Transforming the Nation's Electricity System:

The Second Installment of the Quadrennial Energy Review

Summary for Policymakers

The second installment of the Quadrennial Energy Review (QER 1.2) focuses on the electricity system and its role as the enabler for accomplishing three key national goals: improving the economy, protecting the environment, and increasing national security. As a critical and essential national asset, it is a strategic imperative to protect and enhance the value of the electricity system through modernization and transformation. Reliable and affordable electricity provides essential energy services for consumers, business, and national defense.

The electricity system we have today was developed over more than a century and includes thousands of generating plants, hundreds of thousands of miles of transmission lines, distribution systems serving hundreds of millions of customers, a growing number of distributed energy resources, and billions of end-use devices and appliances. These elements are connected together to form a complex system of systems. The electricity sector is, however, confronting a complex set of changes and challenges, including: aging infrastructure; a changing generation mix; growing penetration of variable generation; low and in some cases negative load growth; climate change; increased physical and cybersecurity risks; and in some regions widespread adoption of distributed energy resources (DER). How these changes are managed is critical and could fundamentally transform the electricity system's structure, operations, customer base, and jurisdictional framework.

QER 1.2 analyzes trends and issues confronting the Nation's electricity sector out to 2040, examining the entire electricity supply chain from generation to end use, and within the context of three overarching national goals to: (1) enhance economic competitiveness; (2) promote environmental responsibility; and (3) provide for the nation's security. The report builds on analysis and recommendations in the first installment of the QER (QER 1.1) on improving energy transmission, distribution, and storage infrastructures, and provides recommendations that must be implemented to optimize and modernize the electricity sector.

Scope and Structure of the Second Installment of the QER

In 2013, President Obama directed the Administration to conduct an interagency QER in order to "establish integrated guidance to strengthen U.S. energy policy". The first installment of the QER (QER 1.1), published in April 2015, focused "on infrastructure challenges, and identified the threats, risks, and opportunities for U.S. energy and climate security, enabling the Federal Government to translate policy goals into a set of analytically based, clearly articulated, sequenced and integrated actions, and proposed investments."

QER 1.2 analyzes trends and issues confronting the Nation's electricity sector, examining the entire electricity supply chain from generation to end use. It builds on analysis and recommendations in QER 1.1, which included electricity as part of an examination of energy transmission, distribution, and storage infrastructures. The scope of QER 1.2 includes generation, transmission, distribution, and end-use application in the electricity sector. It does not explore other energy-related sectors, except where they directly affect the electricity system, such as the critical role of natural gas supply in generation and reliability.

Figure S-1. Organization/Areas of Focus in QER. 1.2

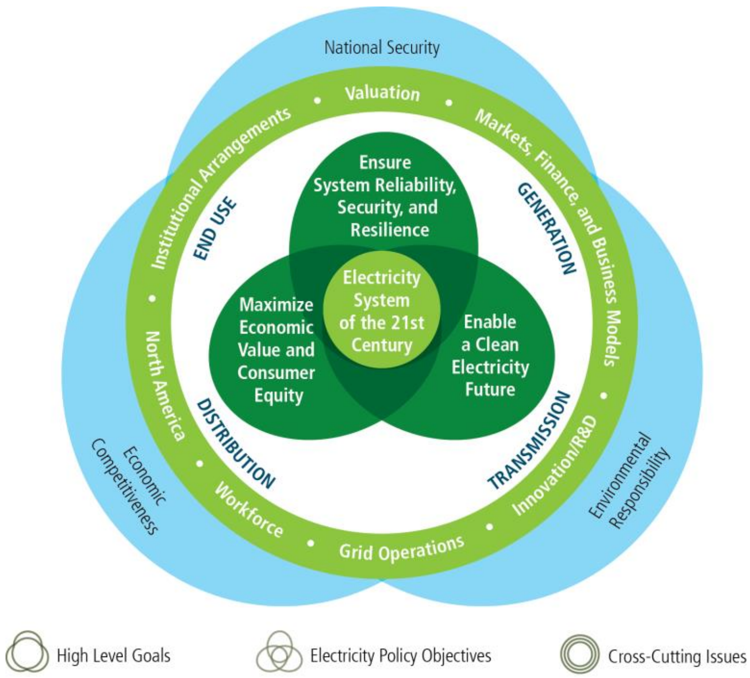


Figure S-1. A comprehensive set of interactions and overlapping objectives and goals must be analyzed to inform policies that will enable the electricity sector of the 21st century. Analysis in QER 1.2 is organized around a set of national goals, integrated objectives, and cross-cutting issues.

