EPRI

TECHNOLOGY INNOVATION

INSIGHTS AND INNOVATIONS

THIRD QUARTER, 2021

Insights and Innovations, *published quarterly, summarizes and provides links to 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. EPRI 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 other 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, EPRI TI white papers, briefs, reports, and other resources are assigned to a single R&D focus area among the list below. Icons identify relevant functional components and R&D topics, illustrating EPRI TI's matrixed nature.

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.17 for more details.*

CLEAN ENERGY

Offshore Wind—A Global Perspective (3002022617)

Q3 2021: As offshore wind project capacity and turbine size increase worldwide, improvements in technology, practice, and investor confidence continue to drive cost reductions. This 2-page infographic covers trends and projections addressing deployment, turbine size, cost of energy, and resource potential. Capital costs for onshore, fixed-foundation offshore, and floating offshore technologies are compared, and transmission interconnection options are introduced. Cost reduction opportunities are identified. ***$***

Advanced Reactor Cost Model Guide Development: Scoping Study Summary Report (3002020925)

Q3 2021: This 56-page report summarizes results of a scoping study exploring main issues, benefits, and challenges related to development of a standardized cost modeling guide (CMG) for

advanced nuclear reactor plants. Participating stakeholders included reactor developers and vendors; utilities and other potential owner-operators; engineering, procurement, and construction firms; and R&D organizations. To support ongoing and future planning for advanced reactor commercialization, key elements of an EPRI-developed CMG include integration of standardized language in the development of a generic cost breakdown structure that parallels traditional work breakdown structures and provides guidance on what should be included in a cost estimate and how it should be assessed. Ideally, different estimates prepared for the same plant or different plants would then have sufficient commonality in approach such that lack of agreement on values would result from varying opinions or data sources, not inconsistencies in treatment.

EPRI Insights: Current Events, Industry Forecasts, and R&D to Inform Energy Strategy, June 2021 (3002021729)

Q2 2021: This 39-page document, the inaugural quarterly *EPRI Insights* brief, features cutting-edge analysis capturing the multi-disciplinary perspectives of EPRI experts. Featured topics include global power generation trends and projections, energy policy and market developments, climate threats, and COVID-19 impacts. Technology highlights address solar plus storage, small modular nuclear reactors, and advanced energy communities.

Small Modular Reactor Vessel Manufacture and Fabrication: Phase 1—Progress (Year 3) (3002021037)

Q2 2021: The project described in this 284-page progress report is applying several advanced manufacturing and fabrication technologies with a goal of producing and testing a two-thirds-scale pressure vessel based on NuScale Power's small modular reactor (SMR) design. EPRI, U.S. Department of Energy, and the Nuclear Advanced Manufacturing Research Centre, working with NuScale and several other industrial members, seek to demonstrate that critical SMR components can be produced in less than 12 months at an overall cost savings of more than 40% versus today's technologies. Innovations being examined include powder metallurgy-hot isostatic pressing, electron beam welding, diode laser cladding, bulk additive manufacturing, and advanced machining. In addition to testing SMR applications, the project is exploring these technologies for other advanced reactor designs and high-temperature power cycles.

Hail Damage Assessment and Module Removal, Replacement, and Recycling Case Study for a Solar Power Project in North Carolina (3002022047)

Q2 2021: The case study featured in this 8-page *Application Insight Brief* covers post-storm damage assessment and removal, replacement, and recycling of damaged modules from a solar photovoltaic (PV) plant in North Carolina. It reviews the limitations of visual inspection and the capabilities of imaging methods for identifying damaged modules. In addition, current PV module recycling practices are highlighted, including uses for recovered glass. Relevant R&D by EPRI and others on hail strike damage, cell cracking and fracture, and performance impacts also is discussed. **$**

Towards Improved Guidelines for Cost Evaluation of Carbon Capture and Storage (3002021990)

Q2 2021: This 118-page report reviews results from an international collaboration engaging key stakeholders in developing new and improved guidelines for evaluating the cost of carbon capture and storage (CCS). Challenges unique to three areas are addressed: consistent cost evaluation for low-carbon energy technologies, such as new capture processes and novel power plant designs, at early pre-commercial stages of development; comprehensive cost evaluation of CCS from non-power industries such as cement plants, steel mills, refineries, and other industrial CO_2 sources; and quality assurance and uncertainty analysis for data and models used in CCS cost analysis.

Capacitive Electrochemical Deionization Technology Review (3002021325)

Q2 2021: According to this 13-page technology review, capacitive electrochemical deionization (CAP-EDI) represents a promising advance over conventional EDI with possible water and waste treatment applications in power plants. The principles of operation and advantages of CAP-EDI are discussed, recent innovations are reviewed, and the technology is compared to other present-day desalination and purification methods. In addition, commercial

CAP-EDI systems are described, and cost-performance potential is reviewed for the following power industry applications: tertiary water treatment, steam generator blowdown and condensate polisher system treatment, reactor coolant system cleanup, and radioactive waste processing.

Powering Decarbonization: Strategies for Net-Zero CO_2 Emissions (3002020700)

Q1 2021: This 21-page white paper summarizes key findings from EPRI modeling of scenarios for achieving "Net-Zero," "Carbon-Free," or "100% Renewables" targets in the U.S. electric sector by either 2035 or 2050 as critical paths toward deep, economy-wide decarbonization. For individual U.S. regions and nationally, the paper reviews and illustrates how differences in the target and its timing affect the contribution and value of different low-carbon technologies, the pace and scale of investment required, the impacts on electricity prices and energy service costs, and the role of the electric sector in enabling economy-wide decarbonization.

Solar Photovoltaics: End-of-Life Management Infographic (3002021132)

Q1 2021: This 2-page infographic reviews end-of-life (EOL) management issues, metrics, and opportunities for solar PV projects. It illustrates projected EOL module volumes in the decades ahead, module composition, PV plant material at decommissioning, and materials recovery rates and markets. In addition, the current state of knowledge on EOL management options and costs is presented, and R&D opportunities are identified. This infographic is the first in a series from EPRI's Renewables and Battery End-of-Life Strategic Initiative, which hosted "Electric Sector Challenges in Circular Economies for Renewables and Batteries," a March 2021 event in EPRI's Washington Seminar Series.

