"ELECTRIFY EVERYTHING" HAS become a common slogan, an easy-to-understand pathway promising a cleaner and more efficient energy system. Indeed, consensus is emerging that dramatic growth in electrification across transportation, buildings, and even some industrial uses will be a key strategy for achieving deep decarbonization. Yet while the concept of electrification is easy to understand, many of the key power system issues remain under-appreciated and unresolved. The full electrification of transportation, for example, would require massive changes to grid design and operation, and full electrification of heat networks in cold climates would place dramatic new pressures on wintertime supply and delivery. In a highly electric economy with significant shares of variable wind and solar electricity, systemic mismatches between supply and demand would necessitate vast amounts of storage as well as entirely new paradigms for capital investment and cost recovery.

The goal of this issue of IEEE Power & Energy Magazine is to provide a snapshot of state-of-the-art research focused on the role of electricity in deeply decarbonized energy systems. Four of the articles take a geographic approach and describe how national or regional electric sectors might evolve in highly decarbonized futures. Two of the articles explore topics that cut across many regions: electrification of heat and market design. The final article summarizes a wide range of recent electrification simulations and proposes principles for advancing the quality of analysis.

In the first article, researchers from the Fraunhofer Institute for Solar Energy Systems describe pathways to a nearly carbon dioxide (CO₂)-free German energy system by 2050. The authors lay out a rigorous simulation approach to evaluate the technical and economic feasibility of achieving three possible CO₂ emissions reductions targets by 2050: 80, 90, and 95%. In all three futures, the transformation of nearly all economic sectors is required. But large and sometimes counterintuitive differences also emerge in meeting these three decarbonization targets. By describing and contrasting these differences, the authors help us understand how a seemingly small difference in emissions targets can have a large system impact.

In the second article, researchers from the National Renewable Energy Laboratory (NREL) describe an almost fully electrified U.S. energy system. Summarizing a recently published study, the authors detail scenarios for high electrification in the United States, with and without accelerated investment in energy efficiency and zero-carbon electricity. The authors explore how each scenario would impact electricity load shapes, generation capacity expansion, and CO₂ emissions. The article also quantifies how much CO₂ reduction can be expected from end-use electrification on its own, as well as when electrification is paired with energy efficiency, zero-carbon electricity, or both. In this way, the authors illuminate issues that can help decision makers identify priorities for cost-effective CO₂ abatement.

In the third article, researchers from National Grid in the United Kingdom describe how electrification contributes to achieving a deeply decarbonized U.K. economy by midcentury. Drawing on their most recent “Future Energy Scenarios” report, which has been published annually since 2011, they lay out what would need to happen in three key energy sectors (heat, transport, and power) to achieve the stated national target of 80% CO₂ reduction by 2050. Across heat and transport, they find rapid growth in end-use electrification and identify customer adoption as a key barrier to the pace needed for achieving the targets.

The fourth article compares and contrasts 2030 decarbonization pathways in two distinct regions of the United States with similar carbon reduction goals: California and the seven-state Northeast region. Researchers from Energy and Environmental Economics, Inc. (E3), National Grid U.S., and Siemens Power Technologies International describe what would need to happen in the two regions to achieve a 40% reduction by 2030. Not surprisingly, given the different climates, renewable resource
endowments, and building stocks, the two pathways look quite different, yet both rely heavily on electrification in achieving the stated goals. These similarities and differences illuminate how the unique features of different regions will powerfully shape energy system evolution under decarbonization.

In the fifth article, a team of researchers from Vector Unlimited, University of Manchester, University College Dublin, and NREL explore heat electrification in depth. Looking across Europe, the team summarizes cutting-edge research into how heating requirements might be anticipated, minimized, and managed. For example, they describe unique research that simulates how household changes, such as relaxing thermostat settings by 2–3 °C, would have significant system impacts as diverse as reducing generation capacity, wind curtailment, and coal generator ramping. The article reveals how important heat electrification will become in energy-system planning in cold climates.

In the sixth article, researchers from Evolved Energy and the University of San Francisco explore the challenges that electrification may pose for electricity market design. In particular, the authors describe the novel and under-appreciated system challenges that would emerge in highly electrified, highly renewable energy systems. They go on to analyze why these challenges would likely pose existential questions for existing electricity market designs and conclude by suggesting concepts for future market design.

In the seventh article, researchers from the U.S. Department of Energy survey the most high-profile U.S. electrification studies of the past five years, identifying commonalities but also significant differences between the studies’ findings and methodologies. For example, the scenarios forecast a wide range of projected electricity growth, ranging from a 1.5x increase to a 3x increase by 2050. The authors then go on to lay out a research program to improve the rigor, consistency, and relevance of electrification studies.

In the concluding “In My View” column, Jim Williams of the University of San Francisco notes that many countries have adopted science-based targets for greenhouse gas reductions, and he then succinctly describes the multiple, overlapping paradigm shifts that would be required to achieve these targets. The list of paradigm shifts spans nearly all parts of the energy landscape: how energy efficiency is promoted by policy, how struggling nuclear plants are dealt with, how electricity markets are designed, and how utilities are regulated.

Together, this collection attempts to provide a useful snapshot of activity in the electrification space. From the diversity of authors and varying geographies being studied, it is apparent that electrification and its impacts have become a vital discussion point within the industry. We hope you will enjoy reading it and continue to engage with the power and energy community to advance the state of the art in this crucial area.