EPRI — TI — TECHNOLOGY INNOVATION

INSIGHTS AND INNOVATIONS

THIRD QUARTER, 2022

Insights and Innovations, published quarterly, summarizes recent EPRI Technology Innovation (TI) products to help inform utility members and advisors, industry stakeholders, and the public about emerging issues, technical and business developments, and R&D findings. TI includes three functional components:

Strategic Insights: Synthesis and communication of key observations, learnings, challenges, and opportunities for the energy future, leveraging EPRI and other R&D, broad stakeholder input, and cutting-edge analyses.

Global Innovation Hub: Platforms for direct engagement with world-leading clean energy incubators and startups and for active participation in interest groups and forums that bring together utility, industry, and other stakeholders.

Early-Stage R&D: Exploratory and applied R&D programs and projects focusing on strategic research gaps, crosscutting areas of science and technology, and innovations aligned with the roadmaps of EPRI's sectors.

In this publication, each TI product is assigned to a primary R&D focus area among the list below. Icons are used to illustrate TI's matrixed nature, identifying each product's functional component plus relevant R&D topics.

Note: *All EPRI TI resources are available to EPRI members for no-cost download by clicking product links. Many resources are publicly available for free. Those marked with* **$** *are available for purchase. See p.* 24 *for more details.*

⭐ Product & Webcast Highlights - Q3

READi Insights: Extreme Heat Events and Impacts to the Electric System (3002025522)
Impacts of climate change on extreme weather, society, and the grid

LCRI Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis (3002024882)
Net-zero technology strategies, projections, and implications

EPRI Insights: Current Events, Industry Forecasts, and R&D to Inform Energy Strategy, August 2022 (3002025354)
Expert perspective on advanced reactors, heat pumps, and more

Quick Insights — Full-Autonomy Electric Vehicles: Charging Infrastructure and Other Implications (3002025400)
Impacts of autonomous vehicles on EV charging and decarbonization

Equity and Resilience: Implications at the Intersection of Climate Change and Community (3002025062)
Opportunities for improving resilience, equity, and quality of life

Technology Update Series: State of Fusion at EPRI (July 11 Webcast)
Historical contributions, ongoing R&D, and next steps

CLEAN ENERGY

⭐ LCRI Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis (3002024882)

Q3 2022: Under the Low-Carbon Resources Initiative (LCRI), EPRI and GTI Energy led an integrated energy system modeling study to evaluate alternative technology strategies for achieving net-zero CO_2 emissions across the U.S. economy by 2050. The project considered scenarios with a full portfolio of clean energy technologies, with limits on geologic CO_2 storage and bioenergy supply, and with higher and lower fossil (gas and oil) supply costs. The executive summary and full report, accessible at https://lcri-netzero.epri.com/, conclude that a broad portfolio of technologies is needed to underpin an affordable and reliable clean energy transition and achieve deep decarbonization. While detailed results are specific to the continental United States, insights on effective technology strategies can be applied to markets around the world.

⭐ EPRI Insights: Current Events, Industry Forecasts, and R&D to Inform Energy Strategy, August 2022 (3002025354)

Q3 2022: This 26-page *EPRI Insights* provides current perspective on the benefits, status, and potential of advanced nuclear reactors, carbon capture and storage, electric heat pumps, and EV charging infrastructure. Technology innovations, deployment challenges and implications, policies and regulations, equity considerations, and other topics are discussed.

Environmental and End-of-Use Considerations in Solar Photovoltaic Module Design and Manufacturing (3002021734)

Q3 2022: This 11-page white paper explores historical and recent PV module design drivers and trends based on published materials and industry surveys and interviews. Augmenting the traditional emphasis on improving performance and cost, module design has increasingly focused on efficiencies in materials and manufacturing

to achieve economies of scale and reduce resource inputs. With growing recognition that the volume of defective, damaged, and spent modules will boom in the decades ahead, an additional design objective—focusing on recyclability, circularity, and sustainability considerations—is emerging. Designing for end of use can help improve the value proposition offered by module manufacturers to their customers while reducing levelized cost of electricity and supporting the industry's long-term sustainability. *$*

Industrial Clusters—A Review of Pairing Nuclear Energy with Other Technologies (3002023932)

Q3 2022: This 58-page report provides a detailed review of industrial clusters—with a focus on use cases involving nuclear energy—and the technological, business model, market, and regulatory developments required to implement them. Industrial clusters combine energy generation, conversion, and storage infrastructure with large end uses of energy products and services. Co-location and coordinated operation of energy infrastructure and industrial facilities and processes create the potential for systemic efficiencies and collective synergies. Findings indicate that opportunities exist for operational light-water reactors—as well as for modular units and advanced high-temperature reactors—to serve various end users that require continuous, reliable sources of electricity, heat, chilled water, and/or hydrogen. *$*

Using Digital Engineering Tools and Methods for New Nuclear Projects—A Review of the State of the Art (3002023905)

Q3 2022: Digital engineering (DE) supports the planning and implementation of complex projects by employing system models and data to create a single source of truth that draws on multiple interoperable software packages. This 58-page report defines DE use cases that represent the state of the art, summarizes benefits and key considerations, outlines implementation approaches, and introduces methods for providing connectivity between software packages. This information will be of value to organizations seeking to apply the latest DE technologies and methods to improve project management, engineering, procurement, construction, and commissioning for new nuclear power plants. *$*

Digital Twin Applications for Advanced Reactors (3002023904)

Q3 2022: The project summarized in this 134-page report investigated how digital twin (DT) technology can help reduce the costs of nuclear power, particularly for the next-generation advanced reactors that are early in the design phase and will be subject to regulatory frameworks that are still under development. Potential benefits, challenges, capabilities, and use cases are described across the reactor technology and plant life cycles, and insights and application guidelines are provided for reactor developers and end users. DTs offer significant potential for reducing overnight capital cost and levelized cost of energy via regulations that allow for twin-based modeling and simulation and via applications that support design, procurement, construction, operations and maintenance, and decommissioning optimization. The report also highlights issues to be addressed through collaborative R&D before such benefits can be fully realized.

⭐ Technology Update Series: State of Fusion at EPRI (July 11 Webcast)

Q3 2022: This webcast, led by EPRI's Andrew Sowder, provided an overview of fusion technology and detailed EPRI's fusion work, starting from a utility requirements document published in the early 1980s. Ongoing activities include the EPRI Fusion Forum and the development of a technology landscape review, the technical basis for fusion's safety case, and an introductory training course. In addition, a strategic R&D program on fusion energy is proposed.

Technology Update Series: Wind Generation (August 23 Webcast)

Q3 2022: This webcast, led by Brandon Fitchett, manager of EPRI's Wind Generation program, introduced previous, ongoing, and planned TI R&D. Successful development of the SABRE™ blade inspection system—commercialized through GE—was described, along with ongoing R&D focused on automated nondestructive evaluation technologies. Six university-based projects funded through the U.S. National Science Foundation's WindSTAR Industry-University Cooperative Research Center were introduced, each engaging an EPRI expert as a mentor. In addition,

EPRI's offshore wind R&D roadmap and other ongoing TI-funded projects were described.

EPRI Fusion Forum (April 20 Webcast; June 6 Webcast; August 17 Webcast)

Q3 2022: This public forum is intended to increase fusion developer community awareness and understanding of utility end-user needs and relevant EPRI work, as well as increase power industry awareness and understanding of fusion technology status and R&D needs. The April 20 webcast featured presentations from fusion technology developer Zap Energy, focusing on its Z-Pinch plasma confinement methodology; and from potential utility end user Duke Energy, providing perspective on the integrated resource planning process and the anticipated need for zero-emitting load-following resources in the decades ahead. The June 6 webcast focused on fusion R&D led by Oak Ridge National Laboratories, addressing U.S. progress on the International Thermonuclear Experimental Reactor (ITER) being constructed in southern France as well as foundational R&D supporting a range of technologies. The August 17 webcast included an update from General Atomics on plans for an advanced tokamak fusion pilot plant, plus results and insights from EPRI's analyses of future markets for nuclear energy in deeply decarbonized energy systems.

⭐ EPRI Insights: Current Events, Industry Forecasts, and R&D to Inform Energy Strategy, April 2022 (3002024170)

Q2 2022: This 33-page *EPRI Insights* is intended to help inform industry decision-making and strategy by providing a snapshot view of industry events, developments, and forecasts based on expert perspectives. This quarterly update contains concise articles addressing "Global Power Generation and Greenhouse Gas Emissions," "Natural Gas Markets in Turmoil," "Climate Threat: Heavy Precipitation and Flooding," "FERC Order 2222," and "Virtual Reality, Augmented Reality, and Robotics for a Safe and Efficient Workforce."

⭐ Understanding Generation and Storage Technology Supply Chain Risks and Needs to Support Electric Utility Sector Decarbonization (3002023228)

Q2 2022: To support rapid growth in demand for clean energy technologies, material and manufacturing supply chains need to be expanded significantly, and transportation challenges need to be overcome. This 36-page white paper presents results from a study focused on the supply chain for wind and solar PV technologies and for lithium ion batteries in stationary storage and electric vehicle applications. The study addressed the following questions for each technology: What is the current state of the material supply chain and manufacturing capacity? What process or material/equipment availability bottlenecks pose risks to meeting accelerated deployment projections and targets? What steps could be taken to reduce or eliminate those risks?