Ammonia and Hydrogen Fuel Blends for Today's Gas Turbines—Combustion Considerations (3002020043)

Q1 2021: As potential fuels for gas turbines, hydrogen and ammonia independently pose combustion challenges relative to natural gas. However, ammonia-hydrogen blends show promise for mitigating some of these issues. This 6-page brief discusses key combustion properties of hydrogen-ammonia fuel blends, associated gas turbine design considerations, and R&D activities.

National Carbon Capture Center 2020 Report (3002020177)

Q1 2021: Established by the U.S. Department of Energy, managed by Southern Company, and supported by EPRI and other industry participants, the National Carbon Capture Center (NCCC) provides testing facilities for carbon capture and utilization technologies at varying stages of development and scales. This 80-page report reviews studies conducted on three post-combustion processes fed by coal-derived flue gas—GTI's 0.5-MW membrane contactor, TDA Research's 0.5-MW adsorption process, and Precision Combustion's lab-scale adsorption concept. In 2021, the NCCC's test plans encompass more than a dozen capture technologies served by coal- or gas-derived flue gas, as well as its first evaluation of a CO_2 utilization technology. **$**

RELIABILITY, RESILIENCE & FLEXIBILITY

Quick Insight: Extreme Cold Events, Changing Climate Threats, and Power System Infrastructure Resiliency (3002022454)

Q3 2021: This 9-page *Quick Insight* brief examines what the polar vortex is, how it affects power system infrastructure, and how utilities might mitigate its effects in the future. Impacts of, and responses to, recent severe weather events are discussed.

Advanced Metering Infrastructure (AMI) Reference Architecture (3002021854)

Q3 2021: While selecting, operating, enhancing, and changing AMI systems are important tasks with significant technical and business implications, no comprehensive reference architecture exists to help utility personnel and other interested stakeholders evaluate the effects of alternative pathways. This 54-page report fills that gap by providing a vendor-neutral reference architecture. It identifies and models the application or technology functions required and the data produced or consumed to define AMI use cases in technology- and deployment-agnostic ways. This approach breaks down an otherwise complex collection of interactions into the core responsibilities of logical components and the data objects exchanged, allowing comprehensive analyses before final decisions are made. **$**

Rapid Emergency Restoration Concept for 220-500kV Transmission Lines (3002021172)

Q2 2021: EPRI is currently developing a concept demonstrator to gauge the feasibility of radically reducing service restoration time for transmission towers in the 230 to 500kV class. The goal for this project is complete replacement of a 500kV structure in 2 to 3 hours, including foundation installation. In this video, the concept is demonstrated, including aspects of the design that enhance safety and ergonomics. **$**

Residential Battery Storage Operations in Rolling Blackouts: Can Customer Energy Storage Improve Grid Reliability? (3002019991)

Q2 2021: This 5-page *Quick Insights* brief provides an illustrative analysis of residential battery storage dispatch and operation depending on owner incentives and price signals, and it highlights the need for R&D to understand and address the following key challenges: how much energy supply residential storage systems could contribute to resource adequacy and current limitations to accessing this potential; how different approaches to procurement of behind-the-meter storage capacity will impact participation in different owner groups and how that impacts the diversity in supply across the system; and how benefits and costs for stakeholders in various markets influence the design of products, tariffs, or customer programs to incentivize the needed level of residential storage participation.

Leveraging Space Applications for Advancing Environmentally Responsible Innovation in the Electricity Sector (3002020720)

Q2 2021: EPRI and the European Space Agency (ESA) have signed a Memorandum of Intent to investigate space applications for advancing environmentally responsible innovation in the electricity sector. This 8-page brochure introduces the collaboration between ESA and EPRI and identifies high-value energy industry applications of satellite assets and technologies, many of which are growing in importance due to digitization, electrification, and other drivers and because climate change is challenging the resilience of the electric system. The EPRI-ESA collaboration will actively pursue pre-operational solutions from space technology in the energy sector and help deepen knowledge and information exchange across the two organizations and industrial sectors.

Identifying the Gaps and Challenges of Resilience Valuation (3002020795)

Q1 2021: To build resilience and mitigate impacts from widespread and long-duration power outages, a variety of solutions—from traditional capital expenditures to customer-owned distributed energy resources (DERs)—may be considered. This 40-page white paper is intended to support multi-stakeholder prioritization of solution portfolios by exploring approaches for estimating outage costs, quantifying the value of energy-based services, and scoping valuation studies, as well as by identifying R&D gaps in translating lost wages, economic dislocations, and other impacts into value. Utility, customer, and other perspectives are captured, and discussion is threat, investor, and solution agnostic, providing a framework for collaborative studies aimed at weighing and prioritizing solutions for delivering targeted customer and societal benefits.

Lithium Ion Battery Technology Evolution (3002020562)

Q1 2021: Advances driven by the EV market have positioned lithium ion battery (LIB) technology as the dominant option for hourly and sub-hourly stationary energy storage applications, and innovation continues. This 5-page brief highlights developments in cathode and anode components, the potential of solid-state designs, and the growing importance of battery recycling and reuse as LIB deployment accelerates.

Strategic Engagement Brief: 2020 Digital Grid Summer Series (3002019940)

Q1 2021: In 2020, EPRI and Stanford University's Bits & Watts Initiative co-hosted the "Digital Grid Summer Series," diving deep into critical topics related to grid digitalization. The series focused on data platforms as a point of information gathering and exchange to accomplish coordinated control of DER within grid operations systems. As described in this 6-page brief, the virtual series kicked off with a 3-day Digital Grid Workshop followed by panel discussions engaging stakeholders from industry, government, and academia. Coming out of this engagement, both Stanford and EPRI plan to launch interest groups to keep these stakeholders connected and to incubate projects, pilots, and demonstrations for advancing data platforms that integrate customer technologies as grid resources.

