ELECTRIC POWER RESEARCH INSTITUTE

A PREVIEW OF THE U.S. NATIONAL ELECTRIFICATION ASSESSMENT

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FOREWORD

Over the past few years, the Electric Power Research Institute (EPRI) has collaborated widely across society and industry to examine the forces that are changing, possibly transforming, the world's energy systems. At the center of this work is our concept of an Integrated Energy Network*—the idea that the integration of supplier and user networks can and will lead to more reliable, flexible, and affordable energy services (*http://ien.epri.com*.)*

In this paper we highlight a robust insight: 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 transmission and generation, equipment providers, and the ultimate impact on environment and the economy. The EPRI modeling approach differs markedly 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 has grown for over a century, and it is poised to continue growing steadily or perhaps accelerate, improving our standard of living. Rapid technological change, such as improvements in batteries and pervasive digitalization, dramatically expand the range of electric technologies that make economic sense—providing superior service at a lower cost. 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, 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 new thinking and discussion around efficient electrification. We invite you to visit our electrification website*, subscribe to our quarterly* electrification newsletter *and participate in our inaugural* Electrification 2018 conference*, August 20–23, 2018 in Long Beach.*

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 developed countries, like the United States, electrification is increasingly taking a different form, as electric end-uses displace use of other commercial energy forms. EPRI uses "efficient electrification" to refer to such opportunities across the economy that yield a wide range of efficiencies—lower cost; lower energy use; reduced air and water emissions; an improved environment, health and safety for customer's workers coupled with the opportunity for gains in productivity and product quality; and increased grid flexibility and efficiency.

Launched in 2017, 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 the benefits of cleaner power generation portfolios. Coupling EPRI's modeling capabilities with its extensive research on end-use technologies and grid operations, the initiative also will assess interdependencies among increased adoption of efficient electric technologies, their potential to provide enhanced control and flexibility, and their impact on grid operations and planning.

To help frame EPRI's broad undertaking, this summary highlights key findings from EPRI's U.S. National Electrification Assessment (USNEA), which assesses customer adoption of electric end-use technologies over the next three decades and key implications for efficiency, the environment, and the grid. The study finds that, across a range of assumptions, economy-wide electrification leads to a significant reduction in energy consumption, spurs steady electric load growth, increases grid efficiency and flexibility, and reduces greenhouse gas (GHG) emissions—even when there is no assumed climate policy. Advances in both end-use technologies and technological integration reduce costs, drive higher adoption, and amplify customer benefits. By highlighting the potential value of efficient electrification, its key drivers, and potential barriers, the assessment focuses attention on needed research and development and the supporting policies and regulatory constructs needed to help enable an efficient electrification future.

KEY INSIGHTS FROM THE U.S. NATIONAL ELECTRIFICATION ASSESSMENT

The U.S. National Electrification Assessment examined four scenarios to consider opportunities, drivers, and challenges for electrification. The ***Conservative*** and ***Reference*** scenarios focused 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 cost of electric vehicles, a key technology for electrification. Two other USNEA scenarios explore the impact of potential future economy-wide carbon policy: a ***Progressive*** scenario in which carbon is valued at \$15/ton CO_2 starting in 2020, and a ***Transformation*** scenario in which the carbon value starts at \$50/ton CO_2 in 2020.[1] In addition, a natural gas price sensitivity analysis examined the potential impact of rising gas costs on efficient electrification. These scenarios are summarized below.

Scenario	Description	Common assumptions
CONSERVATIVE	*Slower Technology Change*	• Annual Energy Outlook 2017 growth path for gross domestic product 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
REFERENCE	*Reference Technology*	
PROGRESSIVE	*Reference Technology + Moderate Carbon Price*	
TRANSFORMATION	*Reference Technology + Stringent Carbon Price*	

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

This assessment does not estimate possible additional benefits of electrification, including improved air quality, increased productivity or comfort, or better workplace safety. They are considered important benefits that are best captured in EPRI's future, more detailed state-/utility-specific assessments. In addition, this assessment does not specifically assume future market transformations, or policy and regulatory frameworks to incent adoption of electrification technologies or spur investment in supporting infrastructure.

Six key insights emerged from the analysis.

1. *Customers increase reliance on electric end uses*

   In the United States, electricity has grown from 3% of final energy in 1950 to around 21% today. Across the four scenarios, electricity's role continues to grow, ranging from 32% to 47% of final energy in 2050. Providing an array of benefits to customers, this trend also has important implications for electric load growth.

   Without efficient electrification, EPRI projects that electric loads will decline, driven by efficiency gains. With efficient electrification, the study projects load growth of 24–52% by 2050. 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, capacity to ensure reliability will, in most cases, be supplied by the utility. By comparison, annual load growth from 1990–2000 was 2.7%, dropping to 0.82%, on average, annually from 2000–2010. For electric companies, such slow but steady growth can moderate potential rate impacts of grid modernization investment.

