power, and chemical manufacturing facilities. Knowledge and capability gaps identified in areas such as metallurgical and mechanical characteristics, irradiation embrittlement, manufacturing, and weldability will help EPRI organize collaborative R&D to establish the property and performance basis for applying advanced steels and nickel-based alloys in Gen IV reactors.

Fusion Power Technology Assessment

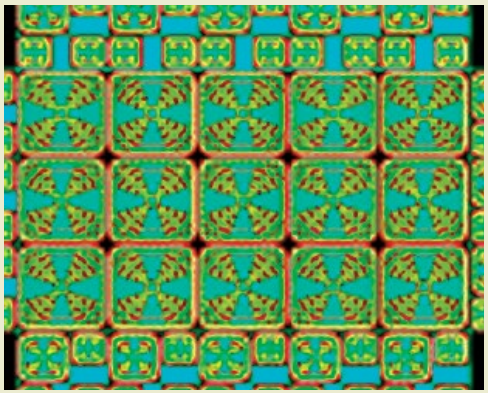
Well-capitalized private sector ventures pursuing innovative concepts deployable at smaller scale than conventional, publicly funded fusion power systems offer potential for accelerated commercialization, according to an EPRI technology and market assessment. Timeframes for modular and scalable production of non-emitting and dispatchable electricity remain about 20 years away, as the basic physics of practical fusion machines are still being explored. EPRI plans continued engagement with selected fusion developers regarding technical progress, business models, and power industry owner-operator requirements.



Automated concrete decontamination and other innovations are being explored by EPRI for improving worker safety while reducing decommissioning time and cost.

Automation Technology for Decommissioning

Innovations identified in scouting, explored with technology developers, and validated in laboratory testing are beginning field demonstration as solutions for reducing time, cost, and worker exposure during the decommissioning of retired nuclear plants. An autonomous rover integrating state-of-the-art radiological monitoring instrumentation will be tested for site characterization and surveillance of radionuclide migration during 2019. EPRI also is planning demonstrations of advanced techniques for concrete decontamination and automated segmentation of reactor vessels and internals.



Cross-Cutting R&D: Nondestructive Evaluation (NDE)

Électricité de France (EDF) is applying a concrete crawler robot outfitted with NDE probes and precision mapping systems—as conceived by EPRI and demonstrated at hydroelectric dams—to inspect cooling towers at nuclear plants. In addition to assessing structural integrity and detecting and characterizing internal flaws, the crawler helps improve safety and efficiency relative to scaffold-based inspections. Ongoing foundational R&D is advancing signal processing and data analytics for enhanced NDE regardless of the target component or flaw. In 2019, algorithms and software are being created to leverage existing video footage of nuclear fuel systems for real-time flaw detection and analysis during future underwater inspections. In parallel, similar innovations are being developed for unmanned aerial inspection of transmission lines and other utility assets.

EPRI Core R&D advances early-stage technologies with potential for achieving large-scale emission reductions and for enabling continued use of globally abundant fossil fuels to supply affordable and reliable electricity in the future IEN. Strategic R&D topics for 2019 include high-temperature materials, carbon capture process testing, geological storage modeling, and advanced sensing and instrumentation.

Success Story

Developed an advanced design and comprehensive knowledge base for engineering dissimilar metal welds with increased tolerance to cycling-induced stresses that can lead to cracking and catastrophic failures in high-energy fossil plant steam piping. Detailed in a guidance document and upcoming code release, EPRI-developed procedures and insights are applicable for replacing crack-prone transition joints between creep-strength-enhanced ferritic steels and austenitic stainless steels and for improving the flexible operations capabilities of next-gen fossil plants.

2018-19 Highlights

Additive Manufacturing for Gas Turbine Components

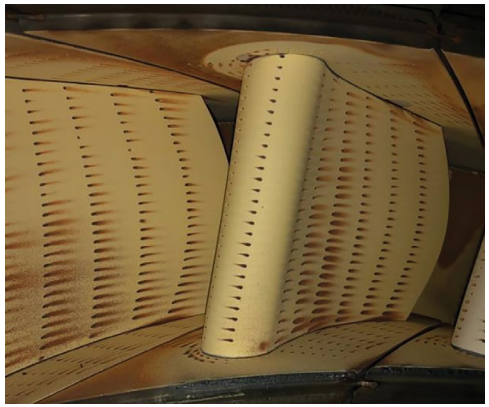
In 2018, six hot-section vane airfoil segments incorporating a novel near-wall cooling design were additively manufactured (AM) and deployed in an F-class combustion turbine for a 4,000-hour trial. Ongoing destructive testing of the ex-service airfoils focuses on validating the innovative cooling strategy for offsetting the generally lower creep resistance of AM materials. Following design, fabrication, and extended demonstration of a full vane set, EPRI expects after-market AM components offering reduced lead times and costs to be commercially available as soon as 2021.

