ELECTRIC POWER RESEARCH INSTITUTE

U.S. National Electrification Assessment

EXECUTIVE SUMMARY

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FOREWORD

Over the past few years, the Electric Power Research Institute (EPRI) has collaborated with many stakeholders to examine the forces that are transforming the world's energy systems. At the center of this work is our concept of an Integrated Energy Network (IEN)—the idea that the effective integration of energy supplier and user networks can and will lead to more reliable, flexible, and affordable energy services (www.ien.epri.com).

In this paper we highlight a key element of the IEN: the critical and growing role that electricity will play in the future energy system. Many others have envisioned a more electric future. EPRI offers a new systematic look, anchored in leading-edge modeling, to understand key drivers, potential barriers, and the possible pace of electrification from many distinct viewpoints: customers, power generation and delivery, and equipment providers, as well as the impact on the environment and the economy. The EPRI modeling approach differs from other studies in many respects—including our representation of economic trade-offs, integration of electric demand and supply, and outlook on the rate of technological change, particularly for energy efficiency, where our view is informed by years of extensive laboratory testing and field demonstration projects.

Electricity's role in the energy system has grown for over a century, and it is poised to continue growing steadily or perhaps accelerate, while improving our standard of living. Rapid technological change, such as improvements in energy storage and pervasive digitalization, dramatically expand the range of electric technologies that make economic sense—providing superior service at a lower cost. Increasingly cleaner electric generation combines with a desire for a cleaner environment and healthier workplaces to potentially accelerate this change and create an ever cleaner and more efficient global energy system.

EPRI's Board of Directors approved an Electrification Initiative in 2017 to study the pivotal role of efficient electrification, including analysis, creation of an electrification technology pipeline, and expansion of R&D collaborations. This document, the U.S. National Electrification Assessment (USNEA), frames the discussion, but it's just the start. We will initiate U.S. state-level studies starting in 2018 to explore the local opportunities and realities; collaborate with member companies and others to gain a richer understanding of efficient electrification outside the United States; continue to accelerate the development of advanced electric technologies and the infrastructure needed to incorporate them to meet customer desire and need; and expand collaborations with other stakeholders at the international, national, state, and local levels, who are focused on understanding electrification opportunities and challenges.

We offer this document to spark discussion of efficient electrification. We invite you to visit our electrification website (www.epri.com/#/pages/sa/efficientelectrification) where you can subscribe to our monthly electrification newsletter and register to participate in our inaugural Electrification 2018 conference (www.electrification2018.com), August 20–23, 2018, in Long Beach, California.

Michael W. Howard, Ph.D., P.E.

President and CEO
Electric Power Research Institute

EXECUTIVE SUMMARY

Electrification describes the adoption of electric end-use technologies. In developing countries, this often refers to making electric power available to customers for the first time. The value of this type of electrification is well established. In more advanced economies, including the United States, electrification increasingly describes electric end-uses displacing other commercial energy forms or providing new services such as 3-D printing and indoor agriculture. EPRI uses efficient electrification to refer to such opportunities across the economy that yield a range of efficiencies—lower cost, lower energy use, reduced air emissions and water use, improved health and safety for customer's workers coupled with the opportunity for gains in productivity and product quality, and increased grid flexibility and efficiency.

EPRI's Efficient Electrification Initiative explores electrification in the context of the global energy system—analyzing the customer value of advanced, end-use technologies that efficiently amplify benefits of cleaner power generation. Coupling EPRI's modeling capabilities with its extensive research on end-use technologies and grid planning and operations, the initiative is assessing interdependent aspects of electric technologies' adoption, electrification's potential to enhance control and flexibility, and the impacts on grid operations and planning.

To help frame EPRI's broad undertaking, this report highlights key findings from EPRI's U.S. National Electrification Assessment (USNEA), which examines customer adoption of electric end-use technologies over the next three decades, along with key implications for efficiency, the environment, and the grid. The study finds that, across a range of assumptions, economy-wide electrification leads to a reduction in energy consumption, spurs steady growth in electric load, and reduces greenhouse gas (GHG) emissions—even in scenarios with no assumed climate policy. Advances in both end-use technologies and technological integration reduce costs, drive higher adoption, and amplify customer benefits. In modeling scenarios with a carbon price, the benefits from electrification are more substantial. This study also focuses attention on needed research and development and challenges for future policy and regulatory frameworks that will guide the transition.