⭐ Technology Update Series: Understanding Supply Chain Needs to Support Decarbonization (April 11 Webcast)

Q2 2022: This webcast began with a presentation by EPRI's Robin Bedilion based on the supply chain white paper addressing wind, PV, and battery technologies. EPRI's John Shingledecker and David Gandy followed with a review of supply chain issues and challenges relating to emerging thermal generation technologies, including small modular reactors, advanced high-temperature reactors, hydrogen turbines, supercritical CO_2 and other advanced power cycles, next-gen concentrating solar power plants with thermal storage, and other bulk energy storage technologies.

National Carbon Capture Center 2021 Report (3002023294)

Q2 2022: The National Carbon Capture Center (NCCC) was established by the U.S. Department of Energy (DOE) to address the nation's need for cost-effective, commercially viable CO_2 capture and utilization options for coal- and gas-fired power plants. The NCCC, located in Wilsonville, Alabama, conducts post-combustion capture and utilization testing using commercially representative flue gas mixtures. It is supported primarily by DOE and cofunded by EPRI and other industrial partners. This 98-page report presents the progress made with CO_2 capture and utilization technologies at the NCCC during the DOE's 2021 fiscal year: October 1, 2020 through September 30, 2021. $

⭐ Current Assessment of Carbon Dioxide Removal Technologies: Technological, Economic, and Policy Implications of Approaches (3002019009), (Technology Update Series Webcast, July 27, 2022)

Q2 2022: Looking beyond carbon capture to prevent emissions from power plants and other industrial facilities, carbon dioxide removal (CDR) strategies take accumulated CO_2 from the atmosphere for storage in geological formations, soils, sediments, and other materials. This 66-page report provides a current review to better understand the viability, costs, benefits, and risks of proposed CDR approaches. The following options are considered in detail: direct air capture (solvent and sorbent technologies), CO_2 mineralization and ocean alkalinity enhancement, biochar and soil carbon sequestration, and other land use and management practices involving coastal ecosystems and forestry. In these early days of R&D focusing on possible broad implementation, it is unclear which CDR technologies and measures may prove most viable. Many involve significant energy inputs and natural resource implications that may challenge deployment at scale.

Technology Update Series: Innovations that have the Potential to Positively Impact Hydro (June 13 Webcast)

Q2 2022: Hydropower facilities have been operating reliably for well over 100 years. The webcast covered innovations intended to help hydropower in its next chapter as a key enabler supplying both bulk power and grid support services toward a net-zero energy future. Francisco Kuljevan, manager of EPRI's Hydropower Generation Program, discussed inspection technologies for dams and spillways, autonomous cavitation damage assessment, modernization upgrades, flexible operations, digital twins, and microelectromechanical machine applications.

EPRI Hydropower Materials Workshop (May 17-18 Webcast)

Q2 2022: Hydropower facility operators are facing the dual challenges of managing legacy assets and evolving dispatch patterns, requiring innovative repair and management solutions. This 2-day

workshop connected hydro asset owners and researchers to discuss common materials and repair concerns, share R&D results and success stories, and help inform EPRI's Hydropower Materials Research Roadmap. U.S. and international plant operators and research groups provided presentations and identified shared priorities.

Technology Update Series: The Next Frontier- 24/7 Carbon-Free Energy (24/7 CFE) (June 21 Webcast)

Q2 2022: On this webcast, EPRI Technical Executive Adam Diamant introduced a 2022 TI project designed to improve understanding of the ongoing evolution in corporate renewable energy procurement and the potential opportunities and challenges associated with 24/7 CFE products. The presentation provided preliminary insights addressing both the procurement and the development of new products that better match hourly customer load to the procurement and dispatch of carbon-free energy.

⭐ Electric Utility Workforce Development and Decarbonization (3002023229; May 9 Webcast)

Q2 2022: This 43-page report summarizes findings from a study assessing needs for craft-level professional labor implied by a 50% reduction in economy-wide greenhouse gas emissions by 2030. Based on a region-by-region characterization of the current state of the skilled electric utility sector workforce versus the current demand, the study explored potential workforce gaps implied by rapid decarbonization of the power generation sector and accelerated economy-wide electrification. To fill these gaps, this report identifies strategies and policies that the construction industry and utility sector could consider to help ensure that an adequately sized and skilled workforce is available to support decarbonization goals in the decade ahead.

2022 Nuclear TI Portfolio Overview Webcast (March 22 Webcast)

Q1 2022: Technical experts from EPRI's Nuclear Sector discussed the TI Nuclear portfolio and its alignment with the sector's visionary goals and member priorities. Results from a highly successful multi-year strategic R&D program on advanced reactors

were highlighted, including high-value products addressing user requirements, safety-in-design methods, and fuel performance plus extensive work in advanced materials and manufacturing methods. Ongoing digitalization R&D also was presented in areas such as blockchain, hardware-based reference signatures, and digital twins.

2022 Generation TI Portfolio Overview Webcast (March 31 Webcast)

Q1 2022: Technical experts from EPRI's Generation Sector discussed the 2022 TI Generation portfolio, which is focused on building internal capabilities and conducting R&D to enable the energy transformation and decarbonization. Successful TI projects in wastewater encapsulation and in advanced manufacturing methods for hot-section gas turbine components were described. Ongoing work is focused in four areas—Materials; Digital Transformation; Environmental Science & Technology; and Carbon Capture & Storage—with significant emphasis on issues relating to renewable generation.

ELECTRIFICATION & END USE

⭐ Quick Insights — Full-Autonomy Electric Vehicles: Charging Infrastructure and Other Implications (3002025400)

Q3 2022: Autonomous vehicle (AV) and EV technologies, though individually transformative and emerging at different rates, are often linked. This 6-page *Quick Insights* brief examines the potential implications of future widespread adoption of full-autonomy EVs for the electric sector, focusing on charging infrastructure and transport decarbonization but also considering DER possibilities. Impacts of AVs on vehicle use patterns, the siting of charging stations and grid infrastructure, the electrification of trucking, and other factors are considered.

2022 Strategic Research Gap Overview: Electrification and End-Use Carbon Reduction Priorities and Projects (May 17 Webcast)

Q2 2022: EPRI continues to focus strategic R&D on economy-wide decarbonization solutions for equitable, sustainable communities and society, with an emphasis on customer adoption as a driver of progress. During this webcast, EPRI's experts highlighted R&D challenges and opportunities in the areas of transport, building, and industrial facility decarbonization and reviewed ongoing and new projects. R&D progress reports were provided in the areas of equitable program design for EV adoption and support, indoor air quality impacts from cooking appliances, charging infrastructure assessment tool for fleet operators and host utilities, and indoor agriculture demonstrations. New TI projects focusing on the shared integrated grid were previewed.

2022 Electrification and Sustainable Energy Strategy (ESES) TI Portfolio Overview (April 7 Webcast)

Q2 2022: This webcast involved a high-level introduction to EPRI's ESES TI portfolio and featured completed, ongoing, and planned work in the areas of data science for environmental, health, and safety applications; prototype development and testing for a zero-carbon residential heat pump water heater concept competitive with gas-fired instantaneous water heating; data-based heat map visualization for automated management of plug loads; and continued development and evaluation of the Total Value Test in bus fleet electrification, indoor agriculture, and water heating applications.

A History of Power Quality—Addressing Evolving Customer Technologies and an Increasingly Complex Power Grid (3002022396)

Q2 2022: Over the past 50 years, the concept of power quality (PQ) has evolved from being unknown and undefined to being understood as a fundamental component of grid performance, utility economics, and customer satisfaction. EPRI's PQ research has helped raise awareness of this important topic while providing solutions to utilities. This 16-page brochure provides a timeline and overview of selected historical PQ developments and events and discusses challenges in the increasingly complex grid environment

associated with new technologies and system configurations that are characteristic of the low-carbon energy transition.

Next Generation Residential Space Conditioning System Evaluation: Summary Final Report of CEC EPC-14-021 Project (3002023618)

Q1 2022: The next-gen residential space conditioning system (RSCS) integrates a variable-capacity compressor, variable-speed blower fan, and other innovations to provide intelligent dual-fuel (gas/electric) heating, high-efficiency cooling, and ventilation with zonal control, automated demand response, and fault detection and diagnostics. This 262-page report details results from laboratory testing focused on optimizing the next-gen RSCS for efficiency, utility integration, and homeowner comfort and from follow-on field evaluation in three single-family homes, cofunded by California Energy Commission and EPRI. In short, the system offers energy cost savings, versatility and resiliency, and other benefits for customers and utilities. Also reported are findings from testing an alternative drop-in refrigerant (R-32), which is considered as a future RSCS enhancement, and from evaluation of ducting requirements specific to California's building stock.

Electrochemical Non-Vapor Compression Chiller (3002021169)

Q1 2022: This 32-slide presentation introduces an innovative absorption-based refrigeration cycle that uses an electrochemical desalination process, rather than a heat source, to create the potential for energy and emission savings in compression chiller applications. Exploratory modeling using assumptions drawn from the literature shows a considerable improvement in efficiency and the ability to maintain capacity and efficiency regardless of temperature lift, due to the electrochemical nature of the desalination process. Additional research is outlined for confirming assumptions made in this initial study and establishing proof of concept in the laboratory. *$*

★ Incubatenergy Labs 2021 Challenge—Final Report & Pilot Demonstration Summaries (3002023039)

Q1 2022: EPRI's Incubatenergy Labs® (IEL) engages startups and utilities in accelerated demonstration projects to provide quick and

objective assessments of how disruptive technologies can be applied in today's rapidly changing energy system. This 67-page report introduces the IEL 2021 cohort development process and participating utilities, highlights key learnings relating to collaborative innovation, and features summaries of 20 pilot projects—more than half involving artificial intelligence (AI) applications. Each project summary includes a technology overview, project description, key learnings, and next steps, as well as perspective from the participating startup and host utility.