Contingency Reserve Dimensioning: Status and Required Attributes (3002018762)

Q1 2021: Contingency reserve requirements are set based on reliability standards and additional ad hoc margins that are risk-agnostic, meaning they do not consider the likelihood of potential events and simply hedge against a predefined worst-case scenario. Ongoing power system transformation is introducing new contingencies as well as raising awareness of the need for improved methods for setting reserve requirements. This 52-page report documents current practices and summarizes the functional needs for a tool to dynamically set the correct amounts of reserve to be procured when needed, where needed, and from the best possible sources.

Integrated Transmission and Distribution Planning of Non-Wires Alternatives: Perspectives on Coordination and Analytics (3002019507)

Q1 2021: Advancing technology, falling costs, and regulatory directives are increasing attention to non-wires alternatives (NWA) for traditional reinforcement solutions for transmission and distribution systems. Fully realizing the benefits of NWAs requires coordinated planning to account for the various complexities and uncertainties introduced. This 46-page report documents how NWAs are addressed in transmission and distribution planning and introduces concepts for businesses processes and analytics supporting coordinated NWA planning. ***$***

Long Duration Energy Storage: Potential Use Cases and Technology (3002019019)

Q1 2021: The recent success of LIB systems for short-duration grid storage has driven interest in and development of long-duration energy storage technologies. This 20-page slide presentation presents application considerations for short- and long-duration energy storage and looks at applicable—and changing—definitions and attributes. It also maps where different storage mediums may provide solutions and provides a high-level snapshot of many of the emerging technologies being developed and their estimated demonstration timelines. ***$***

Grid Considerations for Microgrids (3002020344)

Q1 2021: Because microgrids come in many varieties, can exhibit a wide range of behaviors, and are designed to operate in islanded mode, they pose several potential grid integration challenges. This 14-page technical brief addresses DER interconnection and protection considerations with reference to IEEE Standard 1547-2018 and its known gaps. The focus is on on-grid operations and on transitions to and from off-grid mode; considerations for stable off-grid operation are not addressed.

Emerging DER and DERMS Technologies — Technology Innovation Scouting Report (3002019909)

Q1 2021: This 62-page report is based on innovation scouting by EPRI staff, including attendance at major conferences and

exhibitions, research into vendors and product specifications, and discussion with vendors to understand and document the capabilities of their emerging technologies for accommodating DER and for distributed energy resource management system (DERMS) applications. It addresses (1) transmission- and distribution-class power electronics technologies for regulating voltage, controlling power flow, and increasing hosting capability and (2) emerging DERMS product offerings. After general introductions to each technology area, vendor products and experiences are profiled. $

Introduction to The Control Center of the Future (Slide Deck: 3002019525) (Video: 3002019526)

Q1 2021: EPRI's Control Center of the Future (CCOTF) initiative seeks to develop an efficient, adaptive way for utilities to develop and follow a roadmap toward creating the data, software applications, facilities and hardware, decision support tools, and training needed in the years and decades ahead. This 32-slide presentation and companion video introduce the CCOTF methodology—developed in conjunction with innovative utilities in Europe—for identifying future system and market trends, aligning these trends with emerging technologies, performing a gap analysis, and developing a roadmap and implementation plan. $

Demonstrating Operational Planning Applications in the DCC of the Future (3002019506)

Q1 2021: EPRI developed its Operations, Protection and Systems (OPS) Lab to bridge the gap between emerging technology and its adoption for achieving grid modernization on the distribution system. It provides a means to demonstrate new applications and devices at scale in order to validate implementation in a distribution control center (DCC) and in the field. This 48-page report presents the lab's capabilities and underlying technical requirements. It also provides an overview of the completed, current, and future projects made possible through the OPS Lab. $

Fuels for Small Unmanned Aircraft Systems (sUAS) (3002020263)

Q1 2021: sUAS technologies have potential for monitoring transmission and distribution assets, conducting vegetation encroachment inspections, and surveying general conditions along rights-of-way. Commercially available sUAS primarily rely on LIB technologies, but other energy sources are on the horizon. This 12-page white paper summarizes the current field of candidate technologies for powering sUAS, their advantages and disadvantages, and their current technology readiness level. $

Comparison of UAS-Collected Point Clouds for Vegetation Threat Analysis: An Evaluation of LiDAR and Photogrammetry for Right-of-Way Monitoring (3002020098)

Q1 2021: Ground surveys and manned aircraft patrols are commonly employed to locate potential vegetation threats and line clearance issues, with light detection and ranging (LiDAR) scanners sometimes used during aerial inspections to accurately map potential threats. Utilities are now exploring UAS technology to fly missions to inspect vegetation using LiDAR and photogrammetry (PhoDAR). This 60-page report compares the technologies for effectiveness in performing surveys for vegetation management. $

Incubatenergy Labs 2020: RUNWITHIT Synthetics — Synthetic Environments for Resilience Planning (3002020661)

Q1 2021: Working in collaboration with Salt River Project, RUNWITHIT Synthetics demonstrated a single synthetic environment (SSE) application in utility resilience, creating the dual-disaster scenario of a power outage within the utility's service area during a pandemic. The SSE simulated how dual events can stress critical infrastructures and create health and safety risks, as well as demonstrated the use of artificial intelligence (AI), modeling, and visualization in diagnosing and mitigating vulnerabilities.

Incubatenergy Labs 2020: IND Technology — Early Fault Detection for Power Lines (3002020659)

Q1 2021: Working with IND Technology, Ameren and EPRI assessed the company's early fault detection technology by importing 15 radio-frequency sensor and data collection units from Australia and installing them on 138kV wood pole and steel lattice tower lines and 34kV lines with underbuilt 12kV distribution circuits remotely located in rugged terrain in rural Missouri.

Incubatenergy Labs 2020: Switched Source — Phase-EQ Dynamic Phase-Balancing Technology (3002020660)

Q1 2021: This project investigated the techno-economic benefits of deploying the Phase-EQ for dynamic phase balancing on distribution feeders. The project was divided into three components: (i) identifying the severity of phase imbalance issues, (ii) capturing the technical capabilities of the PhaseEQ device, and (iii) performing cost-benefit analysis.