High-Temperature Dynamic Pressure Sensing

A single-crystal sapphire optical dynamic pressure sensor conceived by EPRI could enable step-change advances in combustion monitoring in harsh gas turbine environments, relative to current technology requiring stand-off tubes that can introduce errors. Drawing on 2018 design studies, a prototype is being fabricated to assess accuracy and robustness in a pilot-scale combustion rig as the next step toward testing in an operational turbine. If commercially viable, this innovation will enable near-real-time combustion tuning to control NO_x and avoid life-limiting damage to hot-section parts.

Solid Sorbent Carbon Capture Membranes

In ongoing research with DOE's National Energy Technology Laboratory (NETL), an EPRI-patented post-combustion carbon capture process with breakthrough potential is undergoing validation testing. The membrane-based technology employs solid sorbent nanoparticles embedded in hydrophobic polymer sheets. Adsorption/desorption cycles lasting about 1 minute—as opposed to at least 30 minutes for most adsorption processes—accelerate CO_2 removal rates, enabling greatly reduced capture system size and cost. In 2019, alternative membrane formulations are being synthesized and tested on simulated flue gas at NETL, and EPRI's world-class carbon capture models are being applied for optimizing membrane properties and process performance.



Additively manufactured gas turbine vane airfoils tested by EPRI are expected to reduce the lead time and cost of procuring replacement components.

Carbon Storage Reservoir Modeling

To complement the DOE-funded Brine Extraction Storage Test (BEST) project at Gulf Power Company's Plant Smith in Florida, coupled modeling of underground reservoir flow dynamics and economics is quantifying the potential cost impacts of key geological variables that influence storage capacity at specific sites. General relations between cost, CO_2 injection rate, and reservoir size, depth, thickness, and permeability have been established. Ongoing modeling focuses on understanding how practical storage capacity could be constrained by reservoir pressurization and on exploring mitigation strategies. The EPRI-led BEST project—initiated in 2015—is moving in to field testing of a novel reservoir management strategy involving one brine extraction well and a second well for adaptive pressure relief.

Cross-Cutting R&D: Water-Energy Nexus

In 2018, EPRI completed a 3-year laboratory and field campaign demonstrating wastewater encapsulation as a viable option for holistic management of liquid and solid wastes from coal plants. Findings show that mixtures optimized based on wastewater and ash chemistries can be pumped to landfill cells for solidification and stabilization to form low-permeability monoliths with long-term resistance to leaching of environmental contaminants. A supplemental project launching in 2019 will engage utilities in continuing to develop technology options for site-specific applications. Meanwhile, to reduce freshwater use and improve cooling efficiency for all types of steam-electric plants, early-stage R&D continues on advanced desalination membranes and novel heat transfer surfaces. Promising concepts will be tested at the new Water Research and Conservation Center under construction at Georgia Power's Plant McDonough-Atkinson.

EPRI Core R&D focuses on maximizing the value of distributed and bulk storage for providing consumers with reliable, safe, affordable, and cleaner energy while optimizing resource utilization across the future IEN. Strategic R&D topics for 2019 include power-to-gas and other novel technologies, valuation methods for hybrid storage systems, control innovations supporting the Shared Integrated Grid, and battery health and safety.

Success Story

Launched the Energy Storage Integration Council **(ESIC) to drive collaboration in developing best practices and tools for analyzing, implementing, and operating storage technologies.** ESIC now includes more than 1,800 participants from utilities, developers, integrators, regulators, and the research community. Publicly available ESIC resources address value and cost assessment, testing, technical specifications, smart inverter functions, commissioning, safety, and other key issues relating to life-cycle management of storage projects.