ASSESSMENT APPROACH

The U.S. National Electrification Assessment examined four scenarios with EPRI's US-REGEN energy-economy model[1] to consider opportunities, drivers, and challenges for electrification (Figure ES-1). The ***Conservative*** and ***Reference*** scenarios focus on how changes in technology cost and performance affect outcomes. In the ***Reference*** scenario, technology costs and performance improve over time across the economy, in some cases rapidly, based on anticipated technology trends. The ***Conservative*** scenario considers a slower decline in the relative cost of electric vehicles, a key technology for electrification. Two scenarios explore the impact of potential economy-wide carbon policy: the ***Progressive*** scenario in which carbon is valued at $15/ton CO_2 starting in 2020, and the ***Transformation*** scenario in which the carbon value starts at $50/ton CO_2 in 2020.[2] In addition, a natural gas price sensitivity analysis examines the potential impact of rising gas costs on efficient electrification.

All of the scenarios use as a starting point, projections from the U.S. Energy Information Administration's Annual Energy Outlook 2017[3] of economic growth, primary fuel prices and service demands (e.g., vehicle miles traveled by region or square feet of commercial buildings that is heated). EPRI technology assumptions are used in examining alternatives for providing these services. State-level policies such as renewable portfolio standards and carbon policies help guide regional technology choices.

This assessment focuses on cost-effective technology choices with and without a carbon price. It does not estimate some of the possible additional benefits of electrification, including improved air quality, enhanced grid flexibility, increased productivity or comfort, or better workplace safety. These will be examined in state-/utility-specific assessments. The assessment does not specifically assume future market transformations or policy and regulatory frameworks that would favor adoption of electrification technologies or spur investment in supporting infrastructure. The assessment also does not model newly emerging applications for electricity (e.g., indoor agriculture and 3-D printing), which offer potential efficiency, productivity, environmental, and other benefits.

CONSERVATIVE	*Slower Technology Change*
REFERENCE	*Reference Technology*
PROGRESSIVE	*Reference Technology + Moderate Carbon Price*
TRANSFORMATION	*Reference Technology + Stringent Carbon Price*

- *AEO 2017 growth path for GDP and service demands, and primary fuel prices*
- *EPRI assumptions for cost and performance of technologies and energy efficiency over time*
- *Existing state-level policies and targets*

Figure ES-1. Study Scenario Overview

1. US-REGEN is an energy-economy model of the United States. It has been employed extensively over the past decade to explore various energy system issues and potential policies. For this study US-REGEN integrated detailed models of consumer choice. Model structure and assumptions can be found in *US-REGEN Model Documentation*, www.epri.com/#/pages/product/3002010956/.

2. In both the Progressive and Transformation scenarios the carbon price increases at 7% real per year through 2050.

3. Annual Energy Outlook 2017: with projections to 2050 at www.eia.gov/outlooks/archive/aeo17/.

KEY INSIGHTS

- *Customers increase their reliance on electric end uses*

In the United States, electricity has grown from 3% of final energy in 1950 to approximately 21% today. Across the four scenarios, electricity's role continues to grow, ranging from 32% to 47% of final energy in 2050. In addition to providing an array of benefits to customers, this trend has important implications for how the electric system will evolve.

Without efficient electrification, EPRI projects that electric loads will decline, driven by efficiency gains. With efficient electrification, the study projects cumulative load growth of 24–52% by 2050 (see Figure ES-2, which summarizes this and other results). The 52% load increase projected in the ***Transformation*** scenario implies a 1.2% annual growth rate. While some of this load growth will be customer-supplied, utilities in most cases will supply capacity to ensure reliability. By comparison, annual load growth from 1990–2000 was 2.7%, dropping to 0.82%, on average from 2000–2010. For electric companies, such slow but steady growth can moderate potential rate impacts of investments for environmental compliance or grid modernization. Moreover, if guided, new flexible loads can improve grid efficiency and performance.

