Chapter III

MODERNIZING THE ELECTRIC GRID

This chapter examines how the electricity grid of the future can provide affordable and reliable clean electricity, while minimizing further human contributions to climate change. After an introduction to the structure of the U.S. electrical grid, the chapter lays out a vision for its transformation and describes the drivers of change toward the future grid. These major drivers cover challenges and opportunities that affect transmission and distribution grids, involve new technologies and services, and require careful consideration of the diverse institutions and business models currently involved in managing the grid. After discussion of a policy framework for the grid of the future, the chapter concludes by presenting a series of recommendations, divided into three major categories: (1) research and development, analysis, and other studies; (2) state and regional planning and managing across jurisdictions; and (3) appropriate valuation, standards, and measurement methods to facilitate the introduction of new technologies and practices to improve the grid.

FINDINGS IN BRIEF:
Modernizing the Electric Grid

Investments in transmission and distribution upgrades and expansions will grow. It is anticipated that in the next two decades, large transmission and distribution investments will be made to replace aging infrastructure; maintain reliability; enable market efficiencies; and aid in meeting policy objectives, such as greenhouse gas reduction and state renewable energy goals.

Both long-distance transmission and distributed energy resources can enable lower-carbon electricity. The transmission network can enable connection to high-quality renewables and other lower-carbon resources far from load centers; distributed energy resources can provide local low-carbon power and efficiency.

The potential range of new transmission construction is within historic investment magnitudes. Under nearly all scenarios analyzed for the Quadrennial Energy Review, circuit-miles of transmission added through 2030 are roughly equal to those needed under the base case. And while those base-case transmission needs are significant, they do not appear to exceed historical yearly build rates.

Flexible grid system operations and demand response can enable renewables and reduce the need for new bulk-power-level infrastructure. End-use efficiency, demand response, storage, and distributed generation can reduce the expected costs of new transmission investment.

Investments in resilience have multiple benefits. Investments in energy efficiency, smart grid technologies, storage, and distributed generation can contribute to enhanced resiliency and reduced pollution, as well as provide operational flexibility for grid operators.

Innovative technologies have significant value for the electricity system. New technologies and data applications are enabling new services and customer choices. These hold the promise of improving consumer experience, promoting innovation, and increasing revenues beyond the sale of electric kilowatt-hours.

Enhancing the communication to customer devices that control demand or generate power will improve the efficiency and reliability of the electric grid. For example, open interoperability standards for customer devices and modified standards for inverters will improve the operation of the grid.

Appropriate valuation of new services and technologies and energy efficiency can provide options for the utility business model. Accurate characterization and valuation of services provided to the grid by new technologies can contribute to clearer price signals to consumers and infrastructure owners, ensuring affordability, sustainability, and reliability in a rapidly evolving electricity system.

Consistent measurement and evaluation of energy efficiency is essential for enhancing resilience and avoiding new transmission and distribution infrastructure. Efficiency programs have achieved significant energy savings, but using standard evaluation, measurement, and verification standards, like those recommended by the Department of Energy's Uniform Methods Project, is key to ensuring that all the benefits of efficiency are realized, including avoiding the expense of building new infrastructure.

States are the test beds for the evolution of the grid of the future. Innovative policies at the state level that reflect differences in resource mix and priorities can inform Federal approaches.

Different business models and utility structures rule out "One-Size-Fits-All" solutions to challenges. A range of entities finance, plan, and operate the grid. Policies to provide consumers with affordable and reliable electricity must take into account the variety of business models for investing, owning, and operating grid infrastructure.

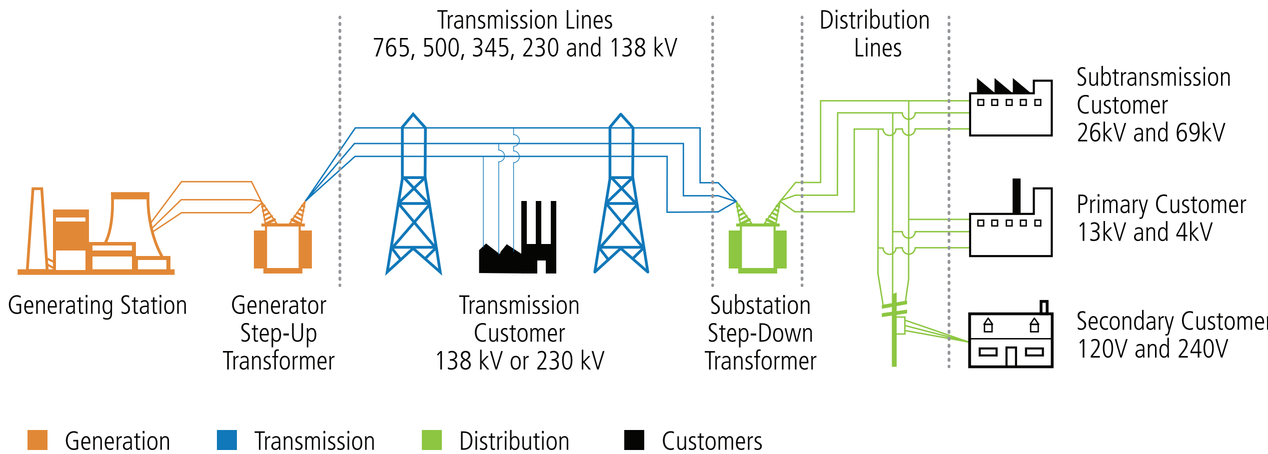
Growing jurisdictional overlap impedes development of the grid of the future. Federal and state jurisdiction over electric services are increasingly interacting and overlapping.

The Electric Grid in Transition

The United States has one of the world's most reliable, affordable, and increasingly clean electric systems—a system that powers its economy and provides for the well-being of its citizens. The U.S. electric system is at a strategic inflection point—a time of significant change for a system that has had relatively stable rules of the road for nearly a century.

The structure of today's U.S. electric grid grew organically over the course of the last century (see Figure 3-1). Historically, it was geographically based—with one-way flows of energy from central station generators, over transmission networks, through substations to distribution systems, and over radial distribution circuits to end-use customers.

Figure 3-1. The Electric Grid[1]



Six components comprise the grid: four physical components, including generation, transmission, distribution, and storage; the information infrastructure to monitor and coordinate the production and delivery of power and operate the grid; and customer demand—the driver of power system operation and investment. New storage technologies could be deployed throughout the power system in the future.

The U.S. electricity sector is influenced by a variety of new forces, some of which will affect the future growth and management of the grid. Current drivers of change within the electricity sector include the growing use of natural gas to power electricity generation; low load growth; increasing deployment of renewable energy and the retirement of coal and nuclear generation; severe weather and climate change; and growing jurisdictional interactions at Federal, state, and local levels. Innovative technologies and services are being introduced to the system at an unprecedented rate, often increasing efficiency, reliability, and the roles of customers, but also injecting uncertainty into grid operations, traditional regulatory structures, and utility business models.

The changing nature of grid operations, the implications of demand response and distributed generation deployment at increasing scale, the introduction of other new technologies, and growing consumer interaction with the grid are putting pressure on the regulatory boundaries that have evolved over the past century. Resolving the institutional, regulatory, and business model issues that could enable the grid of the future will help the United States take full advantage of the range of available energy sources and technologies that will help meet its climate change goals. These sources and technologies include energy efficiency; energy storage; carbon capture, utilization, and storage; electric vehicles; microgrids and other distributed technologies; and nuclear, natural gas, and renewable energy generation. A positive resolution of these issues will also help mitigate the growing vulnerabilities of the grid to cyber, physical, and climate change threats, as well as ensure the grid's reliability under its current institutional structures.

The Electric Grid: Complex, Highly Engineered, Essential for Modern Life

At the core of the electricity system is the grid—a complex, highly engineered network that coordinates the production and delivery of power to customers. There are six elements that make up the grid (see Figure 3-1)—four physical components of the electric system (generation, transmission, distribution, and storage); the information infrastructure to monitor and coordinate the production and delivery of power and operate the grid; and demand—the driver of power system operation and investment. Transmission, storage, and distribution (TS&D) provide the backbone of the grid, with storage increasingly deployed throughout the power system.

Today, the U.S. transmission and distribution system is a vast physical complex of interlocked machines and wires, with a correspondingly complex set of institutions overseeing and guiding it through policies, statutes, and regulations. The U.S. grid delivers approximately 3,857 terawatt-hours[2] of electrical energy from electric power generators to 159 million residential, commercial, and industrial customers.[a] This is accomplished via 19,000 individual generators at about 7,000 operational power plants in the United States with a nameplate generation capacity of at least 1 megawatt (MW).[3] These generators send electricity over 642,000 miles of high-voltage transmission lines and 6.3 million miles of distribution lines.[4] Together with its electric generation component, the grid is sometimes referred to as the world's largest machine; in 2000, the National Academy of Engineering named electrification as the greatest engineering achievement of the 20th century.[5]

Transmission is the high-voltage transfer of electric power from generating plants to electrical substations located near demand or load centers. As shown in Figure 3-1, step-down substations are the boundary between the transmission system and the distribution system that serve retail customers. High-voltage transmission lines can more easily accommodate two-way flows of electricity than the distribution network. High-voltage transmission lines have a range of voltage classes—mostly alternating current with some direct current. Transmission lines are primarily owned by investor-owned utilities and public power and cooperative-owned utilities within each interconnection. New forms of ownership of transmission assets, including independent transmission companies and "pure-play" merchant transmission firms, are beginning to emerge. For the new transmission-focused utilities, the core business and potential source of profits is based on acquiring, developing, building, and operating transmission.

Distribution is the delivery of power from the transmission system to the end users of electricity. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage. This medium-voltage power is carried on primary distribution lines, and after distribution transformers lower the voltage, secondary distribution lines carry the power to customers. Larger industrial customers may be connected directly at the primary distribution level. The poles supporting distribution lines, meters measuring usage, and related support systems are also considered to be part of the distribution system.

A Vision for the Grid of the Future

Today's grid—where power typically flows from central station power plants in one direction to consumers—is fundamentally different from the grid of the future, where two-way power flow will be common on both long-distance, high-voltage transmission lines and the local distribution network.

The grid of the future will be an essential element in achieving the broad goals of promoting affordable, reliable, clean electricity and doing so in a manner that minimizes further human contributions to climate change. To do this, the grid of the future will have to accommodate and rely on an increasingly wide mix of

[a] Here, a "customer" is defined as an entity that is consuming electricity at one electric meter. Thus, a customer may be a large factory, a commercial establishment, or a residence. A rough rule of thumb is that each residential electric meter serves 2.5 people.

resources, including central station and distributed generation[b] (some of it variable in nature), energy storage, and responsive load. It should support a highly distributed architecture that integrates the bulk electric and distribution systems. It should enable the operation of microgrids that range from individual buildings to multi-firm industrial parks and operate in both integrated and autonomous modes.

New technologies for the grid, including storage, will alter the traditional real-time requirements for grid operations and the nature of production, transmission, and distribution of power—opening up new avenues for flexible and cost-effective operation of the grid.

The grid of the future should be supported by a secure communication network—its information backbone—that will enable communication among all components of the grid, from generation to the customer level, and protect the system from cyber intrusions. This communication network will support the ability to monitor and control time-sensitive grid operations, including frequency and voltage; dispatch generation; analyze and diagnose threats to grid operations; fortify resilience by providing feedback that enables self-healing of disturbances on the grid; and evaluate data from sensors (such as phasor measurement units[c]) that enable the grid to maximize its overall capacity in a dynamic manner.

In short, the grid of the future should seamlessly integrate generation, storage, and flexible end use. It should promote greater reliability, resilience, safety, security, affordability, and enable renewable energy, while achieving better economic and environmental performance, including reductions in greenhouse gas (GHG) emissions. It will require business models and regulatory approaches that sustain grid investment and continued modernization while at the same time allow for innovation in both technologies and market structures.

The Department of Energy's (DOE's) Quadrennial Technology Review summarizes the technology challenges and research, development, and demonstration requirements for transforming the grid and achieving this vision. The Quadrennial Energy Review (QER) therefore focuses on the institutional, regulatory, and business model barriers to achieving the grid of the future.

Emerging Architecture of the Grid

The architecture of the grid is a new, emerging concept that defines the grid as not just a physical structure, but one that encompasses a range of actors and needs.[6] This new, broader concept of a grid architecture considers information systems, industry, regulators, and market structures; electric system structure and grid control frameworks; communications networks; data management structure; and many elements that exist outside the utility but interact with the grid, such as buildings, distributed energy resources, and microgrids. The grid's architecture is shaped by public policy, business models, historical and even cultural norms of practice, technology, and other factors. Analyses conducted for the QER (see box on page 3-6) focused on the complex interactions of these players and qualities, with the goal of suggesting recommendations to help drive toward a vision of actively shaping the grid of the future, as opposed to passively allowing the grid to evolve in a bottom-up manner and waiting to see the form that emerges. Analyses carried out for the QER also considered the drivers of change and how those drivers affect both today's grid and the future grid.