Incubatenergy Labs 2020: LineVision — Overhead Transmission Line Monitoring (3002020662)

Q1 2021: This project involved a proof-of-concept demonstration of the LineVision V3 system to investigate the value proposition of a rigorous field trial, which for transmission line health monitoring technologies typically takes about 1 year to complete. The project approach included field testing of LineVision technology installed at sites chosen by Tennessee Valley Authority (TVA) and a parallel data gathering effort by TVA and EPRI to support comparative analyses and follow-up investigations.

ELECTRIFICATION & END USE

Current Events, Industry Forecasts, and R&D to Inform Energy Strategy, September 2021 (3002022779)

Q3 2021: This 48-page *EPRI Insights* document represents EPRI's latest review and synthesis of industry events, developments, perspectives, and forecasts to help inform energy strategy. It features a deep dive into a "Fourth Wave of Energy Efficiency" based on the proliferation of connected devices, highlighting ongoing R&D and demonstration projects in areas such as device communication and control, DER integration, AI, and blockchain. Additional topics include decarbonization, offshore wind, novel power purchase agreement structures, and wildfire threats.

Megawatt Scale Electric Vehicle Charging: Infrastructure Costs (3002022506)

Q3 2021: To support the scaling of high-power charging infrastructure, this 24-page report presents engineering cost data for on-site infrastructure, EV supply equipment, and primary utility interconnections. Regional cost differences are considered, and costs are evaluated on a $/kW basis for these infrastructure categories. A set of infrastructure cost metrics is provided, along with target values that align with increasing levels of EV adoption.

EPRI Strategic Engagement Brief – Review of EPRI's European Workshop Week 2021: How can advanced buildings and communities be scaled effectively and affordably? (3002022538)

Q3 2021: In March 2021, representatives from electric utilities, research organizations, and technology providers convened virtually for EPRI's European Workshop Week 2021, including an "Advanced Buildings and Communities" Session. This 13-page brief summarizes this session, highlighting key takeaways from speakers within the context of discussions of further research and effort needed to decarbonize buildings and communities at an

accelerated pace, both effectively and affordably. Key barriers to scaling energy communities and advanced buildings were identified, including the upfront and operating cost of electrification, the importance and value of resilient energy supply to customers, and the need for trust among all providers of energy resources to a community. Enabling technologies such as building envelope systems, open and scalable community optimization software, and blockchain were discussed, as were innovations in business models and customer engagement.

Canadian National Electrification Assessment: Electrification Opportunities for Canada's Energy Future (English Version: 3002021160) (French Translation: 3002022642)

Q3 2021: This 64-page assessment report builds upon extensive EPRI R&D, energy analysis, and modeling addressing the development and adoption of advanced electric end-use technologies in place of fossil-fueled alternatives. On the basis of emission reduction policies and initiatives adopted at the federal, provincial, territorial, and municipal levels, the analysis investigates and quantitatively characterizes electrification opportunities in Canada's building, transportation, and industrial sectors over the next 3 decades, along with implications for the economy, environment, and electric grid. Results indicate that deep decarbonization pathways entail significant electrification and other major transformations across energy supply, delivery, and use. Electrification saturates or becomes expensive after CO_2 emissions decline by approximately 80%, so additional options such as carbon removal, low-carbon fuels, and demand-side approaches become increasingly valuable for reaching net-zero goals.

The Fourth Wave of Energy Efficiency (3002021998)

Q2 2021: EPRI has identified four waves of energy efficiency. First came the emergence of building codes and standards, then utility demand-side management programs, and more recently increased adoption of more efficient end-use devices and appliances. The fourth wave, described in this 17-page brochure, is expected to result from the increased digitization of society, DER deployment, and the changing supply and demand mix. Customer adoption of "Internet of Things" technologies and platforms in homes, commercial buildings, industrial campuses, and community spaces offers the potential to increase efficiency through comprehensive energy management systems.

Customer Occupancy Models Using Behavioral Load Data (3002017539)

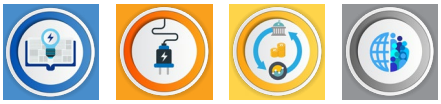
Q2 2021: This 28-page report describes R&D establishing the feasibility of using customer-sited load data as a basis for modeling behavior, occupancy patterns, and energy needs in buildings. The novel approach augments existing survey data and models used to identify occupancy patterns with probabilistic modeling to adaptively examine customer behavior in various areas of the home. Validation testing showed capability to determine the probability of occupancy by type at an hourly level and thereby adjust control strategies for energy use and DER management. Next steps are to integrate the model in a heuristic microgrid and load controller for time-of-use energy management in a commercial building. **$**

Conducting Qualitative Research with Utility Customers: Exploring New Uses of Usability Testing and Other Online Tools (3002017559)

Q2 2021: This 18-page technical update summarizes a study examining two online tools for use in recruiting participants to take part in customer research and in enabling interviewing, task recording, and observation. Relative to traditional in-person interviews, online tools generally did not inhibit natural interactions, offered greater convenience, and supported rapid and inexpensive screening of participants across different regions while simplifying scheduling and incentive payouts. However, these tools depend on the technical capabilities of participants and thus may not be as effective for certain populations. In-person sessions can still be better for building rapport, observing body language, and developing empathy. **$**

All-Electric Homes — Strategies for Adoption and Deployment (3002020199)

Q1 2021: This 7-page brief reviews the state of electrification in the residential sector based on advances in technologies such as air-source heat pumps, heat pump water heaters, induction stovetops, and electric vehicles (EV), as well as recognition of their roles in supporting decarbonization. Approaches for overcoming informational, behavioral, and transactional barriers to electrification—in particular, education and incentive programs for builders and homeowners—are introduced.