In all four scenarios, growth is led by the transportation sector, starting from minimal electric use today. Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) quickly become cost-effective alternatives to conventional vehicles for most drivers. Heat pumps for space and water heating, along with electric technologies in industry and heavy transportation, are increasingly adopted in favorable markets, at rates constrained by stock turnover.

The analysis suggests that the economic potential for electrification is compelling in many applications, yet realizing this potential requires removing policy and regulatory barriers that impact choice or limit supporting infrastructure. For customers, other barriers include a lack of innovative financing or risk aversion stemming from insufficient information on electrification technologies' value and benefits.

- *Final energy consumption decreases*

The modern era has been driven by significant growth in *final energy*—a measure of energy consumed across all fuel types at the end use. Most analyses suggest continued growth for decades to come.[4] In contrast, all four USNEA scenarios project falling final energy consumption. Continued growth in economic activity and energy services across all sectors of the economy is offset by efficiency improvements across the energy system, led by advances in individual end uses, such as lighting, variable speed motors, and more efficient internal combustion engine vehicles, as well as a shift from non-electric to more efficient electric technologies.[5] For the ***Reference*** scenario, the analysis projects a reduction in economy-wide final energy consumption of 22% by 2050, while electricity use grows by 32%. Final energy consumption declines further, and electricity use grows more in the ***Progressive*** and ***Transformation*** scenarios. This fundamental change in the composition of the energy system, which occurs in the ***Reference*** scenario and even in the ***Conservative*** scenario, illustrates the importance of establishing policies and regulations that adopt an economy-wide perspective of energy efficiency.

4. For example, the Energy Information Administration's Annual Energy Outlook 2018 projects slow final energy growth for the United States across a wide range of future scenarios.

5. Energy efficiency assumptions are informed by years of extensive laboratory testing and field demonstration projects, combined with observations of advances being driven by customer technologies–see for example, *The Third Wave of Energy Efficiency*, www.epri.com/#/pages/product/3002009354/.