IEL21Report - HeyCharge: End-to-End Electric Vehicle Charging Solution for Long-Duration Parking Locations (3002023028)

Q1 2022: Providing EV charging for long-dwell locations, like multi-unit residential buildings, can be challenging due to the cost of charger hardware and controls. Innovations that simplify charger installation and charging management have the potential to enable more widespread deployment in these situations, improving the customer experience for EV owners. This 4-page IEL 2021 project summary describes deployment and testing of the end-to-end technology solution developed by HeyCharge for enabling low-cost installation of plug-and-play EV charge points that communicate exclusively through a mobile app. The project was hosted by EPRI, Ameren, and Tucson Electric Power.

IEL21Report - Microgrid Labs: Zero-Emission Fleet Transition Planning and Simulation (3002023032)

IEL "Lunch & Learn" Webcast: Microgrid Labs and Ameren (February 17 Webcast)

Q1 2022: Planning is the first crucial step in transitioning from conventional vehicle fleets to electric mobility, as early decisions can have significant impact on design, cost, and complexity. Electric school buses, for example, have much higher purchase prices than diesel buses and need additional investments in charging infrastructure, but they promise lower operations and maintenance costs plus reduced emissions of pollutants and greenhouse gases. This 4-page IEL 2021 project summary focuses on a test application of the EVOPT software platform developed by Microgrid Labs for completing a feasibility study, system-level

design, and business plan for transitioning a diesel school bus fleet into an all-electric fleet. Ameren hosted the project.

IEL21Report - Community Energy Labs: Customer-Centric Technology for Commercial Buildings and Campuses (3002023015)

IEL "Lunch & Learn" Webcast: Community Energy Labs and Southern California Edison (March 24 Webcast)

Q1 2022: Electrical end uses in the municipal, university, and school (MUSH) segment of the U.S. commercial sector have huge energy efficiency and peak shaving potential, but fewer than 10% of MUSH customers use advanced controls due to lack of awareness, competing objectives, and limited capacity to operate and maintain state-of-the art systems. This 4-page IEL 2021 project summary describes demonstration of the innovative customer engagement strategy developed by Community Energy Labs for improving uptake of, and experiences with, emerging technologies and utility offerings. The demonstration was hosted by Southern California Edison (SCE).

IEL21Report - Copper Labs: Wireless Real-Time Energy Monitoring for Demand Management and Grid-Edge Intelligences (3002023018)

Q1 2022: With the growing deployment of renewable energy and distributed resources, as well as the increase in extreme weather events, understanding when and where electricity is used is becoming increasingly important. While smart meters can capture high-resolution usage data, they typically deliver data to the utility once daily. Other electric meters—as well as most gas and water meters—generally only transmit data every 30 days. Actively tracking real-time use and demand across multiple infrastructures is essential in meeting decarbonization and other objectives. This 4-page IEL 2021 project summary explores the use of wireless, web-based energy monitoring technology developed by Copper Labs for informing demand-side management at customer and utility scales. The pilot demonstration was hosted by Xcel Energy.

IEL21Report - DCSix: Circuit-Level Monitoring and Analytics for a Multifamily Residential Community ([3002023022](#))

Q1 2022: Utilities have a growing need for more reliable and granular information on behind-the-meter (BTM) electricity consumption in buildings to optimize the design and performance of demand-side management programs and to support operational and planning decisions. Energy customers also want to understand their energy consumption and available options for reducing energy costs and carbon emissions. This 4-page IEL 2021 project summary describes a pilot test of the capabilities of the Wattrics energy monitoring devices and the cloud-based analytics platform developed by DCSix Technologies for providing visibility into BTM usage in a multifamily residential community. This pilot was hosted by SCE.
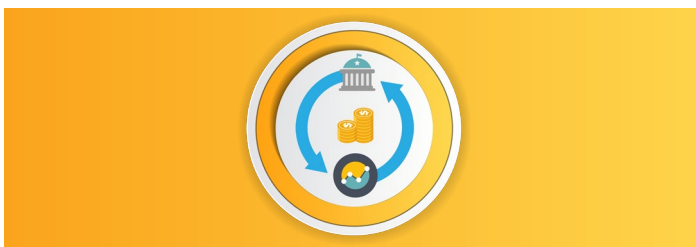
MARKET TRANSFORMATION

Utility Business Model (UBM) Working Group Webcast: Using Innovation Challenges to Enhance Business Model Development Strategy ([September 27 Webcast](#))

Q3 2022: Innovation and transformation are happening across the electric sector. How do utilities keep up with new technologies and applications? One approach for engaging the startup community involves challenges, where topics of interest are identified, and technology providers are matched with potential applications and customers for demonstrations and investments. This webcast engaged working group participants in examining a variety of energy- and utility-focused innovation challenges and considering lessons learned, with a goal of engaging the UBM community in considering potential improvements and future engagements.

⭐ Quick Insight: Energy Crisis in the United Kingdom and the Price Cap ([3002025090](#))

Q2 2022: Over the past two decades, increasing reliance on gas-fired power generation has tightened connections between both electric and gas infrastructures and markets. Meanwhile, continued expansion in gas-fired home heating and other applications has further increased demand for fuel, with typical domestic properties in the United Kingdom (UK) using three to four times as much gas as electricity (by energy volume). This 6-page *Quick Insight* examines policy and market factors underlying the ongoing crisis in the UK and implications relating to fuel poverty, decarbonization, and market resilience in the face of global supply shocks.

UBM Working Group Webcast: "Electric Vehicle Integration" ([May 31 Webcast](#))

Q2 2022: As the public and private sectors plan and make infrastructure investments to support the rapid expansion of transportation electrification, efforts are under way to bring together a broad ecosystem of participants to explore how EV investments will impact utility planning in the near and long term. During this webcast, EPRI's Laura Crowley and the GridWise Alliance's Aurora Eddington explored international and U.S. approaches to infrastructure investment, and utility participants discussed their experiences, explorations, and plans.

UBM Working Group Webcast: "2022 Kickoff" and "Selling Energy-As-A-Service" ([February 22 Webcast](#))

Q1 2022: The electric sector is starting to grapple with UBMs for selling energy as a service, rather than just a commodity measured in kilowatt-hours. This webcast, hosted by GridForward, featured discussion among professionals exploring how assets like storage, microgrids, electric vehicles, and solar can create opportunities to sell energy to utility customers in new ways. Speakers included Andrew Dillon, leader of transportation electrification services for West Monroe Partners; Sanem Sergici, a principal in The Brattle Group specializing in retail rate design and economic analysis of distributed energy resources; Steve Sunderhauf, who works in the Utility of the Future Group within the Regulatory Group of Pepco Holdings, which is owned by Exelon Corporation; and Graham

Turk, an innovation strategist at Green Mountain Power who designs and administers programs in battery storage, EV charging, and flexible demand management.

UBM Working Group Webcast: "Acquiring Business Model Transformation Management Best-Practices Knowledge" (March 29 Webcast)

Q1 2022: Following prior webcasts on UBMs addressing the technological and operational aspects of grid modernization, the March 29 edition focused on the process for successfully managing the imminent business model transformation process. Speakers at this EPRI-hosted webcast included Ron Doades, president of Ronald Doades & Company, an energy industry management consulting firm; Timo Köster, vice president of innovation with EWE AG; Colton Ching, senior vice president of planning and technology for Hawaiian Electric; and Larry Bekkedahl, who as vice president of transmission and distribution is responsible for advancing Portland General Electric's strategy to build the grid of the future.

Smart Grid Interoperability Standards Adoption in Southeast Asia (3002023426)

Q1 2022: Digital technologies and advanced management and control systems are needed to enable grid transformation and decarbonization. Standards that allow digital devices and systems to exchange information freely and easily and respond in a predictable manner must not only be developed but also built into products by suppliers and adopted by end users. This 13-page white paper explores the role of national standards bodies in this process, investigating how smart grid interoperability standards are adopted within five countries in Southeast Asia: Indonesia, Malaysia, Philippines, Thailand, and Vietnam. **$**

Operationalizing Circular Economy Principles for Renewables and Batteries: Electric Power Company Practices (3002023085)

Q1 2022: Transitioning energy systems to circular economic models is expected to reduce natural resource pressures and increase business value across many dimensions. EPRI's conceptual circular economy framework for the electric power sector spans the

industry's procurement and use of products and services (including fuel), the electricity produced and its efficiency of delivery and use, and the management of process by-products and end-of-use materials. This 13-page tech brief documents ways in which circular economy principles are being operationalized through utility business practices. The experiences summarized can be used by other companies for improving understanding of circular economy principles and actions, informing planning, and taking action. **$**

RELIABILITY, RESILIENCE & FLEXIBILITY

⭐ READi Insights: Extreme Heat Events and Impacts to the Electric System (3002025522)

Q3 2022: EPRI's Climate Resilience and Adaptation Initiative (READi, https://www.epri.com/research/sectors/readi) is strengthening the electric power sector's collective approach to managing climate risk. This 6-page *READi Insights* brief evaluates the severity of recent extreme heat events in the context of historical records, climate change projections, and potential future implications. It considers the following questions: What are heat waves and how are they changing? Are climate models capturing these heat extremes? How does extreme heat impact the electric system? Climate READi's planned scope of work also is introduced.