Temperature Impacts on Electricity Demand: US-REGEN Load Projections for Climate Resilience (3002020013)

Q1 2021: This 32-page technical update describes new EPRI modeling capabilities and methods for estimating the potential impact of changes in air temperature on energy demand for space conditioning in the United States out to 2050. Demand for heating and cooling is calculated using scenarios for hourly air temperature in a building energy model emulation that projects the evolution of space conditioning technology and building stocks based on various external assumptions. Nationally, US-REGEN modeling results show that rising temperatures will tend to counterbalance increases in cooling efficiency and in heating electrification.

Hybrid Heat Pump Economic Evaluation (3002020617)

Q1 2021: Following on a study establishing the technical feasibility of operating a hybrid heat pump using electricity and natural gas at the same time, this 22-page presentation summarizes a comparative analysis of the capital, operating, and life-cycle costs and implied environmental benefits of a range of heat pump designs, including the electric-gas hybrid. Installations were modeled in two different climates, New York City and Atlanta, Georgia. Results suggest that a hybrid heat pump is economically feasible in certain climates depending on cost and rate assumptions. **$**

Assessment of an Electric Thermal Oxidizer for Industrial Applications: A Feasibility Study of Substituting Electric Technology for Fossil Fuel Oxidizers (3002018579)

Q1 2021: This 12-page white paper describes bench-scale testing to evaluate use of an electric thermal oxidizer to achieve greater than 95% destruction and removal efficiency of volatile organic compounds in a gas exhaust stream. Conducted at Alabama Power Company's Technology Applications Center, the testing program achieved the target destruction efficiency and demonstrated the technical feasibility of replacing natural gas heating for thermal oxidizer treatment of waste gas streams. The next step is a pilot project at an industrial facility to test the scalability and efficiency of this electrification technology.

Tesla Data Collection Pilot: Insights and Methods (3002020265)

Q1 2020: Data from Teslas as well as other EVs can be expensive and difficult to obtain. This 30-page report describes a study exploring the feasibility of large-scale EV data collection using Tesla's application programming interface (API). A total of 40 Tesla drivers participated. Legal documents protecting customers and customer data proved key for enabling the successful data collection process. The work presented here represents a first step toward an integrated API platform that utilities and other interested parties could use to gain insights on driver behavior, laying the groundwork for a larger data collection effort.

Incubatenergy Labs 2020 Challenge: Final Report & Pilot Demonstration Summaries (3002020189)

Q1 2021: EPRI's Incubatenergy Labs Challenge is an annual accelerator program connecting startups with utilities interested in pursuing the demonstration and scaling of clean energy innovations. This 39-page final report describes how EPRI, 10 selected startups, and 11 utility sponsors pivoted during the pandemic, switching to a fully virtual engagement while still managing to successfully complete pilot demonstration projects on a tight schedule. Individual project summaries are incorporated in this report and available individually.

Incubatenergy Labs 2020: Grid Fruit — AI-Based Control for Commercial Refrigeration (3002020654)

Q1 2021: This pilot project, hosted by Southern California Edison, demonstrated Grid Fruit's data and software platform as a low-cost measure for optimizing refrigeration defrost control in convenience stores. Drawing on AI methods, Grid Fruit builds physics-based and data-driven models of the building envelope and energy profile of individual stores. The twins, when connected to real-world stores, guide implementation of control strategies for optimizing refrigeration operations to achieve a variety of diverse outcomes.

Incubatenergy Labs 2020: Recurve — Customer Targeting for Energy Efficiency Services (3002020655)

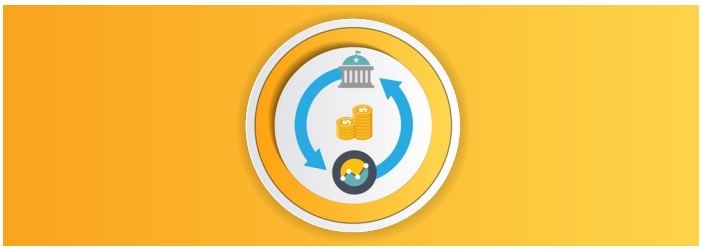
Q1 2021: This pilot explored the use of Recurve's Resource Planner tool and evaluated how advanced metering infrastructure (AMI) data could be applied for identifying and targeting business customers hit hardest by COVID-19. Recurve, EPRI, and Ameren worked together to demonstrate this tool's potential value for increasing the depth of customer targeting prior to direct utility engagement.

Incubatenergy Labs 2020: SHARC Energy Systems — Piranha Wastewater Heat Recovery (3002020656)

Q1 2021: This pilot involved field demonstration of Piranha™ technology, which supplies domestic hot water by capturing and reusing heat contained in wastewater. Thermal energy is extracted from wastewater and transferred to a refrigerant using an electric heat pump and direct expansion heat exchanger that enable high-efficiency operation year-round, in any climate. The demonstration was conducted at a multi-family residential building in North Vancouver, British Columbia, Canada.

Incubatenergy Labs 2020: Ev.energy — Managed EV Charging Software (3002020658)

Q1 2021: Through this pilot, Ameren deployed ev.energy's managed charging software with EV owners, both employees and interested customers, within its service territories in Missouri and Illinois. The project examined benefits in the areas of energy bill savings, greenhouse gas emission reductions, and feeder loading reductions.



MARKET TRANSFORMATION

Innovation Training Benchmarking: A Guide (3002022609)

Q3 2021: This 30-page resource profiles 24 organizations and academic institutions that offer public or private (in-house) training and learning programs in the areas of innovation, design thinking, and innovative business strategy. Information was obtained from web-based research and from interviews with innovation-minded professionals from utilities across the United States and Europe. The guide is designed to assist utilities in assessing and building their own innovation capabilities by supporting the benchmarking of existing or proposed innovation programs, as well as the identification and evaluation of potential service providers based upon specific learning and training needs, experiences, and objectives. **$**

Rethinking Deployment Scenarios to Enable Large-Scale, Demand-Driven Non-Electricity Markets for Advanced Reactors (3002022311)

Q2 2021: EPRI is exploring how the full potential of advanced nuclear energy technolgoies can help to address the interconnected challenges of meeting future global energy demands, maintaining and improving quality of life, and mitigating environmental degradation. This infographic preview an upcoming report that examines four possible deployment scenarios that reimagine the role nuclear technology can play in supplying clean electricity, advanced energy carriers such as hydrogen and ammonia, and potable water. Scenarios cover ship- and land-based advanced

reactors for marine transport and aviation fuels, polygeneration, and bulk hydrogen production.