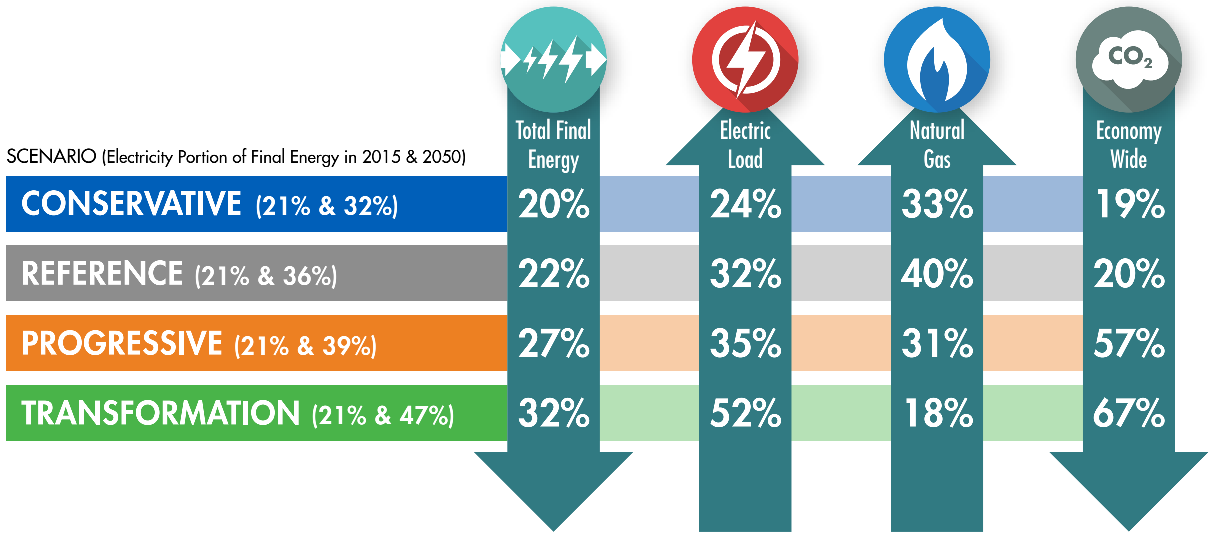

Figure ES-2. High-level Overview of Modeling Results

- *Natural gas use increases*

With respect to natural gas in the United States, perceptions of a limited or dwindling resource a decade ago have been replaced with expectations that it will provide a low-cost, abundant fuel for the long term. Its importance to the electric sector has grown since the late 1980s and recently surpassed coal as the most-used fuel for power generation. Natural gas use continues to grow in all four EPRI scenarios based on its operational flexibility and an assumed ongoing cost around $4/MMBtu. The continued transition to gas creates both economic and environmental benefits (e.g., lower emissions than petroleum, which it often replaces in industry, and lower emissions than coal when used for electric generation). Direct natural gas use in industry and to fuel electric generation grows, while natural gas use in building heat remains relatively flat over time. Electric heat pumps with natural gas backup become attractive technologies in colder regions, utilizing the best features of both with dual-fuel capability potentially providing additional reliability.

In the *Transformation* case (which assumes a significant and growing carbon price), carbon capture and sequestration technology (CCS) enables natural gas to increase its share of electric generation, outweighing declines in the direct end-use of natural gas. In sensitivity analyses that assume that natural gas prices rise gradually to about $6/MMBtu by 2050, natural gas use still increases in all four scenarios despite the price rise.

As the electric sector's reliance on natural gas grows, it becomes increasingly important to incorporate natural gas supply modeling in reliability assessments. Recent disruptions in natural gas supply[6] highlight the importance of considering broader gas supply uncertainty in planning.

Another area in which natural gas may compete and that was not modeled in detail, is for combined heat and power. Electric grid modernization is key to unleashing the potential grid benefits of these technologies.

- *Low-carbon electric generation expands*

The carbon intensity of electric generation has fallen in recent years due to lower natural gas prices and increased penetration of solar photovoltaic (utility scale and distributed) and wind generation. Renewable energy continues to grow across all scenarios, driven by cost declines and state-level policies. In the carbon price scenarios, the share of wind and solar increases more rapidly as part of a diversified portfolio of low-carbon energy sources. Due to the declining marginal value of intermittent renewable energy, its economic penetration is ultimately limited, with nuclear and natural gas with CCS balancing the mix and providing firm capacity. The assumption that natural gas prices remain below $4/MMBtu across the scenarios

6. For example, a 2015–2016 Aliso Canyon natural gas storage leak in southern California led to the ongoing closure of the nation's fourth largest natural gas storage facility and the need for electric companies and state regulators to take extraordinary and costly measures to maintain electric system reliability in the Los Angeles basin. Extreme weather can also create disruptions. For example, extreme cold weather created significant challenges to regional energy systems in January 2014 due to the breakup of the Arctic polar vortex.

implies a greater role for natural gas with CCS in the carbon price scenarios, although the large-scale availability of this technology remains uncertain. In sensitivity analyses in which natural gas prices are assumed to rise gradually over 35 years to $6/MMBtu, wind, solar, and nuclear all have increased generation shares.[7]

As solar and wind generation capacity increases, the power system must operate more flexibly to accommodate their variable output. Although not explicitly modeled in this study, the addition of flexible loads through efficient electrification could emerge as a central strategy to efficient renewable generation integration.

- *Emissions decrease*

In nearly every cost-effective application, electrification also lowers system-wide carbon emissions. Even absent a carbon policy, projected CO_2 emissions fall 20% by 2050 in the ***Reference*** scenario, driven by efficiency gains and efficient electrification. Although not modeled in this analysis, other EPRI research suggests that electrification can improve local or regional air quality by reducing emissions of criteria pollutants. Policies that provide an active signal to cut emissions (the ***Progressive*** and ***Transformation*** scenarios) lead to even greater environmental improvements—notably through a more rapid shift to electricity. For the ***Transformation*** scenario, electricity's projected share of U.S. final energy reaches nearly 50% by 2050, with emissions falling to nearly 70% below 2015 levels.