US-European Workshop: Grid at the Edge: Towards the Zero-Carbon Power Grid with Improved Visibility, Safety and Reliability, Final Report (Conference Paper)

Q3 2022: This 40-page report summarizes discussions and recommendations from the joint US-European workshop held at the 2022 International Conference on Smart Grid Synchronized Measurements and Analytics (SGSMA) in Split, Croatia. The workshop focused on defining topics for future research on grid

visibility, safety, and reliability using synchronized sampling and data analytics technology.

Building the Essential Online Power Quality Course: A Demonstration (3002023450)

Q3 2022: The fast pace of distributed resource deployment and electrification and the changing nature of electrical and electronic loads are accelerating the emergence of power quality (PQ) problems, and existing education and training programs are not keeping up. As a nonbiased researcher and curator of PQ problems, underlying issues, and solutions, EPRI is developing an online PQ training course focusing on how to deal with the emerging challenges of a modern grid. The Power Quality Certificate Training (PQCT) course is being designed to help transform existing engineers, technologists, and technicians into PQ specialists. Approximating a one-semester, three-credit college class, the full PQCT course will comprise 12 modules addressing PQ monitoring, various PQ phenomena, mitigation methods, grid support, and troubleshooting. This 46-page tech update describes course content, curriculum development, competition research, and related activities. **$**

2022 Strategic Research Gap Overview: Electric System Reliability, Resiliency, and Flexibility Priorities and Projects (May 26 Webcast)

Q2 2022: Technical experts from EPRI provided an update on strategic R&D to address systemic challenges associated with changes in electricity supply and markets, significantly higher levels of variable renewables, decreasing levels of dispatchable synchronous generation, distributed resources, digitization, and a changing climate. The presentation featured TI work in the areas of resource adequacy, workforce adequacy, climate resilience, integrated system risk planning, flexible operations, transmission circuit upgrades, and next-generation monitoring and control.

2022 Transmission and Distribution Infrastructure (TDI) TI Portfolio Overview (April 14 Webcast)

Q2 2022: EPRI's experts introduced the TDI TI portfolio, featuring projects in the areas of advanced components; information, communication, and cyber security applications; and asset management solutions. Sample topics included carbon footprint assessment of overhead structure designs; distribution system robotics; assessment of thermolyzer technology for end-of-life management of wood poles; 5G radiofrequency worker exposure; recloser reliability; drone-based corrosion inspection tool; rapid-response transmission tower for service restoration; and robotics for insulator inspection and transmission structure painting.

2022 Integrated Grid and Energy Systems (IGES) TI Portfolio Overview (April 13 Webcast)

Q2 2022: The IGES TI portfolio includes a wide range of leading-edge projects from strategic and long-term energy and environmental planning to real-time system operations. In this webcast, EPRI's experts introduced a sampling, with topics including distributional impacts of economy-wide decarbonization, grid services from aggregated DER and managed EV charging, modeling of grid-forming inverters, planning for climate resiliency, advanced load shedding schemes, and distribution grid resiliency planning.

⭐ Quick Insight: Accessing Flexibility of Customer-Sited Battery Energy Storage Systems (3002025017)

Q2 2022: This *Quick Insight* explores the research question, what role do customer-sited battery energy storage systems (BESS) have in enhancing grid reliability and resilience while facilitating decarbonization? It describes drivers of and growth in BESS deployment and profiles utility programs that employ customer-sited BESS to provide capacity, frequency regulation, demand response, and energy arbitrage, among other services. Factors likely to influence how—and how fast—utilities engage with customer-sited BESS are identified, including ongoing regulatory activity, particularly Federal Energy Regulatory Commission Order 2222.

A Starting Point for Physical Climate Risk Assessment and Mitigation: Future Resilience and Adaptation Planning (3002024895)

Q2 2022: Addressing the risk associated with climate change has been a growing area of focus for many energy industry stakeholders, in particular within the regulatory and financial communities. This 26-page paper examines the current knowledge base of potential climate-related impacts across the power sector, creating the foundation for a standardized and consensus-based framework to inform infrastructure investment and deployment. It also introduces EPRI's Climate Resilience and Adaptation initiative—Climate READi—being launched to convene global thought leaders, the scientific community, and other stakeholders necessary to build a consistent, industry-accepted framework for assessing the impacts of physical climate risks on the power system.

Quantifying Potential Impacts of Water-Related Risks Associated with Climate Change (3002021684)

Q2 2022: The power industry, which is heavily reliant on access to water resources, faces a variety of risks due to changing surface water conditions. This 140-page tech update identifies and quantifies additional or enhanced risks for selected U.S. water basins, building on a prior qualitative risk assessment study performed at regional scale. The case studies include assessments of (1) potential diminished hydropower production, revenue loss, and replacement power cost in the San Juan Basin, New Mexico; (2) potential habitat availability and suitability impacts on threatened and endangered freshwater mussel species in the Tippecanoe River Basin, Indiana; (3) potential changes to annualized flood risk for river-adjacent facilities in the Wabash River Basin, Indiana; and (4) potential decreased operating efficiency and thermal effluent discharge limitations for a thermal generating facility in the Allegheny River Basin, Pennsylvania. **$**

Reconductoring, Tensioning, and Advanced Conductor Technologies for Increasing the Capacity of Transmission Lines (3002023335)

Q2 2022: Building on a previous product (listed below) focused on re-rating, dynamic and ambient adjusted ratings, voltage upgrades, and AC to DC conversion, this 10-page white paper provides in-depth analysis of conductor technologies and techniques for both increasing the capacity of existing lines and building new high-capacity lines. It reviews conductor materials and thermomechanical and thermoelectric responses to loading, and then discusses and compares the following options, listed in order based on degree of increased capacity and increased cost: re-tensioning, enhancing span-specific clearance, applying high-emissivity coatings, reconductoring with standard or non-proprietary high-temperature low-sag (HTLS) conductors, and reconductoring with proprietary HTLS conductors. Industry experience with conductor upgrades is summarized, and applicable EPRI resources are described.

Advanced Transmission Line Designs for High ROW Utilization (3002023331)

Q1 2022: The electric utility sector must address numerous technical challenges to increase transmission system capacity in order to meet U.S. and global decarbonization goals, both by upgrading existing circuits and rights-of-way (ROW) and developing new high-voltage corridors. Following on a recent EPRI technology assessment (3002023004), this 16-page white paper provides a detailed discussion of advanced transmission line designs that can be utilized in new construction to increase ROW capacity.

DER Management Systems Control Strategy Evaluator (3002022252)

Q1 2022: This 48-page technical update describes EPRI's Control Strategy Evaluator (CSE) Version 1.0, which applies EPRI's OpenDSS simulation software as a circuit simulator to test, evaluate, analyze, and quantify the benefits and performance of Distributed Energy Resources Management Systems (DERMS). The software includes the required functions to host Aggregator-DERMS, Local-DERMS, Utility-DERMS, and/or upstream system and grid operators. It has the backend downstream interface functions that write, read, run, and solve the circuit model and includes the upstream interface wrapper, which hosts the hierarchical control strategy under evaluation. CSE v1.0 introduces a simple environment to host and interface single or multiple hierarchical control strategies and has a web-based user interface with a built-in evaluation metrics and controller toolbox for rapidly running

scenarios to evaluate control strategy performance, impacts, and benefits. **$**

⭐ Quick Insights: Extreme Weather Considerations for Resource Adequacy ([3002023371](#))

Q1 2022: This 7-page brief examines how various types of extreme weather can impact the ability of supply and demand resources to meet customer electricity demand and how resource adequacy assessments need to evolve to account for increases in long-term event frequency and severity. Examples include ensuring that load and renewable generation profiles are synchronized based on historical data and projected climate trends; modeling correlated generating unit outages; and developing and applying resource adequacy metrics that highlight the outsized impact extreme weather events may have on the system.

⭐ Enhancing Energy System Reliability and Resiliency in a Net-Zero Economy ([3002023437](#))

Q1 2022: This 29-page white paper examines the reliability and resiliency implications of decarbonization, highlighting key actions and next steps needed to advance the energy sector's abilities to plan, build, and operate a cleaner, more reliable grid over the next decade and through 2050. Key actions include enhancing reliability and resiliency planning through regional and national modeling across transmission and distribution networks; expanding operational capabilities to better control dynamic and decentralized resources; maintaining and incentivizing essential grid services; and streamlining regulatory and stakeholder engagement processes to shorten siting, permitting, and construction timelines.

Strategic Engagement Brief: Collaborative Research Toward eIoT Extensible Information Model Creation ([3002022906](#))

Q1 2022: EPRI collaborates with several university-based research centers focused on the integration of customer end-use equipment in energy systems through grid modernization and IoT-enabled homes and businesses. This 5-page brief describes the collaboration with Dartmouth College's Laboratory for Intelligent Integrated

Networks of Engineering Systems (LIINES) in providing thought leadership and research that aims to benefit the public.

Strategic Engagement Brief: EPRI's Engagement in ESIG Working Groups ([3002022907](#))

Q1 2022: The Energy Systems Integration Group (ESIG), initially known as the Utility Wind Interest Group, brings stakeholders together to "chart the future of energy systems integration and operations" through peer-to-peer networking and knowledge sharing. This 8-page brief describes EPRI's roles within ESIG and highlights activities and accomplishments under the following six technical working groups: Reliability, System Operation and Market Design, Distributed Energy Resources, System Planning, Research and Education, and Wind and Solar Plant Operations and Maintenance.