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[b] There are a variety of options for distributed generation, including photovoltaics, wind, low-head hydropower, combined heat and power, and fuel cells.

[c] Phasor measurement units operate by the simultaneous measurement and comparison of an important electrical property of large-scale alternating current transmission networks known as "phasor angles," thus the name "phasor measurement units." This will provide valuable real-time early warning of potential grid problems, including over very large geographic regions, when the technology is fully deployed and related tools to use the information are implemented.

Electricity Transmission Scenario Analysis

Quadrennial Energy Review scenario analysis used the Regional Energy Deployment System model to determine the impact of varying 10 input assumptions, individually and in combination, on U.S. transmission needs (see Chapter I, Introduction, Table 1-2 for the complete list of cases). The majority of cases characterized clean energy futures, in which renewable energy costs (such as solar and wind) dropped dramatically, or a greenhouse gas cap drove low- and carbon-free electricity generation deployment. An accelerated nuclear retirement case looked at the effect of the rapid loss of baseload capacity and is discussed in depth in the Electricity Appendix. The Quadrennial Energy Review focused on these cases as most likely to "stress" the transmission system, as they would produce significant changes in the electricity sector, and thus large potential changes in transmission needs.

Under the Annual Energy Outlook 2014 Reference case, installed megawatt-miles of transmission infrastructure grew by 0.3–1.5 percent per year and 6 percent total through 2030. While there was a range of new installed transmission across the scenarios, none of the scenarios appeared to require additional buildout beyond that already anticipated in the 2030 timeframe, nor did rates in any scenario exceed recent historical transmission investment levels.

Drivers of Change for the Grid of the Future: Transmission and Distribution

While the architecture of the grid of the future extends well beyond the physical structure of the system, a discussion of the drivers of change for the grid of the future should start with a consideration of the changes that will likely affect both transmission and distribution systems. Both systems may continue to grow in physical size to meet new needs, including demands for lower carbon electricity, but investments to facilitate flexible operations and resilience can enable smart growth, so both transmission and distribution systems can serve customer needs more effectively and economically.

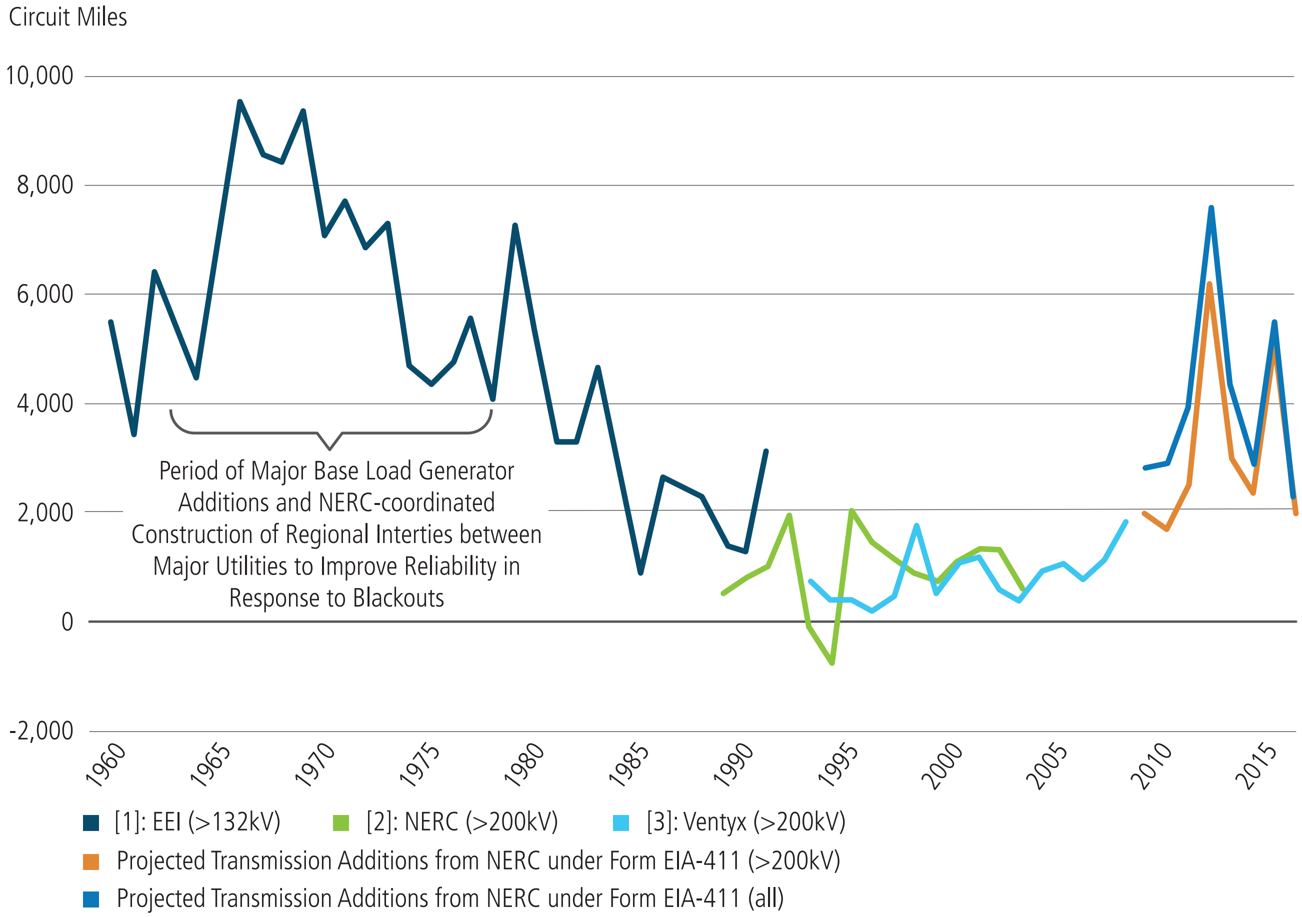
Investments in Transmission Are Expected to Grow

Transmission development and planning activity has been on the rise since the early 2000s, reversing a decades-long decline following the historic build-out of the transmission system in the mid-20th century. As an asset class, transmission attracts significant investment from utilities, financial investors, and project developers. Investor-owned utilities spent a record high of $16.9 billion on transmission in 2013,[7] up from $5.8 billion in 2001.[8] The number of circuit miles added to the Nation's transmission networks has also been on the rise in recent years (see Figure 3-2), but new line construction accounts for just slightly more than half of total investments.[9] Non-line investments—including station equipment, fixtures, towers and undergrounding lines—were increasing even during the lowest period of circuit miles construction from 1997 to 2012 (see Figure 3-3).

Drivers of recent investment increases include new technologies for improved system reliability; development of new infrastructure to ease congestion; interconnection of new sources of generation, including renewable resources; and support for production of natural gas. These investments have very distinct regional characteristics based on the different resources and constraints of each region.[10, 11] The largest increase in transmission spending over the last 15 years occurred in the Western Electricity Coordinating Council, with much of the transmission expansion happening in southern California to relieve constraints and connect to renewable resources.[12]

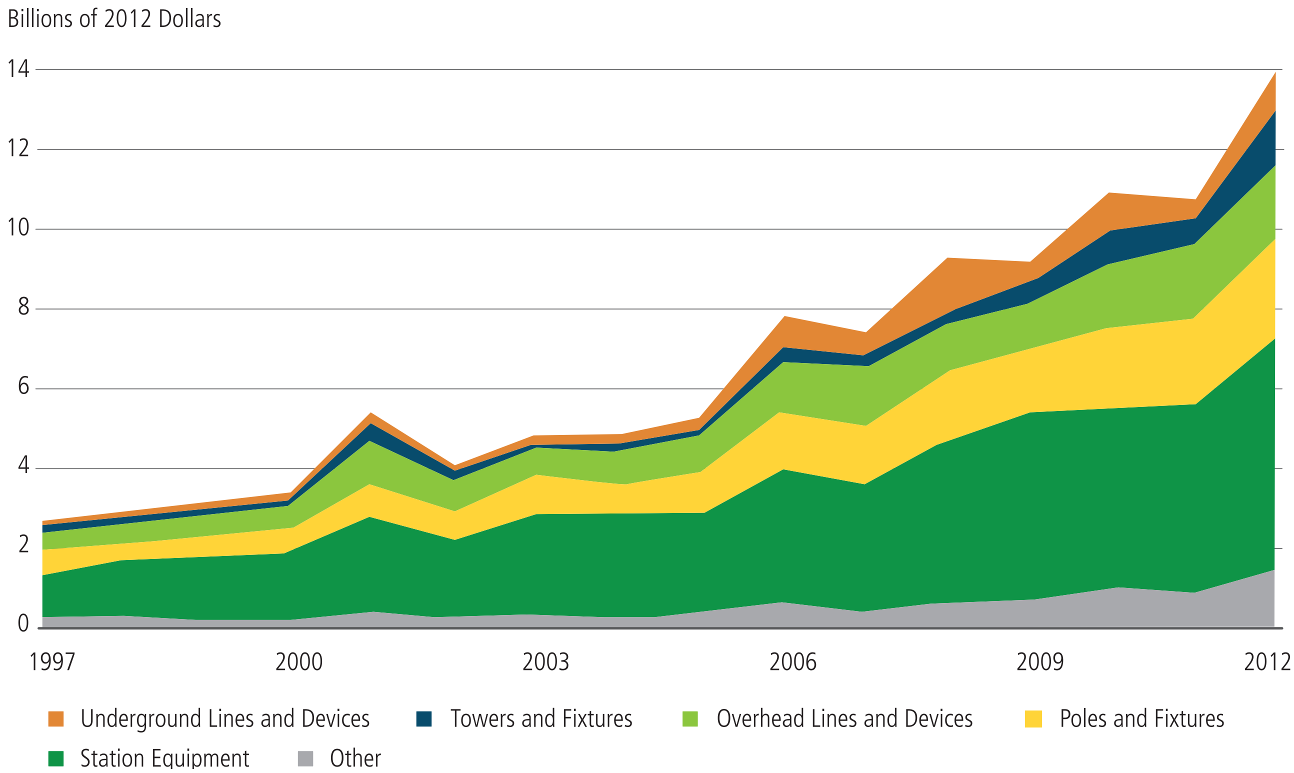
Looking forward over the next several years, a high level of transmission investment is expected to replace aging infrastructure; maintain system reliability; facilitate competitive wholesale power markets; and aid regions in meeting their public policy objectives, such as GHG reduction and renewable energy goals.[13] How much new transmission capacity is built in the future depends on a number of factors, including the amount of transmission necessary to connect high-quality wind, solar, and other energy resources to load centers; uncertainty about state and Federal incentives like the Production Tax Credit; flat or declining electricity demand; and the costs of alternative generation and demand-side resources. For renewables, an additional uncertainty is whether time of permitting or the costs of additional transmission facilities may lead to the development of wind or solar resources that are of lower quality but closer to load (Appendix C, Electricity, includes a more in-depth discussion of transmission). Nevertheless, there are a number of long-distance interregional transmission lines now in various stages of market development.[14, 15]

Figure 3-2. Historic and Projected Expansion of Net Transmission Circuit Miles[16]



Addition of new circuit miles to the Nation's transmission system has increased in recent years after over a decade of lower build-out. This increase has been driven by investments to replace aging infrastructure; maintain system reliability; facilitate competitive wholesale power markets; and support public policy objectives, such as GHG reduction and renewable energy goals. Circuit miles constructed in a year vary more than total transmission infrastructure spending, which has had an upward trend since the late 1990s. Note that historical values are year to year reported net changes in total circuit miles.

Figure 3-3. Investment in Transmission Infrastructure by Investor-Owned Utilities, 1997–2012[17]



Spending on the various components of transmission infrastructure has steadily increased since the late 1990s, driven by factors ranging from the need to replace aging materials, to the development of new technology for increased reliability, to requirements to connect new generation.

Both Long-Distance Transmission and Distributed Energy Resources Can Enable Lower-Carbon Electricity

Both bulk and distributed technologies have the potential to supply low-carbon electricity, enhance system reliability, and operate at a reasonable cost for all consumers. High-quality renewable energy sources suitable for utility-scale generation facilities are often located in remote areas. New long-distance transmission lines may be necessary in the future to connect these resources to demand centers. Conversely, other factors, such as extensive deployment of distributed energy resources, could potentially reduce the need for additional long-distance transmission build-out in the future.

The analyses conducted for the QER examined transmission capacity needs in 2030 under a variety of scenarios (this analysis did not consider distribution line needs). One scenario considered in QER analyses modeled transmission capacity necessary to accommodate high deployment of low-cost distributed energy resources using low-cost solar photovoltaic (PV) as a proxy for all types of distributed generation. The results of scenario modeling show that changes in transmission requirements through 2030 for a high-distributed PV case vary by region. In most regions, 2030 transmission needs are similar to those for a scenario based on the Annual Energy Outlook 2014 Reference case—high deployment of very low-cost distributed energy resources does not eliminate the need for additional transmission capacity. In fact, transmission requirements in the Upper Midwest and Great Lakes regions increase slightly under the distributed PV scenario in order to optimize remaining baseload resources.