EPRI 2020 Flexible Work Arrangements Survey: Benchmarking Results (3002019813)

Q2 2021: This 68-page presentation summarizes responses and provides insights from a web-based survey of flexible work arrangement (FWA) experiences, practices, and policies among companies represented on EPRI's Research Advisory Committee. Survey results indicate that COVID-19 has given companies a new sense of formal policy flexibility regarding work arrangements. Companies report many unique successes when it comes to implementing FWA: 89% of respondents reported positive impacts with employee morale/job satisfaction. Technology advances allow a greater percentage of the workforce to work remotely—without sacrificing productivity or efficiency—than previously thought. However, FWA is a balancing act: Increasing flexibility comes with trade-offs, such as concerns about employee burnout and maintaining corporate culture. **$**

A Framework for the Application of Global Circular Economy Principles for the Electric Power Industry (3002020568)

Q2 2021: The traditional linear economic model—extract, manufacture, use, and dispose—is not sustainable at the scale of material and resource consumption now occurring globally, helping drive efforts to transition to a global circular economy (GCE) model. This 34-page report provides an overview of GCE concepts and policy frameworks developed by the European Union, China, the Organization for Economic Cooperation and Development, and the Ellen MacArthur Foundation. Additionallly, an initial framework for implementation of GCE principles in the electric power industry is presented.

Evolution of Electricity Market Design with 100% Clean Energy (3002019510)

Q1 2021: Under this EPRI project, the following paper has been published: Erik Ela, Andrew Mills, Eric Gimon, Mike Hogan, Nicole Bouchez, Anthony Giacomoni, Hok Ng, Jim Gonzalez, and Mike DeSocio, "Electricity Market of the Future: Potential North American Designs Without Fuel Costs," *IEEE Power and Energy Magazine,* 19 (1), Jan.-Feb. 2021, pp. 41-52. The link above provides access to the article.

MATERIALS, MANUFACTURING & NONDESTRUCTIVE EVALUATION

Nondestructive Microstructure Characterization of Temperate Martensitic Steels (3002021057)

Q3 2021: Nondestructively and reliably determining the condition of Grade 91 steel in the field—especially over large areas—is an ongoing challenge in the industry. This 130-page report investigates the potential of various nondestructive evaluation (NDE) methods to discriminate among eight different microstructure conditions representative of potential in-service conditions. Mockups were manufactured using controlled heat treatments on thick-walled pipe sections and thin-walled tubes. Magnetic, thermoelectric power, and ultrasonic NDE methods were evaluated individually and then in combination to devise an integrated inspection method. Analysis suggests that magnetic methods be the primary approach used since they can identify four key conditions, while ultrasonic methods can be applied to increase confidence and/or identify a fifth condition. **$**

Nondestructive Assessment of Early-Stage Fatigue in Martensitic Steels (3002021058)

Q3 2021: Turbine blade fatigue cracks may grow from an undetectable size to failure between inspections. This 106-page report presents findings from a laboratory assessment of six NDE techniques for use in detecting early stages of fatigue, prior to crack formation, including nonlinear optics and five electromagnetic methods: resistance anisotropy measurements, both through low-frequency alternating potential drop (ACPD) and higher-frequency eddy current techniques, magnetic permeability, magnetic

Barkhausen noise (MBN), and nonlinear eddy current. Results indicate that nonlinear optics, ACPD techniques, and the considered frequency features of the nonlinear eddy current do not seem sensitive to the fatigue damage of interest. On the other hand, eddy current, magnetic permeability, and the considered time domain features of the MBN signal showed some sensitivity to the damage, with the effect seeming to saturate at an early stage in the fatigue process. $

Metallurgical Evaluation of an Additively Manufactured Nickel-Base Superalloy for Gas Turbine Guide Vanes (3002022335)

Q2 2021: Additive manufacturing (AM) components have generally been restricted to lower-stress gas turbine applications such as combustion hardware. EPRI and Power Systems Manufacturing (PSM) recently collaborated in characterizng an AM nickel-based superalloy material used in one of the world's first hot-section applications. This technical paper reports results for tensile, fatigue, and creep tests on the AM Alloy 939 derivative ultimately utilized for gas turbine guide vanes. While tensile and fatigue properties were similar or superior to those of the cast equivalent, a significant debit in creep strength was observed. The paper focuses on microscopy studies throughout each step of the AM process and heat-treatment cycle to understand microstructural features leading to reduced creep strength. Possible mitigation methods and limitations for future applications are also discussed. The paper published in *Proceedings of the ASME Turbo Expo 2020: Turbomachinery Technical Conference and Exposition*, can be accessed using the link above.

High-Temperature Strain Gage Development for Fossil Boiler Applications (3002020983)

Q2 2021: Based on a multi-year R&D effort, this 58-page report summarizes lab testing, development, applications engineering, field installation, and data collection for novel high-temperature strain gages applied for direct monitoring of fossil plant boiler components. Two classes of strain sensors were explored: semiconductor and thin film. Both technological paths showed efficacy, but semiconductor sensors are being pushed to the limit of their material chemistry. As a result of the work performed to date, new possibilities exist. Future plans for applying this technology are to provide telemetry data and enable near-real-time assessment of the impacts of plant operations on component integrity. $

High-Speed Imaging for Visual Inspection of Rotating Machinery (3002019870)

Q2 2021: This 12-page technical brief summarizes a financial feasibility study related to the costs and benefits of extending maintenance and test intervals for turbine valves and overspeed protection system components. Data assessing the cost, time, and power reduction required to perform periodic maintenance and testing of these components were collected from several plants and integrated to represent a generic one-unit plant with 14 turbine valves and output of 1000 MWe. Baseline costs were compared to the expected costs of performing less frequent maintenance and testing based on visual inspections performed via high-speed imaging. This application resulted in a strong business case, yielding cumulative savings over the 25-year remaining plant life.