Dynamic Network Reduction of Bulk Power System with High Share of Inverter-Based Resources ([3002021983](#))

Q1 2022: This 40-page tech update explains and explores a new method for obtaining a dynamic network equivalent for a specified study area within a broader bulk power distribution system, with the goal of helping reduce the effort required to conduct planning studies for systems with high penetration of inverter-based resources. The method divides the bulk system model into two areas—study area (retained portion) and external area (reduced portion)—and applies events within the former to excite the dynamics of the latter. Measurements at the boundary between the areas are used to develop a lower-order representation of the external area that still captures its main dynamic characteristics. This report presents a test case for a simulated bulk power system and compares the response of the reduced network when it includes the equivalent dynamic model versus a simpler typical Thevenin equivalent external. **$**

Measurement and Verification (M&V) for Distributed Energy Resources Providing Grid Services: New Complexities, Common Approaches, and Research Needs (3002023286)

Q1 2022: This 13-page white paper details the complexities associated with M&V of grid services delivered by DERs. It starts by describing new M&V roles, introducing common approaches for performance verification and settlement, and distinguishing between behind-the-meter DER and front-of-the-meter DER and between customer services and grid services. Metering options, M&V challenges relating to value stacking strategies (also called "dual participation"), and research needs are described. The paper concludes with illustrative DER deployment and grid service scenarios highlighting some of these challenges. **$**

IEL21 Report - Urban Electric Power: Zinc Manganese Dioxide Battery for Long-Duration Stationary Energy Storage (3002023037)

Q1 2022: Energy storage is a key technology for enabling the electric grid's transformation toward greater resilience and decarbonization. Battery energy storage systems are being deployed to help increase the value of renewable generation at distributed and utility scales, provide customers with uninterruptible and backup power supply services, and meet grid support needs over durations of up to several hours. This 4-page IEL 2021 project summary describes performance testing of zinc manganese dioxide ($ZnMnO_2$) battery storage systems developed by Urban Electric Power for long-duration applications. EPRI hosted the project, a unique opportunity to gain insight into an emerging battery chemistry, working in collaboration with the technology developer.
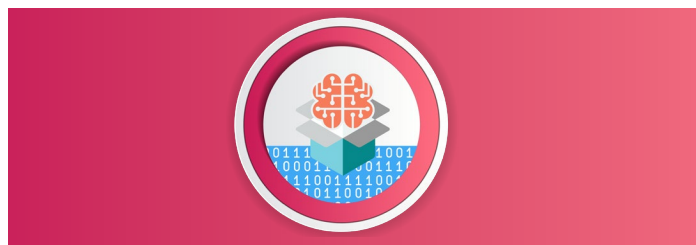
ARTIFICIAL INTELLIGENCE & DATA ANALYTICS

Development of the Event Management Response Tool (EMRT) (3002023816)

Q3 2022: Nuclear plant personnel need to make informed decisions in a reduced amount of time—such as during unplanned repairs or outages—based on relevant industry experience, research findings, and regulatory information and requirements. Locating the needed resources usually requires a document and database search, which can be cumbersome and time-consuming. In 2019, EPRI began investigating use of natural language processing to streamline the search process and improve search results. This 19-page tech brief describes development and testing of the EMRT, an advanced search engine that spans several key data and information sources and uses AI techniques to make searches more intuitive and productive for plant personnel. **$**

Event Management Response Tool (EMRT) v0 (3002021041)

Q3 2022: The EMRT (https://emrt.epri.com/) supports searches across three main areas of information—operating experience, research, and regulatory—in one location. The most relevant results are displayed at the top for each main area, with feedback and machine learning intended to continually improve results. The web application also displays relevant search hits within accessible documents, as well as other topics associated with the initial search. Key benefits include reduced time both to find needed resources and to locate relevant information within them. Also, the EMRT suggests relevant topics and other search terms, which can guide users—including less experienced personnel—in productive directions. **$**

Hydropower Digital Twin Roadmap Development (3002023316)

Q1 2022: This 66-page report presents an overview and primer on digital twin technologies and applications of interest to hydropower facility owners and operators. Potential use cases were identified through stakeholder discussions focused on current monitoring and diagnostics (M&D) practices. They include standardizing monitoring programs with variability in deployed sensor packages, understanding performance differences with variation in asset types, early fault detection, and life prediction analysis. The report includes six roadmaps that detail how to deploy a digital twin in specific areas of interest, and it provides a summary of several techniques used in model development, calibration, and deployment. $

Hydropower Digital Twin: Roadmap (3002023460)

Q1 2022: Digital twins are a blend of physical asset models and data analytics that provide a wide range of insights into the real-world systems they simulate. This 1-page brief highlights the insights available from digital twins of hydropower assets. This includes providing knowledge of physical parameters that cannot be measured, improving M&D practices based on greater awareness of asset performance trends, quantifying the reliability implications of supporting renewable energy integration, improving dispatch through better capability modeling, and supporting "what-if" studies for upgrade and modernization efforts. $

## Data Automation Tool (Case Study: Energy-Water Calculator) (3002022104)

Q1 2022: This 12-page presentation covers a sample use case for EPRI's Data Automation Tool (also known as the Data Scan and Storage Tool), conceived for reading different text files using multiple data formats with minimal user input. The first iteration of the tool would work with time-series tables saved within comma-separated values (CSV) files, an extremely common and versatile format. This use case addresses the Water-Energy Tool (WET), a web-based dashboard for illustrating the energy intensity for water systems in utility service territories. Using the Data Automation Tool, the acquisition of new datasets from a variety of utility service territories could be streamlined in the following ways: The data intake process can be automated. The database can be maintained offline and secure. Database output can be read by WET for analysis and display. $

Artificial Intelligence Applications to Satellite Imagery – A Wildfire Risk Use Case Focused on Identification of Dead and Stressed Trees (3002022002)

Q1 2022: High-spatial-resolution remote sensing is an emerging technology that utilities can employ to proactively manage at-risk trees, minimize outages, and decrease the cost of vegetation management programs. This 48-page report defines and explores a wildfire risk use case involving the application of commercial satellite data, other complementary data, and AI techniques to identify stressed and dead trees in southern California. Results from training an algorithm to detect dead and stressed trees are presented, as are answers to the following research questions: What are costs and benefits of this approach for identifying areas with high wildfire risk, relative to use of traditional methods (e.g., capture of data and imagery by fixed-wing planes or helicopters)? What technical lessons learned can be transferred from this project, in terms of needed spatial/temporal resolution, complementary data, and expertise? Can the same commercial satellite imagery data be applied for other use cases?
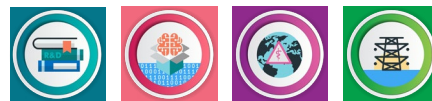
IEL21Report - ThermoAI: Wireless, AI-Powered Cyber Anomaly Detection (3002023036)

Q1 2022: Detection of cyber security events is paramount to the defense-in-depth strategies applied by electric utilities. Past events have shown that sophisticated attacks can go undetected for extended periods due to visibility gaps for non-networked but critical assets, disguised attacks and evasive measures by attackers, and conflicting needs to maintain vigilance while minimizing false positives. This 4-page IEL 2021 project summary describes proof-of-concept testing of ThermoAI's process optimization solution for creating digital twins of power plant systems, comparing them to real-world operating conditions, identifying and classifying anomalies, and detecting cyber security events. The AI.EPRI project was conducted at EPRI's digital instrumentation and control laboratory.

IEL21Report - Buzz Solutions: PowerAI Platform for Automated Visual Inspection of Grid Infrastructure (3002023014)

Q1 2022: Today, visual inspection of transmission and distribution infrastructure can involve the review of millions of images captured in the field by workers, surveillance systems, drones, helicopters, fixed-wing aircraft, and other means. Analyzing these images to turn raw data into actionable inspection information currently requires substantial technical expertise and labor investment, which can hamper a timely response. This 4-page IEL 2021 project summary describes the demonstration of the PowerAI system developed by Buzz Solutions for supporting rapid, automated review of drone-based distribution inspection imagery. The demonstration was hosted by Newfoundland Power and supported by AI.EPRI.

IEL21Report - Datch: Intelligent Voice Assistant for Substation Job Planning by Field Workers (3002023020)

IEL "Lunch & Learn" Webcast: Datch and ConEdison - (January 20 Webcast)

Q1 2022: Existing utility work planning processes can require field employees to spend time manually entering data and work plans using enterprise and third-party software, imposing an administrative burden that takes away from valuable work time. The ability to dictate job task requirements in the field would speed up the process. This 4-page IEL 2021 project summary describes demonstration of the intelligent voice assistant technology developed by Datch in a test integration with an existing third-party work planning application. The Datch Assistant app enables workers to interact with multiple databases simultaneously through a single interface that draws on AI techniques to support intuitive and natural conversations. This pilot was hosted by Con Edison and supported by AI.EPRI.
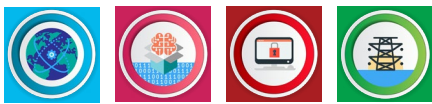
IEL21Report - Enerbrain: Intelligent Energy Monitoring and Control for Commercial Space Conditioning (3002023025)

Q1 2022: According to EPRI and other studies, up to 20% of peak load in commercial buildings can be temporarily curtailed for demand response without significantly impacting comfort, while Internet-of-Things (IoT) sensing and connectivity combined with control system replacements and upgrades can reduce overall building energy use by as much as 30%. This 4-page IEL 2021 project summary describes a test application of the IoT sensing and AI-based monitoring and control solutions developed by Enerbrain for increasing the efficiency and demand responsiveness of heating, ventilation, and cooling (HVAC) systems in small to medium commercial buildings. The project was hosted by EPRI, Duke Energy, and SCE.