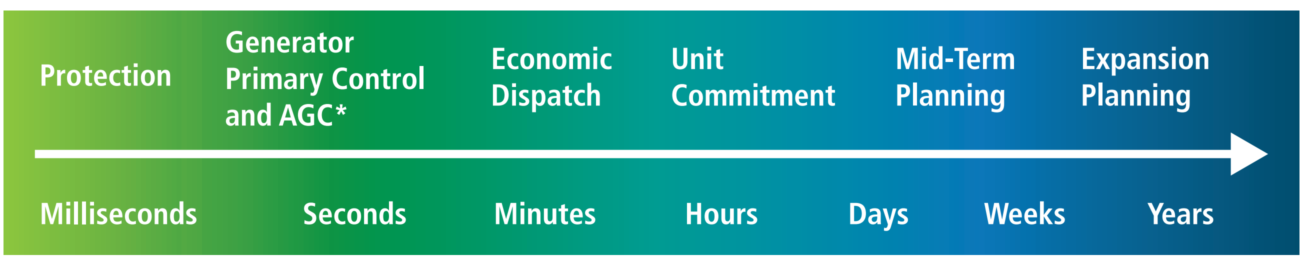
In the Southwest, transmission build-out requirements do, however, drop somewhat with expanded distributed PV because less utility-scale PV would be built in that region. This same effect is seen to a smaller extent in other Western regions. A review of three DOE-funded interconnection-wide studies, performed with American Recovery and Reinvestment Act of 2009 grants from 2012 to 2014, showed that scenarios combining high levels of end-use efficiency, demand response, and distributed generation can reduce the expected costs of new transmission investment. One 20-year scenario modeled in the Western Interconnection resulted in a reduction of $10 billion in transmission capital costs (or 36 percent below the base case).[18]

There are multiple technology innovations that could provide new long-distance transmission options. A serious physical challenge of high-voltage transmission lines is that the physics and safety factors require certain distances between the conducting wires and the ground and persons. Opponents of new transmission lines have called the resulting towers unsightly, intrusive, or "visual pollution." Ways to reduce additional issues with siting include the use of existing transmission line corridors, as well as technology fixes, such as higher-capacity-conducting materials, high-voltage underground lines, and even superconducting cables (also underground). Encouraging progress has been made on higher-capacity conductors that can be restrung on existing towers and on underground high-voltage direct current cables. These technologies should be considered and used when appropriate.

Flexible Grid System Operations and Demand Response Enable Variable Renewables and Reduce Need for New Infrastructure

All power systems have been designed with some level of flexibility to accommodate variable and uncertain load and contingencies related to network and conventional power plant outages. Flexibility is the ability of a resource—whether it is a component or a collection of components of the power system—to respond to the scheduled or unscheduled changes of power system conditions at various operational timescales (see Figure 3-4 for the timescale of different grid operations and planning functions).[19]

Figure 3-4. Transmission Operation and Planning Functions Shown by Timescale[20]



*Automatic Generation Control

Reliable and affordable electricity from the grid requires a continuum of operating, planning, and investment decisions over a wide-time horizon.

Grid operators must respond to trends affecting load patterns across a range of timescales, such as decreased demand growth, the changing demand patterns across the day, increased variable renewables, power plant retirements, and more extreme weather events. Many recent analyses lay out options for flexible electric systems.[21] Increased electric system flexibility can come from a portfolio of supply- and demand-side options, including grid storage, more responsive loads, changes in power system operations, larger balancing areas, flexible conventional generation, and new transmission.[22, 23]

Power Marketing Administrations: Valuable Federal Transmission Assets

Designed to provide customers access to electricity generated by Federal hydroelectric dams, the four Federal Power Marketing Administrations, along with the Tennessee Valley Authority, have a significant footprint within the North American grid. Today, in varying degrees, the operation, maintenance, and improvements to these Federal transmission assets are funded by revenues from and investments by preference customers. Honoring this unique customer-provider relationship, Congress has established two programs that build on the expertise of the Power Marketing Administrations. One is the Section 1222 program established by the Energy Policy Act of 2005 that authorizes the Department of Energy, through the Southwestern and/or Western Area Power Administrations, to partner with third parties to build transmission projects. There is one applicant proposing a line from wind resources in Oklahoma to Tennessee.[d] The other program is the Transmission Infrastructure Program established by the American Recovery and Reinvestment Act of 2009. The program allows the Western Area Power Administration to provide loans to and partner on transmission projects within its service area that support the development of renewable resources. The first Transmission Infrastructure Program project, the Montana to Alberta Tie Line, created 300 megawatts (MW) of transmission capacity specifically for renewable energy.[e] The project immediately enabled 189 MW to be deployed from the Rim Rock wind farm in Montana to markets.[f] The second project to be completed is Electrical District 5 – Palo Verde Hub. In this solar-rich area, the Electrical District 5 – Palo Verde Hub adds up to 410 MW of bi-directional capacity to the electric grid, including 254 MW of capacity connecting to the vital Palo Verde market hub that serves markets in Arizona, southern California, and Nevada.[g]

[d] Department of Energy. "Proposed Project: Plains and Eastern Clean Line." http://energy.gov/oe/services/electricity-policy-coordination-and-implementation/transmission-planning/section-1222-0. Accessed February 1, 2015.

[e] Enbridge. "Montanar-Alberta Tie-Line." http://www.enbridge.com/DeliveringEnergy/Power-Transmission/Montana-Alberta-Tie-Line.aspx. Accessed February 1, 2015.

[f] NaturEner. "Rim Rock Wind Farm." http://www.naturener.us/rimrock. Accessed February 1, 2015.

[g] Western Area Power Administration. "Electrical District No. 5 - Palo Verde Hub Project." http://ww2.wapa.gov/sites/western/transmission/tip/project/pages/ed5pvh.aspx. Accessed February 1, 2015.

Demand Response

Demand response improves flexibility by enabling consumers to participate in load control; it could also reduce the need for new infrastructure. Demand response mechanisms can include automated load control, smart grid and smart metering, real-time pricing, and time-of-use tariffs. Demand response can be a cost-effective grid resource; though, it requires strict regulations for response time, minimum magnitude, reliability, and verifiability of demand-side resources. Experience in the Texas wholesale electricity system and, more recently, in California shows that market designs that include demand response participation can markedly improve system flexibility. For example, industrial customers supply a significant portion of the Electric Reliability Council of Texas's responsive (spinning) reserves and have demonstrated the ability to effectively respond within minutes to a dramatic change in wind output.[24]

Energy Storage

Energy storage technologies, including pumped hydro storage, thermal storage, hydrogen storage, and batteries provide valuable system flexibility. Storage is unique because it can take energy or power from the grid, add energy or power to the grid, and supply a wide range of grid services on short (sub-second) and long (hours) timescales. It can supply a variety of services simultaneously. For example, concentrating solar power paired with highly efficient thermal storage becomes a dispatchable resource (meaning grid operators can control the power output) available throughout the day. Many storage technologies (e.g., batteries, flywheels, and supercapacitors) have fast response rates (seconds to minutes) available over a short time frame; other storage technologies, such as compressed air energy storage, are better suited to offer flexibility in the time frame of hours to days. Pumped hydro storage is usable on a timescale from seconds to days.

Pumped hydro storage currently represents the largest share of storage in the United States, with 42 pumped hydro storage plants totaling about 22 gigawatts of installed capacity, which is equivalent to about 2 percent of U.S. electricity generation capacity.[25] There are currently an additional 37 gigawatts of projects that are in some stage of licensing at the Federal Energy Regulatory Commission (FERC).[26] The original pumped hydro storage plants were built to store power to release at peak demand. New technology (such as variable speed pumps) enable pumped hydro storage to provide ancillary services (i.e., functions that maintain the reliability of the grid); integrate variable renewables; and provide other services, such as restarting down generators during an outage. Under current market structures, options such as dispatchable natural gas are cheaper and faster to permit than pumped hydro storage. FERC has a pilot project underway to test a shorter 2-year licensing process for pumped hydro storage.

Federal and State Activities to Promote Storage

Department of Energy (DOE) support for valuation, early deployment, and education has contributed to storage adoption. For example, Federal Energy Regulatory Commission Order 755 cited a DOE lab study showing that "energy storage resources (such as flywheels and batteries) could be as much as 17 times more effective than conventional ramp-limited regulation resources" for providing frequency regulation.[h] The order requires payment for frequency regulation resources based on a resource's speed and accuracy,[i] resulting in significant growth of storage installations in markets such as PJM.[j] The recent DOE Energy Storage Safety Strategic Plan addresses institutional barriers to enhance the safety and reliability of storage.[k]

States have built on these advances to bring storage benefits to closer to the mainstream. California, home to multiple DOE-funded storage demonstrations,[l, m, n] has been aggressive with policies to promote storage, first with a program to incentivize behind-the-meter storage, and then with its storage mandate, which will require the state's three utilities to deploy 1,325 megawatts of storage by 2020.[o] In Hawaii, recent wind installations in Maui and Oahu have been paired with energy storage,[p] and Hawaiian Electric Company opened a solicitation for up to 200 MW of storage "to meet its goal of adding more renewable generation to the O'ahu grid."[q] Other states, including Arizona[r] and New York,[s] have approved or are actively encouraging their utilities to consider storage.

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[h] Makarov, Y.V. et al. "Assessing the Value of Regulation Resources Based on Their Time Response Characteristics." Pacific Northwest National Laboratory. June 2008. In: 137 FERC 61,064. p. 35. 2011.

[i] Federal Energy Regulatory Commission. "Frequency Regulation Compensation in the Organized Wholesale Power Markets." 137 FERC 61,064. 2011.

[j] PJM Independent Market Monitor. "2013 State of the Market Report for PJM." p. 305. 2013.

[k] Department of Energy. "Energy Storage Safety Strategic Plan." December 2014. http://energy.gov/sites/prod/files/2014/12/f19/OE%20Safety%20Strategic%20Plan%20December%202014.pdf.

[l] Department of Energy. "Fact Sheet: Borrego Springs MicroGrid." September 2013. http://www.sgiclearinghouse.org/sites/default/files/projdocs/1650.pdf.

[m] Department of Energy. "Fact Sheet: Wind Firming EnergyFarm." August 2013. http://energy.gov/sites/prod/files/Primus.pdf.

[n] Department of Energy. "Fact Sheet: Tehachapi Wind Energy Storage Project." May 2014. http://energy.gov/sites/prod/files/Tehachapi.pdf.

[o] Maui Electric Company. "Contract with Auwahi Wind Energy LLC." 2011.

[p] Hawaiian Electric Company. "Request for Proposal (RFP# 072114-01) for 60 to 200 MW of Energy Storage for Oahu." April 30, 2014. http://www.hawiianelectric.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510blca/?vgnextoid=03ebf219fe9a5410VgnVCM10000005041aacRCD&vgnextchannel=a595ec523c4ae010VgnVCM1000005c011bacRCRD&appInstanceName=default.

[q] California Public Utilities Commission. "Order Instituting Rulemaking Pursuant to Assembly Bill 2514 to Consider the Adoption of Procurement Targets for Viable and Cost-Effective Energy Storage Systems." Decision 13-10-040. October 17, 2013.

[r] Arizona Public Service Company and Residential Utility Consumer Office. "APS AND RUCO JOINT REQUEST FOR REVIEW." DOCKET NO. L-00000D-14-0292-00169, Case No. 169. 9 26, 2014.

[s] Consolidated Edison Company of New York. "Petition for Approval of Brooklyn Queens Demand Management Program." 14-E-0302. 2014.

Traditionally, power generation must meet consumer demand in real time. Storage provides a buffer between generation and volatility of customer demand. FERC Order 755, adopted in 2011, recognizes the ability of storage to contribute to frequency regulation on the grid faster than centralized generators. The box on page 3-11 provides more examples of Federal support for storage development and deployment.

The impact of storage can be location-dependent, so grid operators and regulators need new planning tools and procedures to make use of storage as a standard grid component and to optimize storage location and size. Changes in the way the United States values ancillary services can also help make the services provided by storage a competitive option. In the future, distributed storage (e.g., grid-connected electric vehicles) could be a transformative technology.

Changes to Power System Operations

Changes to power system operations and markets can provide significant existing flexibility, often at lower economic costs than building new transmission infrastructure. Operations examples include more frequent dispatch (which reduces the time frame over which a generator must follow a specified output level), smart network technologies, and increased plant cycling.

Smart network technologies and advanced network management practices minimize bottlenecks and optimize transmission usage. They provide unprecedented, real-time visibility across the energy system. Transmission and distribution planners and operators can use this information to employ the most reliable and cost-effective flexibility options. They can consider building new generation and transmission alongside other options like demand response or bigger balancing areas.

Forecasting and planning are low-cost ways of accessing system flexibility. System operators increasingly require variable renewable energy generators to forecast power output to improve the ability of system operators to commit, dispatch resources, deploy reserves, and improve situational awareness.[27] Integrating these data, along with wind and solar plant outage data, into market operations helps variable renewable energy plants participate in electricity markets.