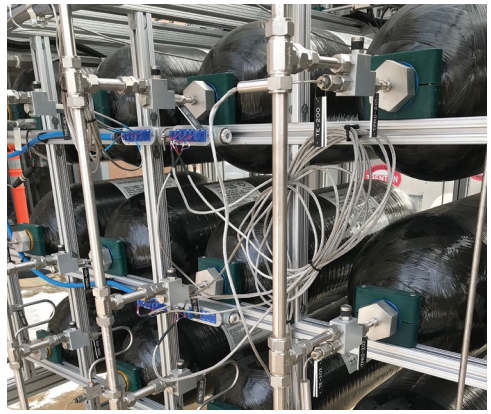
2018-19 Highlights

Water Electrolysis for Large-Scale Hydrogen Production

According to EPRI's assessment, electrolyzer technologies are commercially mature for specialty applications and approaching efficiency and lifetime targets required for large-scale storage of wind, solar, and nuclear power as zero-carbon hydrogen. In addition, multi-megawatt power-to-gas pilots in Europe are demonstrating electrolyzer integration and operation to balance renewables and provide other grid services while supplying hydrogen for pipeline injection, stationary fuel cell, transport, and industrial applications. Given anticipated manufacturing scale-up, large electrolyzer installations have potential to supply electrolytic hydrogen competitive with incumbent fossil-fuel-based hydrogen for fuel cell vehicles by about 2030—but only if low-cost electricity is available. Strategic 2019 technology assessment focuses on stationary fuel cell projects in Europe, while DOE-funded modeling is providing insight on the value of hydrogen technology for grid support and seasonal energy storage in future high-renewables grids.

Battery Storage Health and Safety Considerations

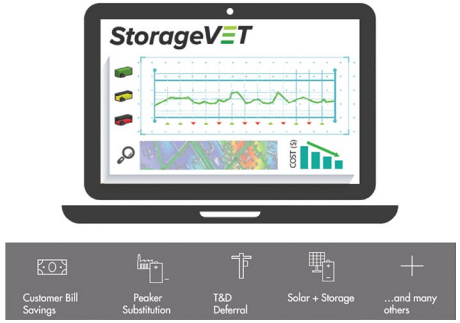
In 2018, EPRI completed a state-of-knowledge review of potential chemical exposures and other risks for workers and the public across the life cycle of established and emerging battery storage technologies. Generally, utility-scale systems pose limited risks during normal operations, but lithium-ion and other major chemistries are susceptible to thermal failures that can lead to fire, explosion, and accidental releases. Other life-cycle stages create significant potential for worker exposures, yet many key chemicals, compounds, and by-products lack comprehensive toxicity information and occupational exposure limits. Even minor changes to battery formulations can affect risk profiles, highlighting the critical need for health and safety research as deployment accelerates, manufacturing scale-up occurs, and technologies evolve. In 2019, EPRI is launching a strategic initiative to address end-of-life management for storage batteries, as well as PV and wind assets



According to EPRI's analysis, electrolyzers capable of competing with fossil-fuel-based technologies in bulk hydrogen markets could emerge by about 2030.

Battery Storage for the Integrated Grid

EPRI initiated pilot demonstration of distributed battery storage technology for the Shared Integrated Grid in 2018, drawing on smart inverter functions and advanced controls that integrate novel dispatch and optimization algorithms to meet customer expectations and allow specified utility interventions. A new 2019 project is applying big data to inform the siting, design, and operation of storage projects by accounting for future uncertainty in grid, market, and other conditions.



Cross-Cutting R&D: Modeling and Analysis

With cofunding from California Energy Commission (CEC), EPRI developed the Storage Value Estimation Tool (StorageVET®) to help utilities, regulators, and others evaluate investments in storage assets. A free, open-source tool, StorageVET® supports quantitative analysis of deployment options at the customer, distribution, and transmission levels. Its project description and dispatch simulation routines offer choices in storage technology, design, economics, and operations and allow for stacking grid services to maximize value. Los Angeles Department of Water and Power applied StorageVET® to develop the business case for load-serving projects pairing batteries with PV, and a dozen other utilities are collaborating with EPRI to analyze diverse applications. In 2019, CEC is cofunding EPRI to develop DER-VET™, a complementary tool addressing the full range of DER, plus microgrid applications, for reliability and optimized sizing and dispatch.