IEL21Report - Future Grid: Using Smart Meter Data for Distribution Network Visualization and Management (3002023027) (Webcast August 17)

Q1 2022: DER deployment and electrification can create challenges for network operators by introducing variable renewable generation and by changing energy flows and load profiles, especially on secondary networks where visibility typically is limited. New grid management tools are needed to help operators take advantage of DERs and other sources of demand-side flexibility as solutions for improving distribution system reliability. This 4-page IEL 2021 project summary describes test applications of Future Grid's system management software, which is widely used in Australia, for providing low-voltage network visibility for utilities in North America. Hosts for this AI.EPRI project included FortisBC and Vermont Electric Cooperative.

IEL21Report - LiveEO: Satellite-Based Post-Storm Disaster Monitoring and Damage Assessment (3002023030)

Q1 2022: After major storms, attaining a comprehensive picture of downed and damaged vegetation and equipment along utility rights-of-way (ROW) and access roadways can be time consuming and may delay initial recovery processes. Remote sensing methods like drones and typical optical satellite imagery cannot operate effectively in many types of weather conditions including cloud cover. This 4-page IEL 2021 project summary covers a demonstration of the damage assessment capabilities of LiveEO's satellite-based solution, which uses AI methods and synthetic aperture radar (SAR) technology unaffected by cloud cover and night to allow near-real-time damage assessment and monitoring. The AI.EPRI project was hosted by Ameren and FortisBC.

IEL21Report - Noteworthy AI: Automated Drive-By Distribution Asset Inspection (3002023033) (July 27 Webcast)

Q3 2022: Proactive inspection of distribution lines can help guide maintenance and safety upgrades to mitigate risk from the increasing number of extreme weather and wildfire events. However, currently available inspection methods—from the ground, a bucket truck, or by unmanned or manned overflight—are costly, time consuming, and require worker involvement. This 4-page IEL 2021 project summary describes field demonstration of Noteworthy AI's automated system for distribution asset inspection using machine vision and edge computing deployed on existing utility fleet vehicles. This AI.EPRI project was hosted by FirstEnergy.

IEL21Report - Pano AI: 360-Degree, AI-Based Imaging for Wildfire Situational and Locational Awareness (3002023034)

Q1 2022: Utilities, government agencies, and other stakeholders need improved methods to rapidly detect ignition events and wildfires, confirm their locations, and assess risks to critical infrastructures and communities. Because current methods rely on many data sources with incomplete coverage, significant noise, and no single source of truth, confirming that a fire event is real can be difficult, sometimes allowing fires to go unattended for too long. This 4-page IEL 2021 project summary describes a demonstration of Pano AI's Rapid Detect platform, which applies continuously rotating cameras sited atop existing mountaintop towers to capture live images across broad areas, backed by AI-based methods for automated smoke detection, risk assessment, confirmation, and alerting. This AI.EPRI project was hosted by Pacific Gas & Electric and Portland General Electric.

IEL21Report - Shifted Energy: Machine-Learning-Based Load Shaping for Residential Water Heating (3002023035)

Q1 2022: Electric resistance water heaters and heat pump water heaters account for a significant fraction of building energy use and peak demand in some U.S. regions. While conventional load control methods have proven effective for lowering energy bills and shaving utility peaks by managing water heater operation, they have limitations that can reduce customer uptake and satisfaction. This 4-page IEL 2021 project summary describes a pilot demonstration

of the active, intelligent load control solution developed by Shifted Energy for transforming electric water heaters into aggregated distributed energy resources that provide multiple grid support services without negatively impacting customers. The AI.EPRI project was hosted by Tucson Electric Power.
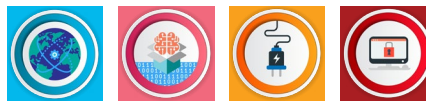
ENVIRONMENT, HEALTH & SAFETY

Investigating Battery Fire Smoke Plume Dispersion: Effects of Deposition (3002024677)

Q3 2022: Failure of large-format lithium-ion batteries can result in the release of flammable gases and lead to fires and additional air emissions. Building on prior research, an EPRI-developed modeling framework for determining deposition and surface concentrations of hydrofluoric acid (HF) and other hazardous pollutants has been extended to consider the impacts of dry deposition, when atmospheric trace gases and particulate matter settle directly on the surface, and wet deposition, when they are conveyed by precipitation or fog. Analyzing wet deposition can also serve as a proxy for studying how HF deposition is affected by using water for fire suppression. This 8-page tech update describes the updated framework and presents results. Adding a dry deposition velocity of 3 cm/s mainly reduces HF concentrations several kilometers downwind of the source but only by 5–10%. In contrast, adding wet deposition and a simulated low rain rate of 3 mm/hr reduces near-source concentrations by an order of magnitude, as well as downwind HF transport. These results suggest that water spraying near the battery source would be an effective measure to reduce HF concentrations. $

Creating a Digital Twin of a Radiological Environment (3002023837)

Q3 2022: This 22-page tech brief summarizes an EPRI-sponsored demonstration in which Createc N-Visage® equipment and

software were applied to create a digital twin of a radiological environment from fixed and portable survey instrument readings. The real-time 3D representation of the radiation dose field offered abilities to accept location and measurement data from various types of instruments, display color-coded heat maps of dose planes using simulated sources in various room locations, visualize the effects of changing conditions on area dose rates, and show the impact of adding shielding of various types and thicknesses. $

### Technology Update Series: Circular Economies for Clean Energy Technologies (April 20 Webcast)

Q2 2022: Increasing attention is being paid globally to the benefits of circular economies—ones which reduce natural resource use and loss through material and equipment recovery. As the energy system continues to undergo major transitions toward a decarbonized future with an increasing range of distributed energy resources, the industry is a prime target for circularity assessments. On this webcast, EPRI's experts provide an overview of circularity concepts as applied to energy systems and discuss how these principles can be practically applied in the business and technology systems of electric power companies.

Robotic Process Automation for Nuclear Power Plants: Evaluation of Near-Term Opportunities (3002023899)

Q2 2022: This 32-page tech update evaluates the potential for automating operations and maintenance (O&M) functions at nuclear power plants by building on existing remote task execution applications for sensors, drones, submersibles, robotics, and accompanying software solutions. A variety of use cases are explored in terms of task frequency and labor requirements, current capabilities and future needs, utility interest and value proposition, potential benefits and barriers, etc. In addition to O&M cost savings, advanced robotic platforms offer opportunities to increase worker safety, decrease calendar time and labor hours, gather information and perform work while equipment is online (rather than during an outage), and improve task performance. Advances are needed in a number of crosscutting areas to support complete automation, including machine vision and image analysis, battery

lifetime, navigation, manipulation and haptic response, and radiation hardening. $
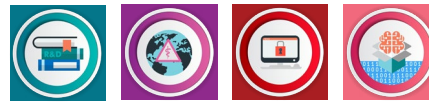
5G Exposure Measurement Pilot Study: Radiofrequency Measurements Near Two 5G New Radio Base Stations in Belgium (3002021620)

Q2 2022: This 90-page report describes a measurement methodology to assess radiofrequency (RF) electromagnetic field (EMF) exposures in the vicinity of two 5G new radio (NR) base stations in Belgium, both installed so that utility workers (and sometimes the general public) can come in close vicinity. One site comprised a base station with an advanced array antenna at low height, the other a lower-power base station on an accessible flat roof. Measurements were conducted near the base stations for both worst-case field levels and time-averaged levels under maximum downlink traffic load. Estimated exposures were compared to maximum permissible limits issued by the International Commission on Non-Ionizing Radiation Protection, U.S. Federal Communications Commission (FCC), and Institute of Electrical and Electronics Engineers (IEEE), as well as current exposure levels in a 4G LTE network in Belgium and a 5G NR network in Switzerland. $

Feasibility of using Mobile Vehicles to Detect Unsafe Backfeeds on Distribution Systems (3002021695)

Q1 2022: After a storm, broken or downed conductors can be energized by backfeed from customer generation, creating potential safety hazards. This 4-page tech brief describes tests conducted to evaluate the feasibility of using a mobile detector to identify backfeed scenarios. The mobile detector, which works by listening to broadcasts from automated meter reading or advanced metering infrastructure meters, could be deployed on vehicles that are assessing damage after major storms. Through a link to the utility's outage management system, the detector could identify meters that are communicating but are predicted out. Alternatively, field workers could be provided with direct visibility into the status of nearby customer meters, identifying those that have power. $

Evaluation of Flood Risk Tools, Models, and Services for Physical Climate Risk Assessments (3002022769)

Q1 2022: Electric utilities and their investors are increasingly analyzing the physical climate risk associated with flooding, now and into the future. Beyond the Federal Emergency Management Agency (FEMA) flood zone maps that have been shown to underestimate risks, newer open-source and proprietary models, tools, and services have emerged. This 90-page report identifies important criteria for evaluating flood risk assessment tools, provides an overview and evaluation of 14 flood risk products based on the criteria, and describes case study applications of selected tools in central Pennsylvania, along the Susquehanna River, and in coastal Texas, near Houston. Case study results are compared to those using industry-standard FEMA maps. *$*

Initial Addition of Chemical Evolution to Battery Fire Modeling Tools: Technical Update (3002023295)