Market Signals

Market signals can enable flexibility. Establishing short-term market products for flexible capacity (e.g., the California Independent System Operator (ISO) and Midcontinent ISO's proposed fast-ramping products) can also incentivize resources to respond to imbalances over the minutes-to-hours time frame. In market structures that more comprehensively value services provided to the grid, demand-side resources and storage could provide low-cost grid services, allowing more efficient grid operations and avoiding generation or transmission investments.[28] Cost savings to the power system attributable to demand response and energy storage can be much larger than the revenue they can receive in current market structures.[29]

Investments in Reliability and Resilience Can Have Multiple Benefits

North American Electric Reliability Corporation standards (subject to FERC review, approval, and independent enforcement authority) require the bulk electric system to withstand certain disruptive events, including most single contingencies and some multiple contingencies, with no interruption to transmission service or major customer outages. Some outages, or "non-consequential load losses," are tolerated in the case of extreme events, where multiple facilities are taken out of service simultaneously. The North American Electric Reliability Corporation requires bulk power system owners and operators to have plans in place to contain extreme events to prevent cascading outages to other regions.[30]

Resilience investments can require a substantial change in physical infrastructure, including building physical barriers or moving equipment, building backup systems, building non-wooden or reinforced poles, and burying lines underground.[31] Resilience investment also includes additional operations and maintenance activities, which primarily means more thorough tree trimming.[32]

Many energy sector investments to mitigate climate change can have co-benefits that make the grid more resilient to climate change impacts and extreme weather. Investments in energy efficiency, smart grid technologies, storage, and distributed generation can also contribute to enhanced resilience from environmental threats.[33] For example, DOE-funded demonstrations of distribution automation systems enabled a utility to restore power 17 hours faster following an outage, while other utilities have experienced marked improvements in outage interruption frequency and duration indices.[34] In addition to providing added redundancy, transmission can also provide the operational flexibility to adapt to long-term changes, such as an increase in the peak-to-average energy demand and water constraints on energy production.[35]

Drivers of Change for the Grid of the Future: New Technologies and Services

A second dimension of the emerging architecture for the grid of the future has to do with new or emerging technological innovations in grid operations. Many of the characteristics that customers desire in the grid of the future—affordability, reliability, sustainability, and an improved customer experience—will be facilitated by new technologies. The challenges to speeding the adoption of these technologies include developing network designs and open standards so they can communicate and operate seamlessly with other elements of the grid, as well as determining the value of the benefits that they bring to customers.

Innovative Technologies Have Significant Value for the System

An array of new technologies and data applications are enabling new electricity-related services, customer control choices, and investments that hold the promise of greatly improving electric consumer experience, as well as promoting a new ecosystem of innovation and revenues beyond the sale of electric kilowatt-hours.

Distributed generation systems provide consumers a number of benefits. According to a 2007 DOE study,[36] these benefits include increased electric system reliability; reduction of peak power requirements; provision of ancillary services, including reactive power; improvements in power quality; reductions in land-use effects and rights-of-way acquisition costs; and reduction in vulnerability to terrorism and improvements in infrastructure resilience.

A revolution in information and communication technology is changing the nature of the power system. The smart grid is designed to monitor, protect, and automatically optimize the operation of its interconnected elements, including central and distributed generation; transmission and distribution systems; commercial and industrial users; buildings; energy storage; electric vehicles; and thermostats, appliances, and consumer devices.[37] Smart grid technologies include a host of new and redesigned technologies, such as phasor measurement units or advanced metering infrastructure, that provide benefits such as increased reliability, flexibility, and resiliency.[38, 39, 40]

Within the delivery portion of the electric grid, smart grid technology is enabling sizable improvements in distribution and transmission automation. Many of these new technologies are "behind-the-meter," involving end-use management or generation on the consumers' premises; these end-use technologies are not directly germane to this installment of the QER. Nevertheless, as parts of an integrated electricity system, with growing effects on TS&D, behind-the-meter technologies do affect and interact with the systems that are the focus of this QER. For example, engineers will need to design and install components of the grid, such as safety interlocks, since two-way power flow, introduced by distributed generation, may pose a danger to line workers.

Emerging technologies on the distribution grid (whether digital communications, sensors, control systems, digital "smart" meters, distributed energy resources, greater customer engagement, etc.) present both technical and policy challenges and opportunities for the delivery of energy services. Power grids evolved organically in a bottom-up manner, as opposed to a centrally coordinated master plan. This build-up has led to large-scale legacy investments that require significant operating margins to maintain system stability, as opposed to more refined margins enabled by the rapid and precise control offered by new and emerging technologies.

These changes have injected uncertainties into a utility business model that typically has relied on continued load growth, steady economic returns, and long payback horizons.[41] While regulators, utilities, and the Federal Government are all engaged in addressing these uncertainties, developing appropriate rate structures for the benefits these technologies provide to the customer and the grid can be difficult, resulting in either over-investment or under-investment and higher costs to consumers.

Another key element in the development and use of information technologies on the grid relates to network coordination. The grid of the future would benefit from overall network architectures that allow for specific grid elements to be aligned in ways that allow them to contribute to solving problems that affect multiple grid components. Whole-grid coordination, in which these distributed elements are made to cooperate to solve a common problem (i.e., overall grid stability), is a key challenge and opportunity for new information and network technologies and approaches.

There are many other opportunities to infuse advanced technology into key operating elements of the grid. Some notable opportunities are shown in Table 3-1.

Table 3-1. Examples of Key Technologies for the Grid of the Future[42]

Grid Component/Opportunity	Description
AC/DC power flow controllers/converters	Technologies that adjust power flow at a more detailed and granular level than simple switching.
Advanced multi-mode optimizing controls	Controls capable of integrating multiple objectives and operating over longer time horizons, to replace simple manual and tuning controls, or controls that operate based only on conditions at single points in time.
Bilaterally fast storage	Energy storage in which charge and discharge rates are equally fast and thus more flexible.
Control frameworks	New hybrid centralized/distributed control elements and approaches.
Management of meta-data, including network models	New tools for obtaining, managing, and distributing grid meta-data, including electric network models.
Synchronized distribution sensing	Synchronization of measurements in order to provide more accurate snapshots of what is happening on the grid.
Transactive buildings	Buildings with controls and interfaces that connect and coordinate with grid operations in whole-grid coordination frameworks.
"X"-to-grid interface and integration	Interface technologies, tools, and standards for the general connection of energy devices to power grids; includes integrated mechanisms for coordinating those devices with grid operations in whole-grid coordination frameworks.
Distribution System Operation	Structure for clear responsibility for distributed reliability.

Innovation will introduce new grid components that are increasingly digitized, can provide new services for customers and grid operators, and continue to produce and reliably deliver affordable electricity to customers.

Communication with Customer Devices Will Improve Efficiency and Reliability of the Grid

The evolving role of the modern-day electricity customer is transforming into a more dynamic, transactive role in which customers are also becoming participants in electric system operations. Customers can create value to the electric system in two ways: as both suppliers of responsive demand and producers of distributed power. As suppliers of responsive demand, customers can provide capacity resources to the system that helps maintain reliability and affordable prices. As distributed producers of power, customers can provide power that could reduce total GHG emissions, increase resilience, and forestall infrastructure investments.

Three impediments to realizing customer value are related to communications. First, comprehensive communication and data standards need to be developed.[43] Competing, proprietary systems inhibit the adoption of technologies and control strategies and drive up the cost of deployment. Second, there is no uniform approach to characterizing the grid services that end-use devices can provide. Third, the communication and control interface devices between the customer as a distributed generator and the distribution system limit the types of service that the distributed generator can provide. In general, the lack of regulatory structures and standards are impeding the full utilization of information technology to enhance the efficiency and reliability of the grid.

Low-cost sensors and controls in buildings, distributed generation, electric vehicle charging, end-use storage, and other innovations make it increasingly important to integrate building devices and control systems with utility distribution systems to fully enable the development of new value propositions. Customer applications in residential and commercial buildings could potentially have economic benefits worth $59 billion (in 2009 dollars) by 2019, including packages of pricing, in-home displays, smart appliances, and information portals that would serve to reduce both energy demand and overall use.[44] Well-designed control systems also can increase building efficiency.[45]

Capturing these benefits requires building communication networks, allowing the components to interoperate and respond to a facility-wide control. One impediment to fully realizing the benefits of information technology is the balkanized structure of regulation. Early information technology adoption was accomplished by vertically integrated utilities that used computers as a tool to enhance their ability to perform existing functions. New information technology enables new behaviors, market mechanisms, and monitoring and operating procedures. While the reliability and efficiency of the system can be improved in the long run, these changes pose a threat to the status quo and have potentially significant unintended consequences and ambiguous benefits for utilities. As a consequence, there is a general caution associated with the wide-scale deployment of new information technology infrastructures and devices.

Speeding the adoption and accrual of potential benefits will require coordination of open standard development and clear business models that enable the benefits to be widely shared. An open standard for energy devices would be analogous to the voluntary industry USB standard developed in the mid-1990s, which allowed simple plug-and-play between smart phones, tablets, computers, chargers, printers, games, and many other peripheral devices. Its existence greatly expanded both the usability and types of all these personal electronic devices. Similar standards are emerging but not settled for the much newer set of information technology-enabled grid devices, leading to an ongoing lack of interoperability.

Implications of Electric Vehicle Penetration for the Grid

Battery-electric vehicles run on electricity and plug-in hybrid electric vehicles run on a combination of electricity and gasoline. In 2013, there were about 70,000 battery-electric vehicles and 104,000 plug-in hybrid electric vehicles—small numbers compared to the approximately 226 million registered vehicles in the United States. Total U.S. sales of plug-in electric vehicles (PEVs) have increased rapidly in recent years, but still represent only about 0.7 percent of new vehicle sales in 2014 (albeit up from 0.6 percent in 2013 and 0.4 percent in 2012). California is home to almost half of all of the Nation's PEVs, but only about 5 out of every 1,000 registered California vehicles are PEVs.[t]

There has also been a rapid recent increase in the numbers of charging stations. From 2011 to 2014, the numbers of public electric vehicle charging outlets grew from fewer than 4,000 to more than 25,000.[u] Various business models for developing new charging stations have emerged, as installation costs can be high.[v, w] For each infrastructure upgrade, utilities and regulators must assess costs (e.g., installation) and benefits (e.g., ancillary services).

According to the National Academy of Sciences in its 2013 report on electric vehicle deployment,[x] *"The existing electric infrastructure does not present a barrier to the expansion of PEV technology in the United States given the projected growth of PEV use in the next decade."* In addition, the report states that *"As PEVs account for a more significant share of total electricity consumption, the committee sees no barriers to provision of generation and distribution capacity to accommodate the growth through the normal processes of infrastructure expansion and upgrades in the electric utility industry."*

The National Academy of Sciences concludes that existing U.S. generation and transmission capacity could accommodate 5 million to 50 million PEVs. However, the report also suggests that if large numbers of PEVs were to be charged at the same time as residences also see peak loads, there could be potential for overloading elements of the local distribution system and thus a need for local upgrades. Furthermore, the National Academy of Sciences notes that concentrations of fast-charging stations, dense clustering of private PEV owner charging, or fleet-charging facilities could require grid upgrades. An assessment prepared for the Independent System Operator/Regional Transmission Organization Council noted that smart grid enhancements could allow electric vehicles to provide services to the grid, particularly related to demand response and load balancing.[y] Furthermore, smart grid developments could enable a shift in charging to off-peak periods and help avoid additional generation requirements.[z]

[t] Energy Information Administration. "California leads the nation in the adoption of electric vehicles." Today in Energy. December 10, 2014. http://www.eia.gov/todayinenergy/detail.cfm?id=19131.

[u] Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels Data Center. "Alternative Fueling Stations by Fuel Type." http://www.afdc.energy.gov/data/10332. Accessed January 16, 2015.

[v] Rocky Mountain Institute. "Pulling Back the Veil on EV Charging Station Costs." RMI Outlet. April 29, 2014. http://blog.rmi.org/blog_2014_04_29_pulling_back_the_veil_on_ev_charging_station_costs. Accessed January 16, 2015.

[w] Greene, D.L. "Alternative Transportation Refueling Infrastructure in the U.S. 2014: Status and Challenges." University of Tennessee Knoxville. March 31, 2015.

[x] National Research Council. "Overcoming Barriers to Electric-Vehicle Deployment: Interim Report." 2013. http://www.nap.edu/download.php?record_id=18320.

[y] KEMA and Taratec Corporation. "Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems." Produced for the ISO/RTO Council. 2010. http://www.rmi.org/Content/Files/RTO%20Systems.pdf. Accessed January 27, 2015.

[z] Hadley, S.W. "Impact of Plug-in Hybrid Vehicles on the Electric Grid." Oak Ridge National Laboratory. 2006. http://web.ornl.gov/info/ornlreview/v40_2_07/2007_plug-in_paper.pdf.