   In all four scenarios, growth is driven 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 many other electric technologies in industry and heavy transport, are increasingly adopted in favorable markets, at rates constrained by their slower 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. Other customer barriers to overcome stem from a lack of innovative financing or information (and consequent risk aversion) about the value of efficient electrification technologies.

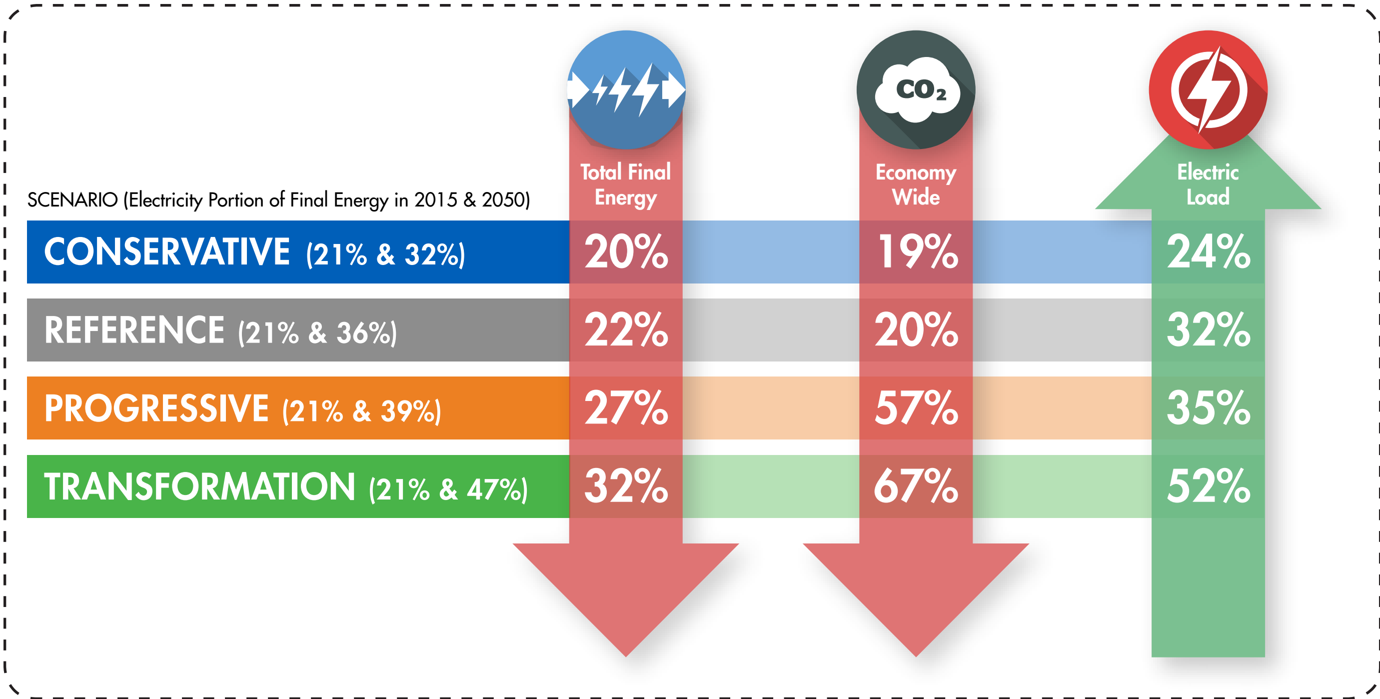
2. *Final energy consumption decreases*

   The modern era has been driven by a significant and continuing growth in final energy—a measure of energy consumed across all fuel types at the end use. Most analyses suggest continued growth for decades into the future.[2] 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 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 much more efficient electric technologies.[3] The result is a reduction in economy-wide final energy consumption of 22% by 2050 in the ***Reference*** scenario, while electricity use grows by 32%. Final energy consumption declines further and electricity use grows more in the ***Progressive*** and ***Transformation*** scenarios. This fundamental reconfiguration of the energy system, which occurs even in the ***Reference*** case, illustrates the importance of establishing policies and regulations that remove any fuel bias by adopting an economy-wide perspective of energy efficiency.

3. *Technology innovation lowers costs*

   Realizing electrification's benefits depends on continued innovation in electrification technologies that reduce costs and improve performance. The value is significant in all scenarios, but is greatest in the ***Transformation*** scenario, in which policy places a high value on lower emissions. Yet, economics alone and broader customer awareness will not be sufficient to realize the full potential for society and customers. Indus-

2. 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.
3. 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*, https://www.epri.com/#/pages/product/3002009354/



try stakeholders will need to build upon lessons learned from past successes, such as utility-administered energy efficiency programs. 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 modernized electric grid.