Q1 2022: Battery fires at energy storage facilities can lead to unexpected releases of air pollutants that may impact nearby communities. This 24-page tech update discusses the status of dispersion modeling for battery fires and then reviews the compounds expected to be present and current knowledge of their behavior and evolution in the atmosphere. These include conventional air pollutants already included in air quality models (such as SO_2, NO_x, volatile organics, and particulate matter), as well as pollutants such as hydrofluoric acid, phosphorus oxyfluoride, organic carbonates, and fluorinated organics. Recommendations are provided for including the chemistry of these novel compounds in air quality models. *$*

Novel Remote PQ Assessment Tools and Algorithms (3002022364)

Q1 2022: The pandemic has challenged capabilities for performing in-person power quality (PQ) assessments. Building on previous testing of wearable headsets and software applications for in-person PQ assessments, this 14-page white paper further explores the technology along with a methodology for effective use in the context of remote PQ assessments performed by onsite personnel who may or may not have access to subject-matter experts. An app for improving remote PQ assessment in conjunction with wearable headset technologies is introduced, as is a machine learning algorithm designed for in-person and remote PQ assessments. *$*

Flow Rate and Turbidity Testing of the AUTOHOLO: Application to White Sturgeon Larvae (3002023302)

Q1 2022: Typical collection-based methods for observing and accurately identifying and quantifying fish larvae susceptible to entrainment at cooling water intake structures (CWIS) involve or may result in mortality. This 30-page report describes a laboratory study to demonstrate an underwater imaging system enabling a switch from lethal collection to reliable, non-lethal observation of the early life stages of endangered fish species. Laboratory experiments were conducted using an autonomous holographic imaging system (AUTOHOLO) at different turbidity and flow rates representative of CWIS conditions. Good detection and quantification results were obtained, and a database consisting of several thousand images was built for future training of a classification algorithm for rapid and automated detection of target species. *$*

EQUITY & SOCIAL JUSTICE

⭐ Equity and Resilience: Implications at the Intersection of Climate Change and Community (3002025062)

Q3 2022: Understanding how climate change, energy infrastructure, and electricity services affect disadvantaged and disenfranchised populations can inform transmission and distribution planning, asset management, and operations decisions to advance resilience for vulnerable communities. This 8-page white paper explores the implications of utility investments at the intersection of equity and resilience, highlighting opportunities, challenges, and potential strategies for improving quality of life as energy systems evolve and the climate changes.

Environmental Justice Benefits of Accelerated Fleet Penetration of Electric Vehicles (3002021916)

Q3 2022: As on-road vehicle emissions have dropped, overall pollutant exposures have declined, but disparities persist across racial-ethnic and income groupings. The modeling study reported in this technical paper aimed to quantify the environmental justice benefits of EV adoption by differentiating concentration changes in near-road settings along one of California's busiest highways. High EV penetration (85% share) resulted in greater reductions in NO_2 and PM2.5 concentrations in communities with more people of color and less educational attainment, suggesting that policies encouraging penetration can address inequalities in exposure and help achieve environmental justice. The paper, submitted for peer-reviewed publication, is cited as follows: Chang, S.-Y., Huang, J., Chaveste, M., Lurmann, F., Eisinger, D., Mukherjee, A., Gerdakos, G., Alexander, M., Knipping, E. (2022). "Accelerated Electric Vehicle Fleet Penetration: Emissions, Air Quality, and Environmental Justice Benefits."

⭐ Equitable Decarbonization Research Roadmap (3002024030)

Q2 2022: This 18-page white paper provides direction for R&D on equity issues relating to the clean energy transition. The roadmap is largely a result of six technical workshops bringing together approximately 370 participants from the research community, governments, utilities, and nongovernmental organizations. The workshops helped identify research questions and knowledge gaps in the areas of modeling and policy, power generation, electrification, energy efficiency, the digital divide, and metrics and tools. A key overarching need is to understand current and historical energy-related injustices as a means of defining pathways forward. Examples include reevaluation of factors and assumptions used in energy models, impacts of grid modernization on consumer costs and gentrification, and community and worker involvement in decommissioning processes.

Measuring Energy Justice (3002023269)

Q2 2022: Policies and programs intended to increase energy equity necessitate accountability mechanisms to verify their efficacy. The task of measuring, tracking, and potentially standardizing aspects of energy justice opens debate over the importance of social, economic, environmental, and cultural factors that may vary by community, class, race, gender, or geography. This 26-page report provides an overview of scholarship pertaining to energy justice measurement, as well as early efforts by state governments to develop and implement energy justice metrics. Often underscoring the lack of human-centered research in the energy field, contemporary scholarship provides numerous examples of metrics that advance justice outcomes using differential and multicriteria approaches.

Update on Environmental Justice Overview--Mapping Tools and Metrics (3002023064)

Q2 2022: This 16-page report provides an overview of energy justice tools and metrics, focusing on updates to and developments in state-level tools for identifying and mapping environmental justice populations. The tools were identified and reviewed by searching the existing literature, including resources available from the U.S. Environmental Protection Agency. Tools that are newer or currently under development might not have been captured in this report.

IEL21 Report - Indow: Interior Storm Window Insert for Improving Performance of Existing Windows (3002023029)

Q1 2022: Windows are a significant source of heating and cooling losses and comfort issues in homes. Exterior storm windows are commonly employed to mitigate these issues but can be expensive and difficult to install and operate. Applying plastic sheeting to interior window framing is an inexpensive but cumbersome and temporary solution that often reduces visibility. This 4-page IEL 2021 project summary describes a demonstration involving field measurement, manufacturing, installation, and monitoring of interior storm window insert kits designed by Indow. The pilot focused on evaluating the technology for improving comfort of low-income and underserved customers while reducing heating and cooling bills and carbon emissions. The project was hosted by Tennessee Valley Authority (TVA).

IEL21 Report - WexEnergy: Snap-On WindowSkin for Improving Performance of Existing Windows (3002023038)

Q1 2022: Windows are the most thermally porous component of the building envelope, single-pane models are the worst offenders, and aging windows of all kinds can suffer from performance problems. Windows also are very expensive to upgrade or replace, creating a barrier to improving comfort and reducing bills especially in low-income and underserved communities. This 4-page IEL 2021 project summary describes a demonstration of WexEnergy's WindowSkin® products as an interior-mounted retrofit solution for reducing thermal energy loss through aging and underperforming windows. The pilot project was hosted by TVA.

⭐ Towards a Healthy Planet: Environmental Opportunities and Costs of the Clean Energy Transition (3002023280)

Q1 2022: This 15-page white paper examines how the process of transitioning from fossil-fired technologies to low-carbon or carbon-free options can address legacy environmental impacts and current challenges, as well as advance society toward an environmentally just future. Among key conclusions, the paper notes that existing financial cost-benefit analysis methods may not appropriately estimate the total costs and benefits of investments relating to clean energy, especially in regard to long-term environmental and human health impacts. The clean energy transition presents an opportunity to include affected communities and incorporate their input throughout all aspects of decision-making processes.

INFORMATION, COMMUNICATIONS & CYBER SECURITY

EPRI Cyber Security Assessments (3002023190)

Q3 2022: This 4-page brochure introduces EPRI's cyber security assessment capabilities, highlighting the different levels and outcomes available. Under *Level 1: Enterprise,* a cross-sector team of EPRI experts assesses a utility's cyber security programmatic maturity and organization across the entire enterprise. Under *Level 2: Business Unit*, a focused operational technology (OT) assessment is led by an individual EPRI sector and draws on cross-sector resources. Under *Level 3: Technical,* an evaluation of a utility's specific systems is conducted using risk-informed methodologies, metrics, or other standards.

A Functional Application Architecture for Grid Model Data Management (GMDM) (3002025383—tech update; 3002025428—model files)

Q3 2022: Grid model data management is a critical element in utility digital transformation. The 66-page tech update describes the development and the features of a GMDM architecture that uses a unified, vendor-agnostic definition of the functionality and data exchanges. It also describes the role of various data exchange standards (including the Common Information Model [CIM]) and identifies the data objects that each standard can support. The functional application architecture can be used to analyze the maturity of a utility's GMDM capabilities, assess the requirement for new technologies and processes, design interfaces that minimize integration costs, and support advanced analytics. The corresponding model files are available in three different formats. *$*

SymPLe Architecture Phase II: Refinement, Advancement, and Demonstration of SymPLe Architecture (3002023841)

Q3 2022: Digital instrumentation and control (I&C) upgrades can help ensure long-term operation of existing nuclear power plants but are challenging to implement in the context of safety-critical functions. From 2015-19, EPRI and Virginia Commonwealth University explored alternatives to software-based I&C systems through the joint SymPLearchitecture project, sponsored by the U.S. Department of Energy. Follow-on EPRI work to advance the SymPLe system and de-risk commercial adoption by nuclear power producers is summarized in this 116-page report. The SymPLe architecture framework now incorporates architectural safety patterns and design-for-security and design-for-integrity principles, as well as addresses IEC 61508 certification needs. As demonstrated through sample applications, SymPLe makes complexity management explicit, reducing testing and verification and validation requirements to support cost-effective digital I&C upgrading activities at existing plants and digital I&C implementations for advanced reactors. *$*

2022 Cross-Cutting TI Portfolio: Information, Communication, and Cyber Security (ICCS) Overview (April 26 Webcast)

Q2 2022: Achieving decarbonization while ensuring reliability and resiliency depends strongly on ICCS innovations to allow secure data sharing with the growing number of stakeholders and technologies and deliver greater value for all. During this webcast, EPRI's experts provided a briefing on the cross-cutting, data-centric ICCS vision for 2030, roadmaps toward next-gen solutions encompassing both technology and standards, accomplishments from last year, and 2022 R&D activities. The ICCS TI portfolio includes 11 project areas enabling interoperability and pervasive telecommunications. Examples include standards for communication and DER interconnection, 5G technology assessments, secure out-of-band data acquisition, cyber security for extreme fast-charging, and reference architecture for operational technology data.