In addition to interoperability, safe and improved connectivity is important to the deployment of new technologies to the grid. For example, there are voluntary industry standards for the interconnection of distributed generation of all types that connect customer-owned generation to the local distribution network. The majority of state public utility commissions use a voluntary standard issued in 2003 by the Institute of Electrical and Electronics Engineers (IEEE) known as the IEEE 1547 interconnection standards. These standards set technical guidelines for the interconnection of distributed resources less than 10 MW in size with the electric grid, including requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. These standards are now in revision, with a goal of completion by 2018. Modifications are taking into account impacts on grid reliability; new technologies that offer two-way communications and intelligent controls; and dispatchability of some types of distributed generation plus extension to demand response, storage, and microgrids.

Updated standards will both improve grid safety and better use distributed energy resources in maintaining overall system reliability. In particular, as large fossil-fueled generators with spinning turbines retire, the system is losing the inertia that has helped maintain grid frequency and thus grid reliability. Properly configured with appropriate communications, inverters used with distributed generation or storage can provide frequency regulation services to the grid to fill this gap. Conversely, improper connections or protocols could lead to simultaneous disconnection of all distributed energy resources under particular circumstances. While there is an existing process underway to update the IEEE 1547 interconnection standards, finding ways to accelerate the update of these standards will provide increased benefits to both customers and the reliability of the system.

Appropriate Valuation of New Services, Technologies, and Energy Efficiency

Ultimately, the electric system exists to serve load—or the demand for electric services—from the residential, commercial, industrial, and transportation sectors. There is a suite of services that the grid provides to meet real-time changes in load and supply, among other things. A better understanding of the full costs and benefits of those services would allow regulators, utilities, and customers to develop more fair and equitable pricing structures.

These services and a range of other important societal goals are enabled by new technologies. Distributed energy and smart grid technologies offer the potential to help meet America's changing energy needs, minimize the environmental impact of electricity generation, strengthen economic growth, and improve the reliability of the Nation's electrical infrastructure. As noted, the full spectrum of existing and emerging technologies includes new intelligent grid (smart grid) delivery technologies, energy efficiency, combined heat and power, fuel cells, gas turbines, rooftop PV, distributed wind, plug-in hybrid and all-electric vehicles, distributed storage, demand response, and transactive building controls.

At high penetrations, many of these new technologies could challenge current distribution systems and the functional integrity of the current electricity system. New investments and changes to existing regulatory, policy, financial, and business structures may be necessary to fully realize the benefits of these technologies. Regulators and policymakers will need to address the operational issues associated with new technologies, as well as longer-term concerns, such as how the loss of revenue (and a utility's ability to cover fixed costs) and load resulting from increasing numbers of some installations of distributed energy resources could challenge utilities' financial health under current business models.

A key element for addressing the operational and business model concerns posed by new technologies centers on valuation (i.e., "What are the benefits of new services and technologies to the grid?" and conversely, "What is the cost of the services the grid provides to customers?"). There is no agreement on the answers, though, as answers depend on the situation. This issue has been examined in numerous valuation studies in the public domain. These studies do not consider the same set of impacts from one study to the next. For example, not all studies explicitly consider impacts on transmission and distribution, such as capacity avoidance, grid support services, or external impacts like avoided GHGs. The monetized estimates that different studies assign to a given service or impact (capacity, energy, system losses) can range by a factor of as much as five or more.

There currently are no transparent, broadly accepted methods that can be used by stakeholders to determine the costs and benefits associated with integrating new services and technologies into the grid.[46] Clearer valuation methods would empower legislators and regulators in their efforts to address their local needs as they formulate strategies and plans to provide a portfolio of electricity options that meet their state-specific goals for reliable, affordable, and clean electricity. It is also important for policymakers to understand that, as they work to value services on both sides of the meter, there is the potential for stranded assets (i.e., assets for which investments have been made but cannot be recovered) on both sides; valuation policies must take these issues into consideration as well.

Net Metering

The challenges associated with integrating new technologies into the current electricity grid system are illustrated by the variety of opinions on net metering. Net metering is a system for paying for generation located on customer facilities—typically, although not exclusively, small residential solar generators. Currently, 45 states have Net Energy Metering programs that credit customers in some way for the energy they produce onsite.[47] The most common type of Net Energy Metering customer today owns or leases a rooftop PV system, but current regulations often apply to other distributed energy technologies, such as gas-fired turbines and combined heat and power. With rapid solar PV market penetration, controversies among utilities, consumer groups, solar businesses, and other stakeholders have arisen in several states over how to account for the full cost of grid services, placing pressure on legislators and regulators to understand conflicting positions and analyses supporting them.

Valuing Ancillary Services

Ancillary services are defined by the North American Electric Reliability Corporation as "those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the transmission system in accordance with good utility practice."[48] Types of ancillary services include ramping, voltage support, and frequency support, all of which are furnished by a combination of generation and transmission facilities. Ultimately, the system operator is responsible for ensuring that there are adequate ancillary services at all times to maintain reliability. The ability to provide ancillary services, such as frequency support, is changing with the transformation of the electric generation system. As the electric system continues to evolve, system planners and grid operators will need to value and integrate the services that new technologies can provide to maintain system stability and reliability. New payments, or changes to existing payment methods (both to generation owners and to other potential ancillary service providers), may be necessary to ensure continued provision of needed ancillary services to maintain grid reliability.

Consistent Measurement and Evaluation of Energy Efficiency

The evaluation, measurement, and verification of energy efficiency savings are critical as efficiency becomes increasingly important as a mechanism to meet a variety of goals, including reducing the need to build additional generation and GHG reduction. Many entities have made progress toward standardizing the evaluation of energy efficiency. These methods can help regulators understand the opportunities energy efficiency creates for infrastructure avoidance.

Ratepayer-funded efficiency programs run by utilities and third parties, energy service companies' projects, codes and standards, and other efficiency programs have achieved significant energy savings over the last three decades.[49] These programs have developed in different ways across the country, along with some state variation in protocols and procedures for measuring and verifying savings. While inconsistencies can complicate efforts to compare measured savings across jurisdictions, a number of important standardization efforts have emerged in recent years at the state and regional levels that have started to address these issues. These include efforts led by the Northwest Regional Technical Forum and the Northeast Energy Efficiency Partnership that include development of regional databases of energy savings. Building on this momentum, DOE's voluntary Uniform Methods Project for Determining Energy Efficiency Program Savings has convened policy stakeholders and technical experts to develop a set of protocols for determining savings from energy efficiency measures and programs. Over the last 2 years, the Uniform Methods Project has issued more than 20 protocols for common residential, commercial, and crosscutting energy efficiency measures. The Energy Information Administration has also tracked energy efficiency program evaluations.

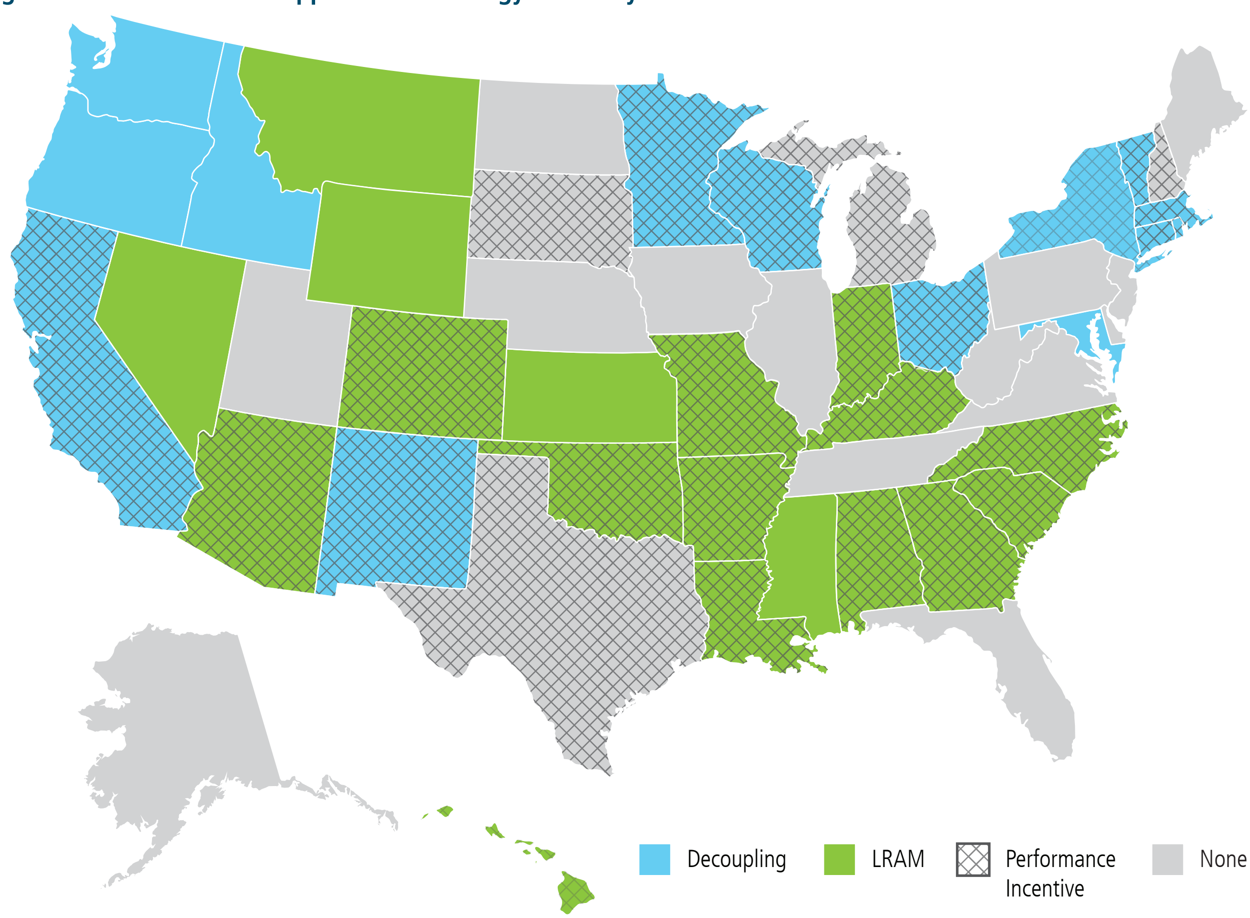
Drivers of Change for the Grid of the Future: Institutions and Utility Business Models

A third dimension of the architecture for the grid of the future encompasses all the actors involved in managing the grid, including in industry and regulatory bodies (at all levels of government). These businesses and institutions shape the operation, management, and regulation of the grid. Incorporation of the new technologies and services will require an evolution in these businesses and institutions.

States Are the Test Beds for the Evolution of the Grid of the Future

States have the primary role in regulating the retail provision of electricity (see Figure 3-5), as well as the siting of transmission and generation. Due to this primacy, states are at the forefront of managing the transition to the grid of the future. Historically, states have been the laboratories for developing policies that reflect their individual and regional situations, and in the electricity sector, state policies reflect differences in resource mix, priorities, geography, economies, and even culture.

Figure 3-5. Different State Approaches to Energy Efficiency[50]



Thirty-six states have adopted regulatory approaches to promote utility investment in energy efficiency: decoupling, lost-revenue adjust mechanisms ("LRAM"), or performance incentives.

As the complexity of the grid increases, states are working to develop policies that incorporate new services and technologies in a manner that maintains affordability and reliability. The unique circumstances of each state have resulted in a diverse set of responses across a range of issues confronting the electricity sector. For example, many states have adopted policies to support utility investments in energy efficiency. There are at least three different regulatory approaches being used: decoupling, lost revenue adjustment mechanism, and a broad set of methods to allow performance incentives (see Figure 3-5). These efforts create a regulatory model that rewards utility shareholders for effective energy efficiency efforts that lower ratepayer bills in the long term. Another example of state innovation is the cost-allocation scheme member states in the Midcontinent ISO and Southwest Power Pool negotiated among themselves for the funding of large region-wide transmission upgrades for each of their regions, which was then approved by FERC.[51, 52]

Different Industry Structures and Business Models Rule Out "One-Size-Fits-All" Solutions to Challenges

The grid is financed, planned, and operated by numerous entities that cross states, regions, and countries. It provides valuable services and includes a variety of industry types and a range of business models that often reflect regional differences in resource mix.

Policies designed to provide consumers with affordable and reliable electricity in the future must take into account the variety of business models for investing, owning, and operating grid infrastructure. The nature of the entities that comprise the grid has changed and will continue to do so. The earliest model of electric service delivery was the investor-owned, vertically integrated utility, namely the Edison Illuminating Company that used the New York City Pearl Street Station generator in 1882 to begin serving customers. Following, in the late 1880s and 1890s, was the establishment of public power utilities, which were also vertically integrated, in small towns to also serve local loads with generation. Now, as shown in Table 3-2, the basic functions of the vertically integrated utility are performed by a wide variety of entities with different ownership structures, pursuing different functions.