EPRI Core R&D is building interoperability architecture and modeling frameworks for the future IEN, as well as advancing early-stage technologies for more reliable, intelligent, and efficient transmission and distribution (T&D). Strategic R&D topics for 2019 include integrated modeling, data analytics, microgrids, and innovations in inverter, sensor, cable, and transformer technologies.

Success Story

Played an instrumental role in creating foundational underpinnings for the Integrated Grid, in the form of the technical specifications for interconnection and interoperability between distributed resources and utility systems incorporated in the 2018 update of the IEEE 1547 Standard. Over a 4-year period, EPRI led expert working groups in which diverse stakeholders defined smart inverter and other specifications and now is working with more than 20 utilities in applying the new standard across T&D system planning and operations.

2018-19 Highlights

100% Inverter-Based Grids

A 2018 scoping study explored the complex operational and planning challenges associated with ensuring reliability in future bulk power grids served only by wind, PV, battery, and other inverter-interfaced resources. Moving from conceptual analysis to modeling and simulation, EPRI designed and tested inverter controls to achieve power sharing among resources and stable voltage and dynamic frequency response upon disturbances for a 100% inverter-based grid. Networks served by inverter-based resources supplemented by minimal synchronous generation also were examined. As the next step in a multi-year EPRI R&D program, early learnings are being further investigated in case studies with utilities anticipating very high levels of wind and solar penetration.

Energy Management Circuit Breaker

The EPRI-developed energy management circuit breaker (EMCB) offers disruptive potential as a plug-in technology that provides traditional protection and on/off functions but also extends metering, power quality monitoring, and control capabilities beyond the point of common coupling and in to service panels for residential and commercial equipment. Successful initial demonstration, kicked off in 2014, engaged industrial partner Eaton in UL certification of a generic EMCB device and an EV charging circuit breaker, along with manufacturing and testing of about 250 units in collaboration with 12 utilities. Ongoing utility demonstrations, running through 2020, are testing smart breaker products commercialized by Eaton for end-use monitoring, demand response (DR), PV monitoring and dispatch, battery control, and EV charging applications. A novel, cloud-based data pool developed by EPRI provides secure connections to private utility networks while also affording access to third-party service providers.

Distribution Relays and Controllers for Asset Management

According to EPRI's latest analysis, modern relays and controllers deployed to protect and stabilize distribution systems also have the potential to monitor their own health and that of surrounding assets such as transformers and conductors. In addition to being located at critical nodes on the grid, these electronic devices generally offer data storage and processing capacity sufficient to host and run apps for detecting performance degradation, fault conditions, and incipient failures to help utilities reduce O&M costs through streamlined maintenance and avoided outages. In 2019, EPRI is exploring additional use cases for relays and controllers to support future demonstrations of distributed intelligence capabilities in conjunction with manufacturers and utilities.

Smart circuit breaker designs conceived and demonstrated by EPRI have disruptive potential for utility monitoring and control of behind-the-meter devices.

Cross-Cutting R&D: Unmanned Aircraft Systems (UAS)

To help maximize value from high-quality images collected by UAS, machine learning and other AI techniques are being tested using EPRI-curated image libraries for T&D assets. Algorithms trained on labeled images of healthy or degraded components show promise for detecting equipment damage and degradation in fresh UAS images. Ongoing R&D will identify T&D use cases in which UAS inspection offers advantages relative to traditional methods, as well as extend image processing innovations to vibration monitoring of power plant components and additional UAS applications. EPRI also is pushing boundaries in UAS payloads, indoor navigation, and flight automation while exploring use cases such as storm damage assessment, dry cask inspection, emission monitoring, and coal pile measurement.

EPRI Core R&D is advancing next-gen technologies and grid-interactive platforms for increasing energy efficiency, demand responsiveness, and grid support value across major end uses and for decarbonizing heating and transportation systems in the future IEN. Strategic R&D topics for 2019 include hybrid heat pumps, novel refrigerants, customer interfaces and analytics, and electrification of water heating, aviation, and other systems.

Success Story

Established efficient electrification as a technology, policy, and business solution for leveraging end-use innovations and modernized grids to benefit customers and utilities and reduce economy-wide emissions. EPRI's U.S. electrification assessment quantified nationwide benefits and triggered state- and utility-level analyses. Electrification 2018, EPRI's first international conference held in California, attracted crowds and helped trigger Electrification Europe 2019, a 2019 U.S. Electrification Symposium Series, and Electrification 2020.