- *Pressures increase to modernize grid infrastructure, operations, and planning*

As the end-use mix includes more vehicle charging and heating applications, seasonal low temperatures will drive heating demand, while reducing the efficiency of electric vehicles—resulting in a shift in overall loads to the winter months. While electricity demand in most U.S. regions peaks during the summer, peak loads could shift to winter by 2050 across the USNEA scenarios, assuming no efforts to actively manage loads. At the same time, these new electric loads provide significant opportunities for more flexible and responsive demand response, as well as storage. Realizing such benefits is contingent on investment in a flexible, resilient, and integrated grid[8] and clear electricity market signals. Such demand-side changes coupled with more diverse, dynamic electric supply, create an array of challenges and opportunities for system planners and operators.[9]

- *Technology innovation lowers costs and creates opportunities.*

Realizing electrification's benefits depends on continued innovation in electric technologies to reduce costs and improve performance. The value is significant in all scenarios, but is greatest in the ***Transformation*** scenario, in which policy establishes a high value on lower emissions. Yet, economics alone and broader customer awareness will not be sufficient to realize the full potential for society. Industry stakeholders will need to build upon lessons learned from past successes, such as utility-administered energy efficiency programs to advance electrification technologies. In addition, effective rate designs coupled with policy and regulatory frameworks can be structured to support investment in electrification end-use technologies and enabling infrastructure, including a more resilient, integrated electric grid.

7. Given this study's focus on energy demand, only a few scenarios were examined for exploring generation. Key factors other than the price of natural gas, the value of carbon, and the availability of CCS that affect the technology mix include: renewable mandates, cost declines and technology change over time, relative costs of capital, the evolution of electricity markets (which affect both the total capacity of renewables and the relative economics of central versus distributed PV), the cost and availability of transmission, the cost and duration of storage, environmental constraints other than CO_2, the impact of renewable variability on the cost of the rest of the system, and flexible load. EPRI research has explored these factors in many other studies. Recent examples include a 2017 model comparison paper from NREL, EPRI, EIA, EPA and DOE, *Variable Renewable Energy in Long-Term Planning Models: A Multi-Model Perspective*, www.nrel.gov/docs/fy18osti/70528.pdf; and an article by John Bistline, "Economic and Technical Challenges of Flexible Operations under Large-Scale Variable Renewable Deployment" in *Energy Economics*, Vol. 64, May 2017.

8. *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources.* www.epri.com/#/pages/product/000000003002002733/.

9. *Developing a Framework for Integrated Energy Network Planning (IEN-P): Ten Key Challenges for Future Electric System Resource Planning*, EPRI 3002010821 (forthcoming 2018).

ACTIONS TO REALIZE THE FULL BENEFITS OF EFFICIENT ELECTRIFICATION

The U.S. National Electrification Assessment brings into focus the potential for efficient electrification to transform the energy system. Yet it points to many actions that appear necessary to realize the full benefits. All require research, development, and demonstration to develop and test technologies, and to inform policy, regulation, and market choices—examining how alternatives may affect the grid and the energy system.

- *Accelerate technology research, development, and demonstration*
  - Cleaner electricity production. Cleaner, more efficient power generation is essential to realize the full environmental benefits of efficient electrification. Electric generation has reduced its environmental footprint significantly over the past decade. Future gains depend on continued improvement of renewable energy, natural gas, coal, and nuclear technologies; increased flexibility in dispatch and improvements in storage; expansion of biofuels; and development and demonstration of CCS.
  - Grid modernization. Grid investment must enable the dynamic matching of variable generation with demand, while supporting new models for customer choice and control. Investments are needed also to maintain reliability and enhance resiliency. Grid capacity planning and operation will need to address the integration of electric transportation networks with the grid through smart charging, fast charging, and storage utilization.
  - Continued, rapid advances in electric end uses. Falling battery costs, digitalization, advances in materials, and increasing production scale can improve the efficiency and performance of a range of electric technologies, from automobiles to industrial equipment. Transformative shifts on the horizon include mobility-as-service models and autonomous vehicles, indoor agriculture, additive manufacturing, and electro-synthesis of chemicals.
- *Develop new analytical tools*
  - More in-depth studies of opportunities and challenges of efficient electrification. The USNEA provides a starting point for considering and examining efficient electrification, offering insights and a framework for additional analyses. For the United States and other countries, detailed regional studies are needed for a realistic understanding of the costs, the benefits, and the barriers that will drive customer choices in varied circumstances.
  - New cost-benefit frameworks for assessing individual electrification projects. New methods for comparing options for providing energy services are essential to support informed regulation and to implement programs that address barriers to customer adoption of technologies. Improved understanding of diverse customers' perspectives is essential in building more useful models.
- *Expand focus on reliability and resiliency*
  - New metrics for reliability. As the electric system increases its reliance on variable renewables and just-in-time delivery of natural gas, it is important to re-examine concepts of reliability that historically focused solely on the electric system and on framing resource adequacy, primarily annual peak demand. Looking ahead, system reliability may be framed in multiple hours by comprehensively considering system flexibility, natural gas delivery risk, and other factors.
  - Greater focus on electric system resiliency. The scenarios depict an expanding role for electricity in the energy system, which heightens requirements for resiliency with respect to both natural forces (e.g., extreme weather) and physical or cyber attacks. As electric systems "go digital" from generation through billions of connected devices, the points of entry for attack increase exponentially. That same digital capability can be harnessed to locate, isolate, and recover from both natural disruptions and attacks.