The variety of ownership and scope of the entities that comprise the grid leads to a complex set of motivations and decision drivers. The reliable operation of the grid is a testament to the integration of these different interests. There are five different predominant ownership types: (1) investor owned; (2) cooperatively owned, owned by their member customers; (3) publicly owned, such as by municipalities, states, public utility districts, and irrigation districts; (4) Federally owned; and (5) merchant companies that are competitive entities in generation, transmission, or retail supply.

Table 3-2. Taxonomy of Utility Business Models (examples, ownership, and scope)[53]

	State-Regulated IOUs	Cooperatively Owned	Publicly Owned	Federally Owned	Merchant
Vertically Integrated (T,D,G)*	Oklahoma Gas & Electric	None	Los Angeles Dept. of Water & Power	None	None
Transmission and Distribution	Pepco	Southern Maryland Electric COOP (SMECO)	Clallam County Public Utility District	None	None
Generation and Transmission	None	Basin Electric G&T	New York Power Authority	Tennessee Valley Authority	LS Power
Generation and Distribution	DTE Energy; Consumers Energy	Fox Island (ME) Electric	Lansing (MI) Board of Water & Light	None	NRG
Transmission	None	Upper Missouri Power Cooperative	Transmission Agency of Northern Calif.	Western Area Power Adminstration, Bonneville Power Administration, Southwestern Power Administration	ITC; Hudson Transmission; Transource Energy; Clean Lines Energy Partners
Distribution	Mt. Carmel Public Utility Co.	Kenergy	Nashville Electric Service	None	None
Generation	None	Oglethorpe Power Corporation	Wyoming Municipal Power Agency	Bureau of Reclamation	Calpine; BP Energy; Tenaska;

* (T,D,G= Transmission, Distribution, and Generation)

There is a diversity of ownership structures in the U.S. electricity sector. Such diversity often precludes one-size-fits-all policies.

Although all utilities may invest in demand response and energy efficiency, each ownership pattern engenders different interests in performance of service, investment, and market structure. For example, cooperatives have been innovative in their use of direct load control to modify peak load conditions,[54] while publicly owned utilities have been leaders in energy efficiency.[55] Because investor-owned utilities earn a return on capital expenses, and without special incentives, do not earn a return on cost-saving operational expenses, this class of utilities tends to lead in the development of new service through capital-intensive assets.

Investor-owned companies have fiduciary obligations to increase shareholder value. Regulated entities that earn profit based upon a return on invested capital lack a strong incentive (absent explicit requirements and incentives) to invest in energy efficiency practices. In contrast, public power and cooperative utilities are motivated to keep customers' bills down and, as such, can optimize the provision of service by using both capital-intensive options and less capital-intensive alternatives (e.g., energy efficiency).

Merchant generators whose profits are the residual revenues after expenses are paid (including return on capital) are motivated to maximize revenue. The Federal Power Marketing Administrations, such as the Western Area Power Administration and the Bonneville Power Administration, must follow the dictates of their statutory authorities. The balancing authorities, some of which are Regional Transmission Organizations or ISOs, in turn, are concerned about maintaining reliability while operating the bulk power system.

Fragmented and Overlapping Jurisdictions Threaten to Impede Development of the Grid of the Future

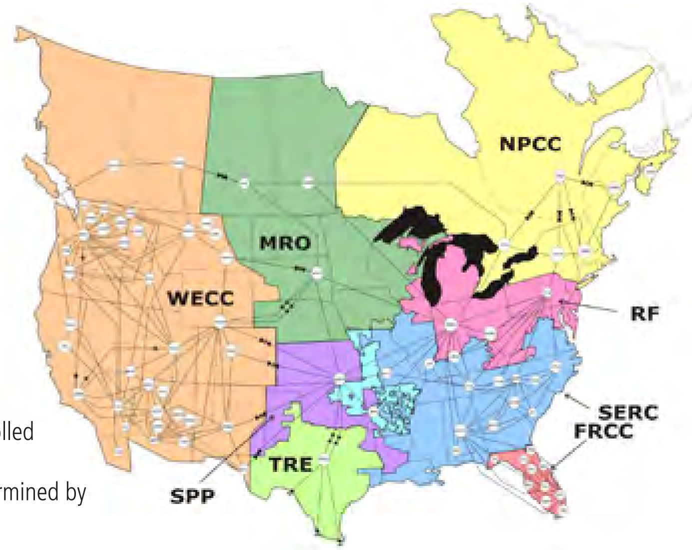
Federal, regional, and state institutions and regulatory structures that have evolved over decades to manage the electric grid are increasingly interacting and overlapping. The geographical boundaries of the institutions are not coincident with the flow of electrons on the physical system. The increasing physical complexity of the grid will only complicate governance and analysis. Policymaking to address regulatory and operational challenges of the evolving grid is more difficult because models used to analyze the physical flows of electricity do not align with the institutional and regulatory structures (see Figure 3-6).

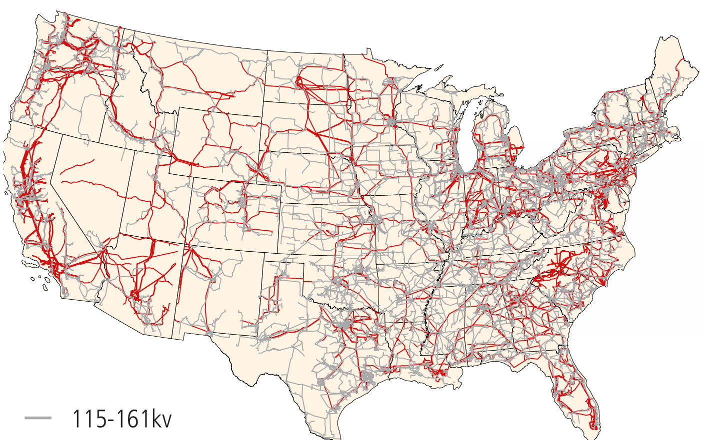
The current Federal-state regulatory boundary dates back to the 1930s, when the Federal Power Act substantially expanded the responsibilities of the Federal Power Commission (the predecessor to FERC) and created Federal oversight of wholesale sales of electricity and of transmission of electricity in interstate commerce, as well as state oversight of retail sales and distribution of electricity. In recent decades, organized wholesale markets have spread geographically and incorporated a greater variety of products with a broader set of market participants. This trend—coupled with the increased ability of end-use consumers to supply distributed generation, demand response, and other services—has and will continue to raise questions about the dividing line between state and Federal jurisdiction.[56]

This threatens to impede the development of markets that efficiently integrate both utility-scale and small-scale participants. While FERC and the National Association of Regulatory Utility Commissioners have engaged in a collaborative dialogue on a range of topics (smart grid, demand response, enforcement, and others) since 2006,[57] Federal and state regulators should seek new ways to coordinate goals across their respective jurisdictions, without which the Nation will not be able to take full advantage of the efficiencies offered by emerging technologies and the grid of the future.[58]

Figure 3-6. Select Electricity Jurisdictions[59]

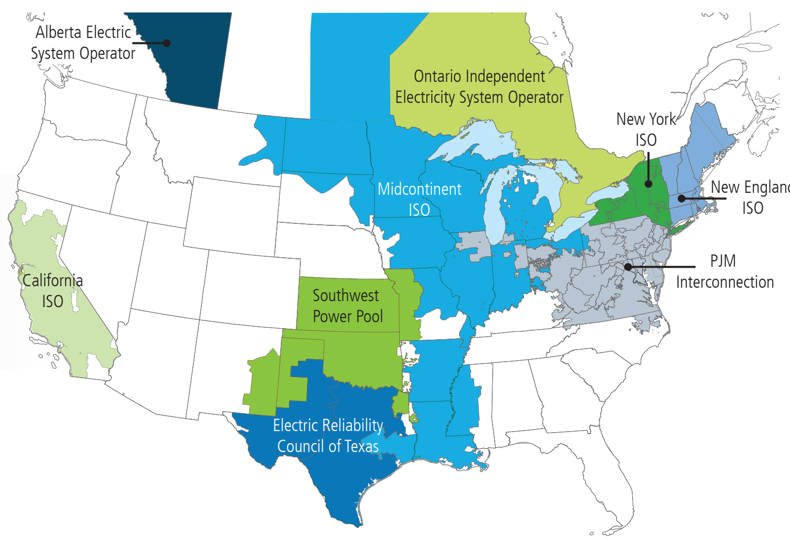
NERC Regional Entities and Balancing Authorities





Federally Regulated Power Lines

Regional Transmission Organizations (RTOs)/Independent System Operators (ISOs)



Transmission lines, which are regulated at the Federal level, cross state boundaries and connect the regional organizations that manage and operate the bulk power electricity grid. In contrast, states regulate the distribution of electricity to end-use customers for entities under their jurisdiction, as well as the siting of transmission on non-Federal lands. Further, in most states, local appointed or elected governing boards handle the regulation of distribution for their publicly or cooperatively owned electric utility. This diversity of institutions and differences in jurisdictional boundaries create challenges in grid governance (given that changing the grid in one location can alter electricity dynamics over a large area).

Policy Framework for the Grid of the Future

The transition from today's existing grid to the grid of the future will be challenging. The electric grid is highly complex, has significant regional variability, and should be managed to accommodate a range of possible futures. The vision of the future electric grid described earlier in this chapter was developed after a year-long QER process of analyses and stakeholder engagement. The recommendations that follow are guided by five key policy principles that emerged from this work.

- The future grid should encourage and enable energy efficiency and demand response to cost effectively displace new and existing electric supply infrastructure, whether centralized or distributed. The policies, financial tools, and pricing signals that enable customers to save money and energy while enhancing economic growth should be preserved and strengthened as business models evolve.

- The future grid should provide balanced support for both decentralized power sources and the central grid. As the costs of decentralized power sources and storage continue to fall, there will be increased opportunities for end users to partially or completely supply their own electricity. At the same time, the vast majority of American homes and businesses will continue to rely on the power grid for some or all of their electricity. It is essential, then, that investment in both centralized and decentralized systems occur in a balanced manner, preserving high-quality service for all Americans while simultaneously enabling new options and services that may reduce energy costs or climate impacts. Similarly, access to renewable energy, energy efficiency improvements, and new energy-related services should not be limited to isolated customer groups, but rather become an integral part of the universal service that both decentralized and centralized grid customers enjoy.

- In the future grid, new business and regulatory models must respect the great regional diversity in power systems across the United States, as well as the critical roles played by state, local, tribal, and regional authorities, including state public service commissions and regional grid operators. The drivers of change in the power system cut across the traditional boundaries of state and Federal regulation and thereby introduce new challenges in designing and overseeing new business and regulatory models. An unprecedented amount of consultation and collaboration will be necessary to ensure that national objectives are met alongside complementary state policies in power systems that are inherently regional in their scope and technology.

- Planning for the future grid must recognize the importance of the transmission and distribution systems in linking central station generation—which will remain an essential part of the U.S. energy supply for many years to come—to electricity consumers. Transmission and generation both benefit from joint, coordinated planning. Transmission can allow distant generation—where there may be excess capacity—to supplement local supply and avoid the need to build new plants. New generation sometimes requires new transmission, especially remotely sited renewables or new nuclear plants. Utility and Regional Transmission Organization planning processes and tools should continue to evolve to evaluate transmission, generation (both central and distributed), and demand-side resources holistically.

- Finally, the careful combination of markets, pricing, and regulation will undoubtedly be necessary in all business and regulatory models of the future grid. While the precise nature and scope of the market structures in the future grid may vary considerably, there is little doubt that markets in one form or another will be an important means of providing access to new technologies and services. Even in settings where prices are regulated, novel approaches can allow beneficial new pricing and service structures. Moreover, both new and traditional financing options provided by capital markets will be an important element in the future industry landscape.

QER Recommendations

The Administration and Congress should support or incentivize investment in electricity infrastructure reliability, resilience, and affordability through the development of tools, methods, and new funding for planning and operating the grid of the future. Accordingly, we recommend the following:

Provide grid modernization research and development, analysis, and institutional support: A modernized 21st century grid will require a governing framework that values and optimizes the benefits from new technologies and services, as well as a physical infrastructure that maintains reliability, resilience to disruption, cost effectiveness, and flexibility to adapt to these changes. Early and strategic investments by DOE in foundational technology development, enhanced security capabilities, and institutional support and stakeholder engagement provide decision makers with a common set of tools that balances electric industry and consumer interests. Though small relative to the size of the industry, DOE's investment is significant compared to utilities' limited spending on innovation, which stems from an investor-owned business model where profits are based on return on capital expenditures, as well as public- and consumer-owned power's requirement for lowest feasible rates. The President's Fiscal Year 2016 Budget requests $356 million for DOE's Grid Modernization Initiative.