INFORMATION, COMMUNICATIONS & CYBER SECURITY

Cyber Security Vision for 2030 (3002022715)

Q3 2021: As technology, policy, and business developments transform the electric sector and build new interdependencies with other energy sectors and infrastructures, the approach to operations technology cyber security must evolve beyond the traditional role of safeguarding against attacks that attempt to destroy or disable grid systems. This 12-page white paper describes critical future states and gaps that must be addressed to achieve an intrinsically secure energy system by 2030. It examines these states within the

context of four key industry drivers: foundational security and resilience, value transformation, digital transformation, and decarbonization.

Preparing for the 2030 Energy System: A Vision for Electric Utility Information and Communication Technologies (3002022716)

Q3 2021: Information and communication technology (ICT) in the electric utility industry encompasses the acquisition of data from the field, the movement of data from its source to its final destination, and the conversion of data into actionable information. This 4-page white paper provides a summary of industry drivers and identifies three key ICT future states—data-centricity, interoperability, and pervasive telecommunications—that must be achieved in order to enable decarbonization while providing the necessary grid flexibility and resiliency.

HAZCADS: Hazards and Consequences Analysis for Digital Systems - Revision 1 (3002016698)

Q3 2021: Previous EPRI work (3002000509) showed that systems-theoretic process analysis (STPA) is effective in identifying unsafe control actions in digital instrumentation and control (I&C) systems, and that fault tree analysis (FTA) is effective in identifying random hardware failures and their risk sensitivity relative to top events such as core damage, radiological release, and lost generation. This 162-page report introduces the HAZCADS Revision 1 methodology as a practical, risk-informed approach, structured around defined activities, that leverages the strengths of STPA and FTA to guide engineers concerned with designing or assessing digital I&C systems or component applications in commercial nuclear power facilities. This transformative methodology is designed to determine the contributions digital systems play in overall plant risk and to determine an appropriate level of control method effectiveness, commensurate with risk, for each element of a digital I&C system. $

Integrated Security Operations Center and Monitoring and Diagnostics Digital Data Integration for Advanced Cyber-Physical Detection Capability—A Roadmap for the Energy Sector (3002019701)

Q2 2021: This 62-page report provides a repeatable roadmap for implementing a combined operational and security analytical model, and it demonstrates the benefits of integrating real-time security data with operational data streams used for power plant monitoring and diagnostics. The recommended roadmap involves three functional areas: integration and curation of data feeds, analytics software development, and people and process integration. Nine energy sector analytics use cases integrating the two data feeds were explored and prioritized based on industry benefit and implementation burden. Several "quick win" applications were identified for utilizing existing technology, people, and processes to realize near-term value. $

Utility Blockchain Interest Group: Energy Blockchain Update, May 2021 (3002022169)

Q2 2021: EPRI's Utility Blockchain Interest Group (UBIG) uses a collaborative approach to accelerate industry learning on real-world applications and to connect blockchain leaders in the global energy space through our network of international members and stakeholders. This 8-page briefing is intended to assist UBIG participants and other interested stakeholders in remaining current on notable activities in the industry and beyond. It includes a sampling of recent developments, along with insights from EPRI's subject-matter experts, to support information exchange and to stimulate discussion. $

Work Order Management Business Analysis and Testing (WOMBAT) (3002020888)

Q2 2021: As part of a multi-year intitiave to develop extended reality (XR) applications within a work order and maintenance context, EPRI has created the WOMBAT tool. The objectives of the project summarized in this 96-page report were twofold—to demonstrate use of an interface compliant with the International Electrotechnical Commission Common Information Model (CIM) in creating an improved test harness; and to identify new data requirements for support of in-plant XR. Results show that WOMBAT is a step improvement over previous harnesses for CIM-based conformance testing for XR applications, and they

demonstrated once again the ease with which a messaging infrastructure can be created when using a standards-based approach.

In-Plant Common Information Model for eXtended Reality, Human Machine Interface (3002019867)

Q1 2021: Drawing on research in XR applications and supporting technologies, EPRI published a 2020 report (3002019865) that introduces a full stack of capabilities required for a messaging infrastructure to support XR in power generation facilities, specifically for data exchange centered on work management. Among other things, the stack includes a human-machine interface (HMI) for a handheld device capable of data exchange with EPRI's WOMBAT database on both Wi-Fi™ 6 and 5G bands. This video addresses the HMI.

Preparing for the 2030 Energy System: Why We Need a New Cyber Security Vision (3002020794)

Q1 2021: This 7-page white paper examines the cyber security impacts on operations technology associated with four metatrends shaping electricity and energy infrastructures: decarbonization, digital transformation, resiliency, and the changing value of cyber security. It introduces the concept of "intrinsic security"—fully integrated in an enterprise's mission, processes, technology, and culture—as a key enabler of the future electric sector and energy system. It also describes the need to develop a 2030 cyber security vision and roadmap to guide the electricity industry as the next-generation grid emerges and evolves.

Incubatenergy Labs 2020: Kognitiv Spark — RemoteSpark Subject-Matter Expert Tool (3002020653)

Q1 2021: This pilot project demonstrated the feasibility and value of implementing the remote subject-matter expert solution developed by Kognitiv Spark using a commercially available augmented reality product, the Microsoft HoloLens2. The RemoteSpark application offers capabilities uniquely suited for industrial environments and isolated work sites.