- *Inform policy, regulatory, and electricity market designs*
    - Coordinated, economy-wide policies. The dramatic sectoral shifts projected in all four scenarios underscore the value of taking a broad view of energy policy, rather than addressing issues piecemeal. Uncoordinated approaches for electricity, transportation, and industry or across energy sources create unnecessary costs. Broadly considered policies may enable more effective, less disruptive shifts, with respect both to the energy sector and society. For example, for environmental policy, this assessment's modeling assumes a consistent carbon signal applied to all sectors of the economy. Yet today no country takes this approach, choosing various policy approaches for different sectors. Policies focused on one sector can limit the interactions among multiple sectors to achieve broader goals. For example, efficient electrification could reduce economy-wide emissions even while leading to a relatively small increase in electric sector emissions.
    - Updating energy efficiency codes. A review of energy efficiency measurement and cost tests (e.g., for appliances, heating, and transportation) is needed to remove fuel bias and to frame regulations that enable efficient electrification and encourage traditional energy efficiency.
    - Facilitating market transformation. Targeted programs—similar to efforts with energy efficiency—may be needed to address barriers to efficient electrification, where it makes sense economically and among public priorities.
    - Electricity market designs to send consistent signals to both supply- and demand-side. With new electric supply and demand technologies projected to emerge, it becomes increasingly important to value energy, capacity, flexibility, locational value, storage, and other attributes. EPRI's research on advanced energy communities with zero net energy and all-electric residences clearly shows the need for valuing both energy and grid connectivity.[10]

CONCLUSION AND NEXT STEPS

EPRI's U.S. National Electrification Assessment brings into focus the potential for efficient electrification to create value for customers and society, looking across energy end-use sectors. Its analyses point to actions needed to define benefits more precisely and to establish an effective transition. EPRI is moving forward on many fronts, with near-term actions that include:

- Detailed, state-level assessments to examine the costs, benefits, drivers, barriers, and challenges to efficient electrification, integrating local knowledge and circumstances. EPRI is pursuing similar collaborations internationally. These studies will examine a broader array of drivers for investment and transformation of energy systems, including local air quality.
- A benefit-cost framework in 2018 for assessing individual efficient electrification projects to support investment and inform regulatory decision-making.
- Establishing electric technology centers of excellence at universities and other institutions to create, demonstrate, and field test a range of emerging electric technologies.
- Expanded research in resiliency and cyber security to address emerging challenges for the electric sector and for society as it continues to electrify.
- Facilitating awareness among all industry stakeholders and customers through active outreach. Initiate an annual international conference for diverse groups that will drive the electric future—generators small and large, grid operators, end-use vendors, universities, research labs, regulators, policymakers, city governments, businesses, smart communities, and individual customers—to consider, pursue, and realize the benefits of efficient electrification.

In addition, EPRI's ongoing research addresses efficient electrification as their primary scope or as part of a broader or supporting scope of work. Chapter 5 provides information on these programs, or they can be found online at www.epri.com/#/portfolio/en/2018/home.

10. See, for example, *Grid Integration of Zero Net Energy Communities*. www.epri.com/#/pages/product/3002009242/.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electric utility revenue in the United States with international participation in 35 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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