To reflect the rapidly shifting grid landscape, DOE should continue to pursue a multi-year, collaborative, and cost-shared research and development, analysis, and technical assistance program:

- Technology innovation resulting from research and development coordinated among DOE offices, creating new tools and technologies in areas such as the following:
  - Design and planning tools to model emerging needs
  - System control and power flow to optimize for new grid capabilities
  - Grid sensing and measurements for determining changes in variable generation markets and infrastructure conditions
  - Devices and integrated systems testing for evaluation and validation of new technologies in a systems context
  - Grid security and resilience efforts to protect, prevent, analyze, and respond to threats by developing physical and cybersecurity technology and standards
  - Risk management, including integrated demonstration of promising new technologies with new institutional approaches.
- Institutional support and alignment, including analyses, workshops, and dialogues to highlight key policy and market challenges and options for grid transformation.

The cost of this program is estimated to be $3.5 billion over 10 years.

Establish a framework and strategy for storage and flexibility: Energy storage is a key functionality that can provide flexibility, but there is little information on benefits and costs of storage deployment at the state and regional levels, and there is no broadly accepted framework for evaluation of benefits below the bulk system level. DOE should conduct regional and state analyses of storage deployment to produce a strategy for flexibility and storage. The strategy will integrate the findings from these analyses and make them easy for all types of stakeholders, including regional and state leaders, to understand and implement where appropriate. It will also establish a common framework for exploring means, methods, and technologies that can enhance grid flexibility, regionally, in states, and load-serving entities.

QER Recommendations (continued)

The national energy system storage strategy will address a suite of approaches that enable flexibility, including integrated planning methods, system operations and markets, demand and storage, conventional and variable renewable generation, and interconnected transmission networks.

Conduct a national review of transmission plans and assess barriers to their implementation: Transmission is critical both to ensuring reliability, as well as to connecting generation to load. While DOE has funded interconnection-level analyses of transmission needs and specific studies of transmission needs for renewable generation, a more detailed and comprehensive national review of transmission plans is warranted. DOE should carry out such a review to include assessments on the types of transmission projects proposed and implemented, current and future costs, consideration of interregional coordination, and other factors. Synthesizing this information at a national level would better inform and guide the development of transmission, including opportunities for additional regional or interregional coordination. In conjunction with such a review, it will be critical to assess incentives and impediments to the development of new transmission. Such an assessment should include a review of existing Federal incentives, implementation of Section 1222 of the Energy Policy Act of 2005 to enable third-party transmission projects partnered with the DOE Western and Southwestern Power Administrations, implementation of the $3.25 billion Western Area Power Administration Transmission Infrastructure Program, siting constraints, and other incentives and impediments that may exist at both the national and local levels.

Provide state financial assistance to promote and integrate TS&D infrastructure investment plans for electricity reliability, affordability, efficiency, lower carbon generation, and environmental protection with a focus on regional coordination: States are the test beds for the evolution of the electric power system. DOE should provide competitive funding for states to promote and integrate TS&D infrastructure investment plans for electricity reliability, affordability, efficiency, lower carbon generation, and environmental protection (including climate mitigation).

- As described in this chapter, states can play an important role in promoting grid reliability as new technologies, including distributed generation, are added to the grid, and consumers demand more services from the electric power system. The increasing interdependency of natural gas and electricity systems creates additional planning requirements, as does climate change and extreme weather events.
- States have historically established separate agencies for reliability and environmental regulation of the electric power sector that operate independently of each other. The actions required to meet the goals of an affordable, resilient, reliable, and cleaner electricity sector are, however, becoming increasingly interdependent. States can provide innovative ways to address new trends that allow the electric sector to reliably provide services that meet environmental, resilience, and efficiency goals. In making awards under this program, DOE should require cooperation within the planning process of energy offices, public utility commissions, and environmental regulators within each state; with their counterparts in other states; and with infrastructure owners and operators and other entities responsible for maintaining the reliability of the bulk power system.

The estimated support for this program is about $300 million to $350 million over 5 years.

QER Recommendations (continued)

Coordinate goals across jurisdictions: Technology is indifferent to state-Federal boundaries and jurisdictions; technology users cannot be. Both Federal and state governments need to play constructive and collaborative roles in the future to ensure that consumers and industry are able to maximize the value of new technologies to enhance resilience and reliability and mitigate climate change. While the notions of retail versus wholesale have, in some respects, become blurred, the states still have a strong and important role in electricity regulation. The variety and strength of state policies on energy efficiency, storage, renewable energy, smart grid, and even GHG regulation demonstrates the undiminished importance of the power sector to state leaders, notwithstanding technological change. At the same time, portions of the electric power sector have an important role to play in improving the efficiency of the wholesale markets overseen by FERC at the Federal level. DOE should play a convening role to bring together public utility commissioners, legislators, and other stakeholders at the Federal, state, and tribal levels to explore approaches to integrate markets, while respecting jurisdictional lines, but allowing for the coordination of goals across those lines.

Value new services and technologies: Efficient characterization and valuation of services provided to the grid by existing and new technologies is important for maintaining reliability and affordability of the rapidly evolving electricity system and providing clear price signals to consumers. Existing methods for establishing values and rates should appropriately compensate new technologies, with the potential to more effectively provide grid services reliably, affordably, and in compliance with environmental regulations. The Federal Government can play a role in developing frameworks to value grid services and approaches to incorporate value into grid operations and planning.

- DOE should convene stakeholders to define the characteristics of a reliable, affordable, and environmentally sustainable electricity system and create approaches for developing pricing mechanisms for those characteristics.

- The ability of distinct grid components to provide grid services should be evaluated, and options for increasing the viability of components to provide grid services should be reviewed—this would allow market operators and regulators to have a more complete understanding of the range of technologies and strategies that can provide grid services.

- DOE should also work with stakeholders to develop a framework(s) for identifying attributes of services provided to the grid by electricity system components, as well as approaches to incorporate the valuation of grid service attributes in different regulatory contexts (e.g., pricing or incorporation in planning processes).

- The convening efforts recommended here will build on past DOE workshops on the value of storage and distributed energy resources (discussed in Chapter X, Analytical and Stakeholder Process). The frameworks developed through this process could be used by FERC, state public utility commissions in ratemaking proceedings, Regional Transmission Organizations in their market rule development, or utilities in the operation and planning of their systems.

QER Recommendations (continued)

Improve grid communication through standards and interoperability: A plethora of both consumer-level and grid-level devices are either in the market, under development, or at the conceptual stage. When tied together through the information technology that is increasingly being deployed on electric utilities' distribution grids, they can be an important enabling part of the emerging grid of the future. However, what is missing is the ability for all of these devices to coordinate and communicate their operations with the grid, and among themselves, in a common language—an open standard. One analogy is the voluntary industry USB standard developed in the mid-1990s that allows simple plug-and-play between smart phones, tablets, computers, chargers, printers, games, and many other peripheral devices, and whose existence has greatly expanded both the usability and types of all these personal electronic devices. Similar standards are emerging but not settled for the much newer set of information technology-enabled grid devices (i.e., a lack of interoperability exists). The Department of Commerce's National Institute of Standards and Technology (NIST) was very active in working with industry and other interested parties to develop several generations of voluntary standards to bring interoperability to grid-connected devices. NIST's efforts have now transitioned to the industry-based Smart Grid Interoperability Panel. DOE is supporting efforts by IEEE to develop next-generation standards for inverters used by distributed generation. While the Federal Government lacks authority to mandate standards in these areas, it can take additional steps. In conjunction with NIST and other Federal agencies, DOE should work with industry, IEEE, state officials, and other interested parties to identify additional efforts the Federal Government can take to better promote open standards that enhance connectivity and interoperability on the electric grid.

Establish uniform methods for monitoring and verifying energy efficiency: The measurement and verification of energy efficiency savings will be increasingly important as efficiency continues to become not just a source of revenue, but a mechanism by which the utility can meet its GHG reduction goals. Regulators need ways to understand, validate, and value savings from energy efficiency practices, including understanding the value of infrastructure avoidance as a result of efficiency investments. Through its Uniform Methods Project, DOE should accelerate the development of uniform methods for measuring energy savings and promote adoption of these methods in public and private efficiency programs.

RECOMMENDATIONS IN BRIEF:
Modernizing the Electric Grid

Provide grid modernization research and development, analysis, and institutional support. The Department of Energy (DOE) should continue to pursue a multi-year, collaborative, and cost-shared research and development, analysis, and technical assistance program for technology innovation that supports grid operations, security, and management, as well as for analyses, workshops, and dialogues to highlight key opportunities and challenges for new technology to transform the grid.

Establish a framework and strategy for storage and grid flexibility. DOE should conduct regional and state analyses of storage deployment to produce a common framework for the evaluation of benefits of storage and grid flexibility, and a strategy for enabling grid flexibility and storage that can be understood and implemented by a wide range of stakeholders.

Conduct a national review of transmission plans and assess barriers to their implementation. DOE should carry out a detailed and comprehensive national review of transmission plans, including assessments on the types of transmission projects proposed and implemented, current and future costs, consideration of interregional coordination, and other factors. A critical part of this review should be to assess incentives and impediments to the development of new transmission.

Provide state financial assistance to promote and integrate transmission, storage, and distribution infrastructure investment plans for electricity reliability, affordability, efficiency, lower carbon generation, and environmental protection. In making awards under this program, DOE should require cooperation within the planning process of energy offices, public utility commissions, and environmental regulators within each state; with their counterparts in other states; and with infrastructure owners and operators and other entities responsible for maintaining the reliability of the bulk power system.

Coordinate goals across jurisdictions. DOE should play a convening role to bring together public utility commissioners, legislators, and other stakeholders at the Federal, state, and tribal levels to explore approaches to integrate markets, while respecting jurisdictional lines, but allowing for the coordination of goals across those lines.

Value new services and technologies. DOE should play a role in developing frameworks to value grid services and approaches to incorporate value into grid operations and planning. It should convene stakeholders to define the characteristics of a reliable, affordable, and environmentally sustainable electricity system and create approaches for developing pricing mechanisms for those characteristics. The goal should be to develop frameworks that could be used by the Federal Energy Regulatory Commission, state public utility commissions in ratemaking proceedings, Regional Transmission Organizations in their market rule development, or utilities in the operation and planning of their systems.

Improve grid communication through standards and interoperability. In conjunction with the National Institute of Standards and Technology and other Federal agencies, DOE should work with industry, the Institute of Electrical and Electronics Engineers, state officials, and other interested parties to identify additional efforts the Federal Government can take to better promote open standards that enhance connectivity and interoperability on the electric grid.

Establish uniform methods for monitoring and verifying energy efficiency. Through its Uniform Methods Project, DOE should accelerate the development of uniform methods for measuring energy savings and promote widespread adoption of these methods in public and private efficiency programs.

Endnotes

1. North American Electric Reliability Corporation. "Understanding the Grid." August 2013. http://www.nerc.com/news/Documents/Understanding%20the%20Grid%20DEC12.pdf. Accessed March 4, 2015. Reproduced with permission.
2. Energy Information Administration. "Electric power sales, revenue, and energy efficiency Form EIA-861 detailed data files 2013." February 19, 2015. http://www.eia.gov/electricity/data/eia861/. Accessed February 25, 2015.
3. Energy Information Administration. "Energy in Brief: How many and what kind of power plants are there in the United States?" December 26, 2013. http://www.eia.gov/tools/faqs/faq.cfm?id=65&t=2. Accessed February 19, 2015.
4. Edison Electric Institute. "EEI Statistical Yearbook 2013." Table 10.6. http://www.eei.org/resourcesandmedia/products/Pages/ProductDetails.aspx?prod=617A7D67-9678-44FC-AE6F-6876ADAE7406&type=S. Accessed March 18, 2015.; Platts. "Platts UDI Directory of Electric Power Producers and Distributors, 122nd Edition of the Electrical World Directory." p. vi. 2014. https://www.platts.com/IM.Platts.Content/downloads/udi/eppd/eppddir.pdf. Accessed March 2, 2015.
5. National Academy of Engineering. "Greatest Engineering Achievements of the 20th Century." 2000. http://www.greatachievements.org/. Accessed January 5, 2015.
6. Quadrennial Energy Review Analysis: Taft, J.D. and A. Becker-Dippman. "Grid Architecture." Pacific Northwest National Laboratory. PNNL-24044. January 2015. http://energy.gov/epsa/qer-document-library.
7. Edison Electric Institute. "Actual and Planned Transmission Investment by Shareholder-Owned Utilities (2008–2017)." January 8, 2015. http://www.eei.org/issuesandpolicy/transmission/Documents/bar_Transmission_Investment.pdf. Accessed March 18, 2015.
8. Edison Electric Institute. "Transmission Investment: Adequate Returns and Regulatory Certainty are Key." p. 6. June 2013. http://www.eei.org/issuesandpolicy/transmission/Documents/transmission_investment.pdf. Accessed February 25, 2015.
9. Edison Electric Institute. "Actual and Planned Transmission Investment by Shareholder-Owned Utilities (2008–2017)." January 8, 2015. http://www.eei.org/issuesandpolicy/transmission/Documents/bar_Transmission_Investment.pdf. Accessed March 18, 2015.
10. Department of Energy. "National Electric Transmission Congestion Study—Draft for Public Comment." August 2014. http://energy.gov/sites/prod/files/2014/08/f18/NationalElectricTransmissionCongestionStudy-DraftForPublicComment-August-2014.pdf. Accessed March 18, 2015.
11. Energy Information Administration. "Electricity transmission investments vary by region." Today in Energy. September 3, 2014. http://www.eia.gov/todayinenergy/detail.cfm?id=17811. Accessed March 18, 2015.
12. Energy Information Administration. "Electricity transmission investments vary by region." Today in Energy. September 3, 2014. http://www.eia.gov/todayinenergy/detail.cfm?id=17811. Accessed March 18, 2015.
13. Edison Electric Institute. "Actual and Planned Transmission Investment by Shareholder-Owned Utilities (2008–2017)." January 8, 2015. http://www.eei.org/issuesandpolicy/transmission/Documents/bar_Transmission_Investment.pdf. Accessed March 18, 2015.
14. Edison Electric Institute. "Transmission Projects: At a Glance." March 2015. http://www.eei.org/issuesandpolicy/transmission/Documents/Trans_Project_lowres_bookmarked.pdf. Accessed April 15, 2015.
15. Western Electricity Coordinating Council. "2024 Common Case Transmission Assumptions." June 2, 2014. https://www.wecc.biz/_layouts/15/WopiFrame.aspx?sourcedoc=/Reliability/RPCG_2024CCTA_Report.pdf. Accessed February 2, 2015.
16. Chang, J., J. Pfeifenberger and M. Hagerty. "Trends and Benefits of Transmission Investments: Identifying and Analyzing Value." The Brattle Group. Presented to the CEA Transmission Council, Ottawa, Canada, September 26, 2013. http://www.brattle.com/system/publications/pdfs/000/004/944/original/Trends_and_Benefits_of_Transmission_Investments_Chang_Pfeifenberger_Hagerty_CEA_Sep_26_2013.pdf. Accessed March 4, 2015. Reproduced with permission.