Hardware-Based Reference Signatures — An Approach to Digital Hardware Verification (3002022348)

Q2 2022: Globalization of semiconductor manufacturing has resulted in the disaggregation of design, fabrication, and packaging steps and highlighted the need for new techniques that can combat the introduction of counterfeit, recycled, or aged components into the supply chain, as well as validate hardware to mitigate advanced cyber security threats. This 72-page report describes preliminary R&D results and ongoing efforts to establish an approach for verifying the authenticity and integrity of hardware components for nuclear power plants and other energy infrastructure. It explores potential threats to operational hardware systems, reviews conventional verification methods, and analyzes their effectiveness and cost. A staged physical verification framework is proposed for field inspection of printed circuit boards, microprocessors, and integrated circuits, and planned proof-of-concept experiments on selected genuine and counterfeit/tampered devices are described. *$*

Utility Blockchain Interest Group: Energy Blockchain Update, Winter 2022 (3002023511)

Q1 2022: EPRI's Utility Blockchain Interest Group (UBIG) uses a collaborative approach to accelerate industry learning on real-world practical applications and to connect blockchain leaders in the global energy space. In order to do this, it is important to stay up to date and aware. In this 6-page newsletter, EPRI experts compiled a sampling of notable developments, activities, and events in the industry and beyond and added their own insights to share with UBIG and stimulate discussion. *$*

⭐ Preparing for the 2030 Energy System: A Vision for Electric Utility Information and Communication Technologies (ICT) and the Role that EPRI's ICT Program Plays in Helping Members Realize This Vision (3002022716)

Q1 2022: ICT is a key aspect of the digital transformation that is foundational to enabling decarbonization and providing grid flexibility and resiliency. ICT in the electric utility industry encompasses the acquisition, movement, and conversion of data from its source to its destination as actionable information. This 10-page white paper provides a summary of industry drivers, three ICT future states necessary for utilities to address the drivers, the

EPRI ICT program's strategy, and key past deliverables and accomplishments.

Distributed Ledger Technology and the Internet of Thingss (3002023493)

Q1 2022: Distributed ledger technology (DLT)—the most common of which is blockchain—and the Internet-of-Things (IoT) are emerging digital technology concepts with potential to revolutionize the electricity industry. This 10-page white paper examines the intersection of these two technologies, namely how DLT could provide an encrypted record of transactions of the vast amounts of data among devices and machines in emerging IoT applications in the utility industry. This paper seeks to uncover the impact of DLT on data architecture, communications, and security in the context of utility IoT applications, and it points toward next steps in addressing the gaps in implementation. *$*

Field Communicating AR/VR Technology Enablers (3002023218)

Q1 2022: Augmented and virtual reality (AR/VR) technologies are finding real-world industry applications where workers take advantage of digital information associated with objects within their field of view. Microsoft Hololens 2, a widely used AR tool, utilizes a mobile computing platform that includes a modem. This 26-page report investigates this AR tool's potential to also provide communications support in field environments, including cellular service.

Utilizing AMI Data for Fault Anticipation (3002021414)

Q1 2022: This 34-page tech update describes why and how a utility can integrate non-meter sensors and actuators into their AMI communications network in support of a wide variety of fault anticipation use cases. General characteristics of such devices are enumerated, followed by a case study of Con Edison's deployment of gas leak detectors on its AMI network. Guidelines are provided

to support successful integration of various kinds of non-meter devices within electric utility AMI networks. *$*

IEL21Report - Design Interactive: Instructor-Led, Live-Streamed Augmented Reality Training for Remote Workers (3002023023)

IEL "Lunch & Learn" Webcast: Design Interactive and Con Edison (April 27 Webcast)

Q1 2022: Conventional face-to-face training of utility workers at centralized facilities requires travel time, can be expensive, and introduces health risks in a time of pandemic. Online learning has limited applicability for many field-worker job skills. The ability to provide live-streamed, hands-on training to remote workers would help utilities transfer knowledge safely, effectively, and at scale with less disruption to productive activities in the field. This 4-page IEL 2021 project summary describes a test application of augmented reality training tools developed by Design Interactive. Con Edison hosted the demonstration, with field workers applying the tools both to develop and deliver training on a new cable termination procedure.

IEL21Report - Dynamhex: "Decarbonization-as-a-Service" Platform for Utility Planning and Customer Engagement (3002023024)

Q1 2022: The role of buildings as a lever for achieving economy-wide emission reductions and sustainability goals is gaining in importance. Utilities are ideally positioned to work alongside governments, companies, and other entities in aligning both internal and external decarbonization objectives with energy efficiency, demand response, electricity supply, and additional customer offerings. However, these customers often lack the data, expertise, and funds needed to create and manage their decarbonization plans. This 4-page IEL 2021 project summary describes collaborative demonstration of the decarbonization-as-a-service platform developed by Dynamhex for assisting customers in capturing and analyzing energy and emissions data and reducing their carbon footprints by taking advantage of utility offerings. The project was hosted by Ameren.
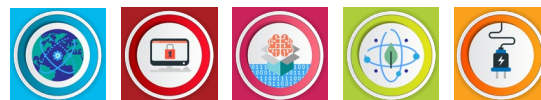
MATERIALS, MANUFACTURING & NONDESTRUCTIVE EVALUATION

2022 Cross-Cutting TI Portfolio: Nondestructive Evaluation (NDE) Overview ([April 25 Webcast](#))

Q2 2022: This webcast provided an overview on the vision, value, objectives, and priorities of EPRI's cross-cutting NDE TI program. A team of EPRI experts highlighted recent deliverables and provided updates on continuing and new R&D projects. Topics included proof-of-concept demonstration of machine learning for flaw depth sizing in heat exchanger tubing; NDE benchmarking for irradiation-embrittled austenitic stainless steel; high-energy x-ray inspection for underground transmission system components; virtual NDE ultrasonic testing (UT) training; advanced UT for additively manufactured components; and use case development for sample applications of the visual inspection and surveillance integrated operations network (VISION).


Ultrasonic Vibration Monitoring of Components Inside of a Pressure Boundary Using Externally Mounted Instrumentation – Proof of Concept ([3002023864](#))

Q2 2022: Vibration monitoring is widely used for condition monitoring of components and systems, but the technology cannot currently be applied to equipment contained within a larger pressure boundary component. This 100-page report summarizes successful proof-of-concept testing of an ultrasonic vibration monitoring system developed to monitor the thermal sleeve inside the control rod drive mechanism of a pressurized water reactor. The theory of using a time-of-flight measurement of an ultrasonic pulse reflected from a vibrating target has been demonstrated. This unique operating principle allows vibration monitoring of components that could not be instrumented in the past, and it can do this without a need for calibration. **$**

Realtime Augmented Reality for Nondestructive Examination ([3002023458](#); [3002023457](#) - video)

Q2 2022: Conventional NDE imaging techniques provide static snapshots that do not typically show the location of internal flaws in power plant components relative to welds, geometry, and other features, complicating characterization. This 31-page report and the accompanying short video summarize a successful bench-scale demonstration of a real-time NDE system that applies augmented reality (AR) technology to address these visualization limitations and enhance the efficiency and effectiveness of NDE. The recommended next steps define how future development of the AR platform could enhance its unique capabilities for better data visualization as applied to complex geometric parts.
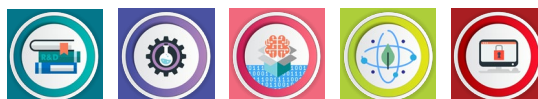
IEL21Report - Eneryield: Predicting Incipient Failures in High-Pressure Fluid-Filled Underground Cable Systems ([3002023026](#))

IEL "Lunch & Learn" Webcast: Eneryield ([June 7 Webcast](#))

Q1 2022: The high-pressure fluid-filled (HPFF) cables that underpin the majority of U.S. underground transmission systems are reaching or have exceeded their design lifetime of 40 years. Innovative methods for detecting incipient cable failures are needed to prevent high-impact events, improve reliability, and optimize asset management and maintenance interventions. This 4-page IEL 2021 project summary describes a demonstration to apply Eneryield's machine learning algorithms and other AI-based techniques for generating data-driven insights and predicting imminent disturbances and HPFF cable faults. New York Power Authority hosted this AI.EPRI project.

ACCESSING INFORMATION RESOURCES

Individual EPRI TI resources featured in this publication can be accessed by clicking the links provided.

EPRI TI resources are available for download at no additional cost to EPRI members by logging in at www.epri.com. Free and publicly available EPRI TI resources can be downloaded by other individuals and entities through EPRI's website.

Resources available for purchase by non-members can be ordered by calling the EPRI Order Center at 800.313.3774 (Option 2) or 650.855.2121. You may also send an email to orders@epri.com.

Visit the EPRI TI homepage for the latest resources: www.epri.com/research/sectors/technology

Visit EPRI's Thought Leadership page for the latest strategic insights: thoughtleadership.epri.com

For more information, contact the EPRI Customer Assistance Center at 800.313.3774 (Option 4) or askepri@epri.com.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.