Software Containerization for Utility Field Use (3002018633)

Q1 2021: As the capabilities of meters and other field devices have advanced, their ability to take on a new functions has increased to the degree that some can run operating systems such as Linux. Software containers, which are isolated computing environments for running applications, have been extensively used for delivering secure, high-quality distributed software. This 4-page paper examines the opportunities for software containerization for utility field use. ***$***

ARTIFICIAL INTELLIGENCE & DATA ANALYTICS

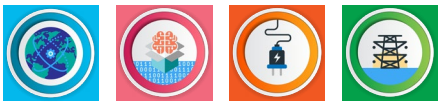
The Tag Whisperer: How Natural Language Processing Can Benefit Utility Generation Fleets (3002020297)

Q1 2021: This 9-page brief introduces EPRI's Tag Whisperer v1.0 tool, which provides a standardized approach for naming incoming data streams from sensors and other utility assets to support monitoring and diagnostics applications. This tool is designed to ingest multiple existing naming standards, apply natural language processing and other methods to search through a list of tags/channels coming in from a site or a fleet, and automatically identify potentially applicable standards for individual assets. Pilot testing results highlight promise for creating standardized tag names for distributed data sources and identify opportunities for enhancement.

Incubatenergy Labs 2020: PingThings — PredictiveGrid Time-Series Data Platform (3002020657)

Q1 2021: This pilot, hosted by Ameren, demonstrated the PredictiveGrid™ platform for creating data-driven applications for realizing the full value of utility time-series data assets. PredictiveGrid is a data management, analytics, and AI platform designed to work with time-series measurements from any grid

sensor, from AMI to synchrophasors to power quality and continuous point-on-wave monitoring.



Potential Applications for Artificial Intelligence and Machine Learning in Coal Combustion Product Research: Methods and Applications (3002020324)

Q1 2021: This 52-page report explores the ways that AI and machine learning may be used in R&D addressing coal combustion products and management facilities. Analytical approaches are introduced and potential applications are explored, especially in the areas of leachate quality, leachate quantity, and groundwater impacted by leachate. ***$***

Utilization of Emerging Data Science Technologies to Electric Power Sector Environmental Challenges: Index of Research (3002020681)

Q1 2021: From December 2017-February 2021, EPRI published 45 environmental science and technology reports addressing methods and applications involving high-volume, high-velocity, or high-variety data; AI and other solutions for data aggregation, cleansing, analysis, or visualization; and innovations that generate or integrate big data streams. This 5-page index lists these reports and identifies those available free to the public, published in academic journals, available at no extra charge to EPRI members, and available for purchase.

Application of Data Analytics to Mine Nuclear Plant Maintenance Data (3002020120)

Q1 2021: This 96-page report describes an initial application of data analytics and machine learning techniques to determine the extent to which analysis of large amounts of equipment data can lead to insights that will improve equipment reliability and reduce significant equipment-related events within the nuclear power industry. Maintenance work order records collected by EPRI were analyzed first to provide general insights into the cost and performance of different maintenance strategies. After a natural language processing dictionary was developed to support contextual analysis of these records, the analysis was successfully extended to consider effectiveness on a component-by-component basis. ***$***

Using Machine Learning to Predict Flow-Accelerated Corrosion Wear Rates (3002019731)

Q1 2021: This 7-page technical brief describes an initial effort to use machine learning models to predict flow-accelerated corrosion wear rates based on the CHECWORKS™ database. The results are compared to the predictions provided by the CHECWORKS™ model and to measured wear rates. The machine learning models show potential to offer significant improvements in predictive accuracy in the low-wear-rate regime. ***$***

EQUITY & SOCIAL JUSTICE

Equity and Environmental Justice Considerations for a Clean Energy Transition (3002021206)

Q2 2021: The traditional linear economic model—extract, manufacture, use, and dispose—is not sustainable at the scale of material and resource consumption now occurring globally, helping drive efforts to transition to a global circular economy (GCE) model. This 34-page report provides an overview of GCE concepts and policy frameworks developed by the European Union, China, the Organization for Economic Cooperation and Development, and the Ellen MacArthur Foundation. Additionallly, an initial framework for implementation of GCE principles in the electric power industry is presented.

ENVIRONMENT, HEALTH & SAFETY

Differentiators in Safety Performance: Successful Initiatives in the Electric Utility Sector to Reduce Serious Injuries and Fatalities Fact Sheet (3002022475)

Q3 2021: In a first-of-its-kind, 2-year study, EPRI explored the question, "What measures of safety culture, safety management, and business factors most influence safety performance?" Answers can help organizations efficiently direct limited resources to the safety activities and elements of the business that may have the greatest positive impact on safety outcomes. This 2-page fact sheet describes insights and findings from the first empirical study to identify, among many potential organizational factors, the ones that are most influential and should be prioritized in safety programs at commercial nuclear power plants and other utility facilities.

Comparing Company Characteristics and Injury Rates—Differentiators of Safety Performance, Phase 2: Data Analysis and Results (3002021082)

Q3 2021: A previous EPRI study identified 110 potential differentiators of safety performance in the electric utility sector and validated a set of surveys to measure them. This 96-page report analyzes results from surveys distributed to 13 companies. Single and multiple linear regressions revealed nine variables both strongly and significantly correlated with safety performance. These variables can be organized around the themes of human factors (especially safety communication from management), leading indicators, prevention through design, contractor selection and management, and incentives/disincentives. Results suggest that prioritzing management of these variables provides a means for using limited resources most effectively to optimize safety performance. Future research is recommended to collect more data to confirm and refine results and potentially identify other influential variables.

Comparing Company Characteristics and Injury Rates: Identifying Organizational Differentiators of Safety Performance (3002021085)

Q3 2021: This 58-page presentation complements recent EPRI technical reports that identify and explore organizational differentiators of safety performance. It contains updates on data collection challenges during the COVID-19 pandemic and identifies keys to enhancing safety performance. Additionally, recommendations, applications, and next steps are provided. ***$***

Sustainability Priorities for the North American Electric Power Industry: Assessment of Emerging Artificial Intelligence-Enabled Approaches (3002021526)

Q2 2021: EPRI third industry-level sustainability priorities assessment involved a comparison of traditional approaches and AI-enabled methods. This 66-page report reviews existing AI-based methods and tools, and it evaluates similarities, differences, and complementarities with traditional methods based on test application of one service provider's method for an industry-level identification of sustainability priorities for the North American electric power sector. Findings indicate that AI-enabled methods have merit but may be best considered as a complement, instead of a replacement, to human expertise.

ACCESSING INFORMATION RESOURCES

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

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Together...Shaping the Future of Energy

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