17. Energy Information Administration. "Investment in electricity transmission infrastructure shows steady increase." Today in Energy. August 26, 2014. http://www.eia.gov/todayinenergy/detail.cfm?id=17711. Accessed March 4, 2015.

18. Quadrennial Energy Review Analysis: Hadley, S.W. and A.H. Sanstad. "Impacts of Demand-Side Resources on Electric Transmission Planning Demand Resources and Transmission Requirements." Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory. January 2015. http://energy.gov/epsa/downloads/report-impacts-demand-side-resources-electric-transmission-planning.

19. Perez-Arriaga, I.J., H. Rudnick and M. Rivier. "Electric Energy Systems: An Overview." In: Electric Energy Systems Analysis and Operations, eds. Gomez-Exposito, A., A. Conejo and C. Canizares. CRC Press. 2008.

20. Massachusetts Institute of Technology Energy Initiative. "The Future of the Electric Grid." p. 35. 2011. http://mitei.mit.edu/publications/reports-studies/future-electric-grid. Accessed January 7, 2015. Citing: Perez-Arriaga, I.J., H. Rudnick and M. Rivier. "Electric Energy Systems: An Overview." In: Electric Energy Systems: Analysis and Operation, eds. Gomez-Exposito, A., A. Conejo and C. Canizares. CRC Press. 2008. Reproduced with permission.

21. Hand, M.M. et al. eds. "Renewable Electricity Futures Study." National Renewable Energy Laboratory. 2012. http://www.nrel.gov/analysis/re_futures/. Accessed February 26, 2015.; GE Energy. "Western Wind and Solar Integration Study." National Renewable Energy Laboratory. May 2010. http://www.nrel.gov/docs/fy10osti/47781.pdf. Accessed February 25, 2015.; Lew, D. et al. "The Western Wind and Solar Integration Study Phase 2." National Renewable Energy Laboratory. September 2013. http://www.nrel.gov/docs/fy13osti/55588.pdf. Accessed February 25, 2015.; International Energy Agency. "The Power of Transformation Wind: Sun and the Economics of Flexible Power Systems." 2014.; Ma, O. et al. "Demand Response and Energy Storage Integration Study." In development. http://www1.eere.energy.gov/analysis/response_storage_study.html. Accessed February 25, 2015.

22. Hand, M.M. et al. eds. "Renewable Electricity Futures Study." National Renewable Energy Laboratory. 2012. http://www.nrel.gov/analysis/re_futures/. Accessed February 26, 2015.

23. GE Energy. "Western Wind and Solar Integration Study." National Renewable Energy Laboratory. May 2010. http://www.nrel.gov/docs/fy10osti/47781.pdf. Accessed February 25, 2015.

24. Ela, E. and B. Kirby. "ERCOT Event on February 26, 2008: Lessons Learned." National Renewable Energy Laboratory. July 2008. http://www.nrel.gov/docs/fy08osti/43373.pdf. Accessed February 2, 2015.

25. Deane, J., B.Ó. Gallachóir and E. McKeogh. "Techno-economic review of existing and new pumped hydro energy storage plant." Renewable and Sustainable Energy Reviews. 14(4). May 2010. p. 1293–1302. http://www.sciencedirect.com/science/article/pii/S1364032109002779?np=y. Accessed January 15, 2015.

26. Federal Energy Regulatory Commission. "Pumped Storage Projects." November 21, 2014. http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp. Accessed February 1, 2015.

27. Federal Energy Regulatory Commission. "Integration of Variable Energy Resources." 139 FERC ¶ 61,246. 2012.

28. Ma, O. et al. "Demand Response and Energy Storage Integration Study." In development. http://www1.eere.energy.gov/analysis/response_storage_study.html. Accessed February 25, 2015.

29. Ma, O. et al. "Demand Response and Energy Storage Integration Study." In development. http://www1.eere.energy.gov/analysis/response_storage_study.html. Accessed February 25, 2015.

30. North American Electric Reliability Corporation. "Transmission System Planning Performance Requirements." p. 6. http://www.nerc.com/files/TPL-001-4.pdf. Accessed January 27, 2015.

31. Edison Electric Institution. "Before and After the Storm: A Compilation of Recent Studies, Programs, and Policies Related to Storm Hardening and Resiliency." 2014. http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf. Accessed January 27, 2015.; Executive Office of the President. "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages." 2013. http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf. Accessed January 27, 2015.; Electric Power Research Institute. "Enhancing Distribution Resiliency: Opportunities for Applying Innovative Technologies." 2013. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001026889. Accessed January 16, 2015.; Drexel, J.M. "Risk Assessment for Storm Hardening." ConEdison, Inc. 2014. Presentation at the Resilient Grid Workshop, Brookhaven National Laboratory, October 16–17, 2014. http://www.bnl.gov/rsg2014/files/talks/Drexel_BNLConEd.pdf. Accessed January 27, 2015.

32. Quanta Technology. "Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Storm Hardening Programs." 2009. http://www.puc.texas.gov/industry/electric/reports/infra/Utlity_Infrastructure_Upgrades_rpt.pdf. Accessed January 27, 2015.

33. Quadrennial Energy Review Analysis: Los Alamos National Laboratory, Sandia National Laboratories, and Argonne National Laboratory. "Synthesis of Impacts/Disruptive Events on TS&D Infrastructure (Vol 1–3: Electricity, Liquid Fuels, Natural Gas." 2014 (forthcoming at http://energy.gov/epsa/qer-document-library).

34. Department of Energy. "Smart Grid Investments Improve Grid Reliability, Resilience, and Storm Responses." November 2014. http://energy.gov/sites/prod/files/2014/12/f19/SG-ImprovesRestoration-Nov2014.pdf. Accessed February 25, 2015.

35. Dell, J. et al. "Chapter 4 Energy Supply and Use." p. 113–129. In: Climate Change Impacts in the United States: The Third National Climate Assessment. Global Change Research Program. 2014. http://nca2014.globalchange.gov/report/sectors/energy. Accessed April 2, 2015

36. Department of Energy. "The Potential Benefits of Distributed Generation and Rate-Related Issues that may Impede their Expansion—A Study Pursuant to Section 1817 of the Energy Policy Act Of 2005." February 2007. http://www.ferc.gov/legal/fed-sta/exp-study.pdf. Accessed February 25, 2015.

37. Electric Power Research Institute. "Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid." 2011. https://www.smartgrid.gov/sites/default/files/doc/files/Estimating_Costs_Benefits_Smart_Grid_Preliminary_Estimate_In_201103.pdf. Accessed February 25, 2015.

38. Jongejan, A. et al. "Dynamic Pricing Tariffs for DTE's Residential Electricity Customers." Center for Sustainable Systems, University of Michigan. April 2010. http://css.snre.umich.edu/css_doc/CSS10-04.pdf. Accessed February 25, 2015.

39. Pinney, D. "Costs and Benefits of Conservation Voltage Reduction – CVR Warrants Careful Examination." National Rural Electric Cooperative Association. 2013. http://www.nreca.coop/wp-content/uploads/2014/01/NRECA_DOE_Costs_Benefits_of_CVR_b.pdf. Accessed February 25, 2015.

40. Department of Energy. "Operations and Maintenance Savings from Advanced Metering Infrastructure – Initial Results." December 2012. http://energy.gov/sites/prod/files/AMI_Savings_Dec2012Final.pdf. Accessed February 25, 2015.

41. Edison Electric Institute. "Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business." January 2013. http://www.eei.org/ourissues/finance/documents/disruptivechallenges.pdf. Accessed February 25, 2015.

42. Quadrennial Energy Review Analysis: Taft, J.D. and A. Becker-Dippman. "Grid Architecture." Pacific Northwest National Laboratory. PNNL-24044. January 2015. http://energy.gov/epsa/qer-document-library.

43. Massachusetts Institute of Technology. "The Future of the Electric Grid." p. 197–229. 2011. https://mitei.mit.edu/system/files/Electric_Grid_Full_Report.pdf. Accessed February 2, 2015.

44. Booth, A., M. Greene and H. Tai. "US Smart Grid Value at Stake: the $130 Billion Question." In: McKinsey on Smart Grid: Can the smart grid live up to its expectations? McKinsey & Co. http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid. Accessed February 14, 2014.

45. Roth, K.W. et al. "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential." p. 9–92. TIAX LLC. 2005.

46. Department of Energy. "Summary and Presentations from 'Estimating the Benefits and Costs of Distributed Energy Technologies' Workshop Now Available." December 8, 2014. http://energy.gov/oe/articles/summary-and-presentations-estimating-benefits-and-costs-distributed-energy-technologies. Accessed February 2, 2015.

47. Department of Energy. "2014 Report to Congress: Smart Grid System Report." August 2014. http://energy.gov/sites/prod/files/2014/08/f18/SmartGrid-SystemReport2014.pdf. Accessed March 17, 2015.

48. North American Electric Reliability Corporation. "Glossary of Terms Used in NERC Reliability Standards." Updated May 8, 2014. http://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf.

49. Consortium for Energy Efficiency. "2013 Annual Report." http://www.cee1.org/ar/. Accessed January 15, 2015.

50. Bhargava, A. "This map shows how 36 states are modernizing the utility business model." Opower. http://blog.opower.com/2014/09/utility-business-model-20-map/. Accessed March 2, 2015. Reproduced with permission.

51. Federal Energy Regulatory Commission. "FERC removes barriers to development of needed transmission in Midwest Region." December 16, 2010. http://www.ferc.gov/media/news-releases/2010/2010-4/12-16-10-E-1.asp. Accessed February 2, 2015.

52. Southwest Power Pool. "FERC Approves New Cost Sharing Method for Expanding SPP's Transmission Grid." June 17, 2010. http://www.spp.org/publications/FERC%20Approves%20New%20Cost%20Sharing%20Method%20for%20Expanding%20SPP%20Transmission%20Grid.pdf. Accessed February 2, 2015.

53. Department of Energy, Office of Energy Policy and Systems Analysis. 2015.

54. National Rural Electric Cooperative Association. "Request for Information Addressing Policy and Logistical Challenges to Smart Grid Implementation 75 FR 57006: Comments of the National Rural Electric Cooperative Association." p. 14–16. November 1, 2010. http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/NRECA_RFI_Comments.pdf. Accessed February 1 2015.

55. Southwest Energy Efficiency Project. "Municipal Utility Energy Efficiency Programs: Leading Lights." p. 4–5. March 2011. http://swenergy.org/publications/documents/Municipal%20Utility%20Energy%20Efficiency%20Programs%20-%20Leading%20Lights.pdf. Accessed February 1, 2015.

56. See, for example, Electric Power Supply Association v. FERC, 753 F.3d 216 (D.C. Cir. 2014). Petition for certiorari pending.

57. National Association of Regulatory Utility Commissioners. "FERC, NARUC Revamp 'Sunday Morning Collaborative.'" January 25, 2013. http://www.naruc.org/News/default.cfm?pr=348&pdf. Accessed February 2, 2015.

58. Bhatnagar, D. et al. "Market and Policy Barriers to Energy Storage Deployment." Sandia National Laboratories. September 2013. http://www.sandia.gov/ess/publications/SAND2013-7606.pdf. Accessed April 2, 2015.

59. Department of Energy, Office of Energy Policy and Systems Analysis. 2015.