4. Emissions decrease

In nearly every cost-effective application, electrification also lowers system-wide carbon emissions. Even without a carbon policy, CO_2 emissions fall 20% by 2050 in the ***Reference*** case, driven by efficiency gains and efficient electrification. Although not modeled in this analysis, improvements in air quality through reduction in criteria pollutants can be even more significant in some locales for driving a transformation.[4] 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. Electricity's share of total energy reaches nearly 50% by 2050 in the ***Transformation*** scenario, with emissions falling to nearly 70% below 2015 levels. The figure above summarizes the energy consumption, CO_2 emission, and load projections for 2050 across the four scenarios.

5. Natural gas use increases

In the United States, natural gas is a low-cost, seemingly abundant fuel. Its importance to the electric sector has grown since the late 1980s, and recently natural gas surpassed coal as the most-used fuel for power generation. Overall natural gas use continues to grow in all four EPRI's scenarios, which assumed continued low natural gas prices. Gas use also increases when higher gas prices are coupled with the other ***Reference*** scenario assumptions. In three scenarios, natural gas use increases both for direct end use and for electric generation. Notably, in the ***Transformation*** case (which assumes a significant and growing carbon price), carbon capture and sequestration (CCS) technology is needed for natural gas to remain a growing part of the electric generation mix. In this case, end-use of natural gas is projected to decline as the carbon price rises, but an increase in gas-fired electric generation (with CCS) supports continued growth in overall gas consumption.

6. Pressures increase to modernize grid infrastructure, operations, and planning

As the end-use mix shifts to include more vehicle charging and heat applications, seasonal low temperatures will drive heating demand, while reducing

4. *Environmental Assessment of a Full Electric Transportation Portfolio: Executive Summary* (EPRI-NRDC study). https://www.epri.com/#/pages/product/000000003002006881/

the efficiency of electric vehicles—resulting in a shift in overall loads toward the winter months. While electricity demand in most U.S regions peaks during the summer, peak loads could shift to the 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 modernized grid[5] and clear electricity market signals. In addition, these demand-side changes, coupled with rapid changes in electric supply, create an array of new challenges and opportunities for system planners and operators.[6]

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. Five actions are fundamental, each requiring R&D to develop and test technologies, and to inform policy, regulatory, and market choices.[7]

1. *Expanded R&D to accelerate technology development*
    - 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 also needed to maintain reliability and enhance resiliency. A catalyst to electrify transportation, the integration of an electric transportation network with the grid through smart charging, fast charging, and storage utilization will need to be part of grid capacity planning and operation.
    - Continued, rapid advances in electric end uses. Falling costs of batteries, rapid advances in 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.
2. *New policy and regulatory designs*
    - Coordinated, economy-wide policies. The national assessment modeling assumed a consistent carbon signal applied to all sectors of the economy. Yet, no country is taking this approach, choosing various policy approaches for different sectors. If policies target sectors, it is important not to limit their interactions (e.g., efficient electrification) as a tool in reducing overall emissions; a small emissions increase in the electric sector may often lead to an overall emissions reduction for the economy.
    - Updating energy efficiency codes. A review of efficiency measurement and cost tests (e.g., for appliances, heating, and transport) is needed to remove fuel bias and frame regulations that enable efficient electrification and continue to encourage traditional energy efficiency.
3. *New electricity market designs*
    - Market designs to send the right signals to both supply- and demand-side. With new technologies projected to emerge on both sides it becomes increasingly important to value energy, capacity, flexibility, locational value, storage, and other attributes. EPRI's research on advanced energy communities

5. *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources.* https://www.epri.com/#/pages/product/000000003002002733/
6. See Integrated Energy Network-Planning paper, forthcoming.
7. Note that EPRI's role differs across these issues. For example, while EPRI research directly accelerates development and demonstration of electric technologies, its role in the policy/regulatory domain is to develop the science and technology to inform decisions.

with zero net energy and all-electric homes clearly shows the need for valuing both energy and grid connectivity.[8]

4. New analytical tools

- More in-depth studies of opportunities and challenges of efficient electrification. The USNEA provides a starting point for discussing efficient electrification, offering insights and a framework for additional analyses. Detailed regional studies are needed in the United States and other countries to understand more realistically the costs, the array of 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 in 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 an essential focus in building more useful models.

5. Expanded focus on resiliency

- Greater focus on electric system resiliency. The scenarios depict electricity's expanding role 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.

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 the end-use sectors. Its analyses point to actions needed to define these benefits more precisely and to establish an effective transition. EPRI is moving forward on many fronts. The Institute's near-term actions include:

- Initiate detailed, state-level assessments to examine the costs, benefits, drivers, barriers, and challenges to efficient electrification, integrating local knowledge and circumstances, and pursue similar international collaborations. These studies will examine a broader array of drivers, including local air quality.
- Develop a benefit-cost framework in 2018 for assessing individual projects to support investment and inform regulatory decision-making.
- Establish electric technology centers of excellence at universities and other institutions to create, demonstrate, and field-test a range of emerging electric technologies.
- Expand research in resiliency and cyber security to address emerging challenges for the electric sector and for society.
- Facilitate awareness across 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 provide the resources they need to understand and realize the benefits of a more electrified world.

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

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA • 800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com