2018-19 Highlights

Next-Gen Electric Heat Pumps

Residential air-source heat pump (ASHP) technology delivering unprecedented all-season efficiency, demand responsiveness, and electrification potential—as envisioned by EPRI in 2011—is now commercially available. During a 5-year strategic R&D program, conceptual design and modeling informed laboratory optimization of component and subsystem innovations, leading to technical specifications for next-gen ASHPs with broad geographic applicability. Subsequently, EPRI has brought together manufacturers and utilities for prototype development, demonstration, and early commercial deployment to test advanced attributes such as all-season DR functionality, elimination of supplemental heating elements, substitution for fossil-fired heating in temperate and cold-weather climates, and hybridized electric-gas heating. Meanwhile, based on successful proof-of-concept testing completed in 2018, the next ASHP innovation in EPRI's pipeline—hydrophobic coatings for reducing frost adhesion on heat exchanger coils—is undergoing laboratory evaluation for lowering defrost-related energy penalties in heat pumps, as well as refrigeration systems.

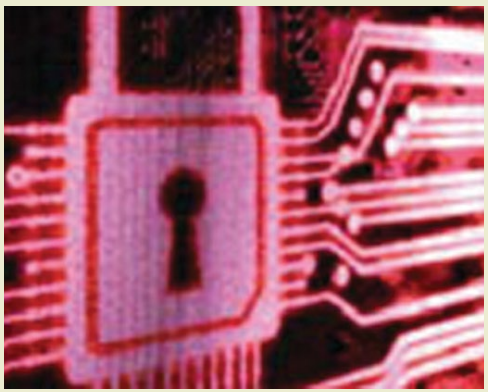
Advanced Energy Communities

In collaboration with real estate developers, utilities, and other key stakeholders, EPRI is supporting the design and leading the analysis of a series of advanced energy community (AEC) demonstrations that integrate efficiency, DR, electrification, PV, and storage technologies within single-family residential developments and multi-family buildings. These customer-focused projects—involving both new construction and major retrofits—are generating insights on how coordinated technology deployment and operation can accelerate heating and transport decarbonization and affect customer comfort, convenience, and cost. AEC demonstrations also will help utilities understand the future of peak loading, ramp rates, and renewables balancing, as well as serve as a testbed for EPRI's open enabling platform, which is being created to ensure interoperability between IoT devices and utility networks.

Housing projects that integrate intelligent, efficient, and clean technologies are providing EPRI with a testbed for decarbonizing buildings while supporting the grid.

Ammonia for Transport Decarbonization

According to EPRI's recent assessment, converting excess renewable or nuclear energy to hydrogen then ammonia creates an electrofuel with potentially significant advantages for the carbon-constrained future. In particular, conventional infrastructure could be used for long-distance transmission, storage, and localized distribution of liquid ammonia, which as a transport fuel offers higher energy density than hydrogen or lithium-ion batteries. Advances in direct combustion and co-firing technologies and in cracking to produce hydrogen are needed to enable widespread use of ammonia as an energy carrier and in transportation, power generation, and other applications. EPRI plans continued scouting in these areas, as well as integrated analyses exploring opportunities for power producers to capture value via hydrogen-ammonia synthesis.



Cross-Cutting R&D: Cyber Security

As IoT technologies such as smart thermostats, loads, meters, and inverters proliferate, EPRI is assessing hardware-based solutions such as physically unclonable functions, trusted platform management, and trusted execution environments for providing identity management—an essential element for achieving secure communications and interoperability between utility systems and billions of future grid-edge devices. In 2019, a repository of promising early-stage concepts and technologies is being developed through innovation scouting, and strategic R&D partnerships with leading universities and commercial entities are being pursued to accelerate technology development around identity management use cases involved in modernizing the grid and in securing the future IEN.

RESOURCES AND CONTACTS

EPRI TI white papers, reports, podcasts, fact sheets, and other publicly accessible resources are available at www.epri.com and www.eprijournal.com • EPRI members have access to all TI activities, results, and publications by logging in at membercenter.epri.com and participating in advisory meetings • For more information contact the EPRI Customer Assistance Center at 800.313.3774 (askepri@epri.com) • Ideas for EPRI R&D are encouraged!

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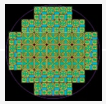

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