This summary follows the organization of the main report, starting with an introduction to electricity generation issues and the changing context, corresponding to the first chapter of the main report. The summary then highlights key findings based on deep analysis from several sections on the integrated objectives of the report.

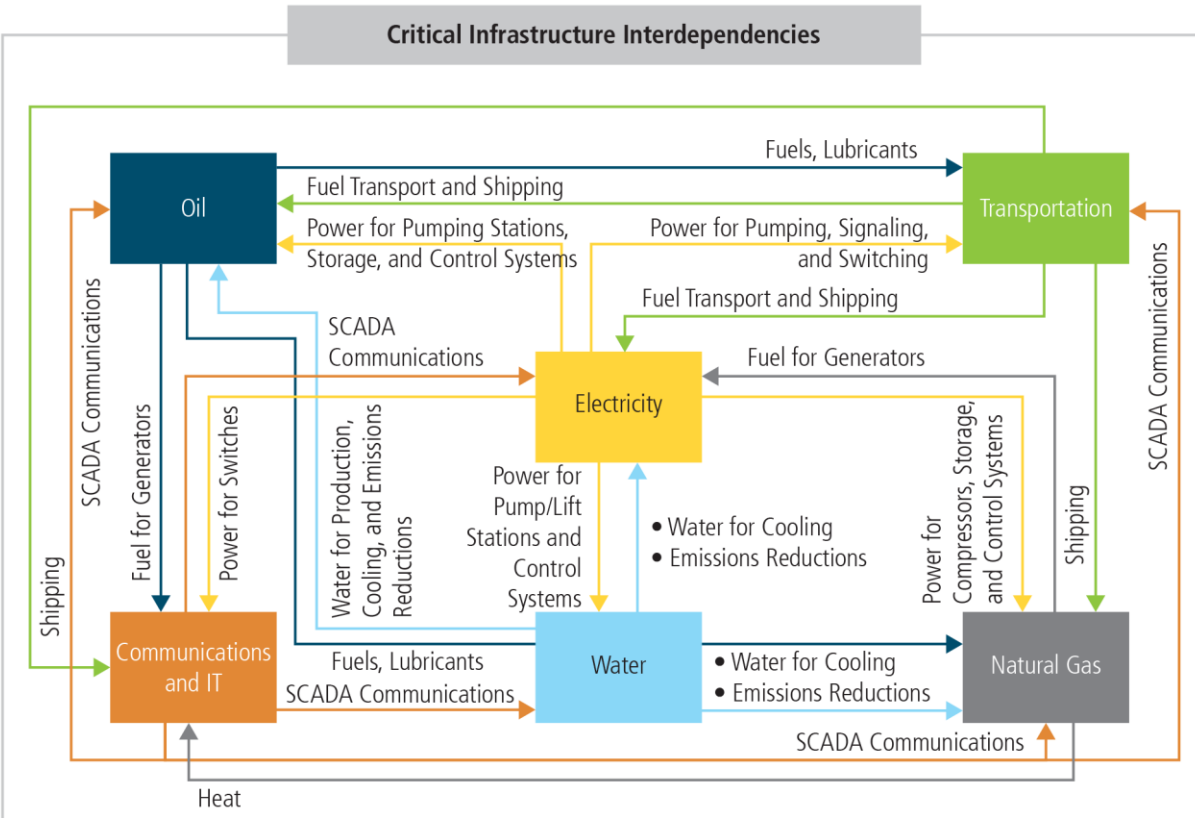
This summary also includes brief summaries of select recommendations to modernize and transform the electricity sector. Specific descriptions of and rationale for the 76 QER recommendations are in the 21st Century Electricity System chapter. The QER also includes an Appendix with an Electricity System Overview.

The Electricity Sector and National Goals

While respecting state, regional, and tribal prerogatives, the QER 1.2 supports development of consistent Federal strategy that accounts for the complex electricity sector context. The analysis conducted for the QER 1.2 identified three major *integrated objectives* that address the needs and challenges to enable the electricity sector of the 21st century. These objectives—discussed in detail in several QER 1.2 chapters—include (1) Maximizing Economic Value and Consumer Equity, (2) Enabling a Clean Electricity Future, and (3) Ensuring System Reliability, Security and Resilience. In addition to these objectives, QER 1.2 also explores several cross-cutting issues and includes in-depth chapters on two of these: workforce issues and North American electricity system integration.

The nation's critical infrastructures depend on electricity. Electricity is at the center of key infrastructure systems that support these sectors, including transportation, oil and gas production, water, communications and information, and finance. These electricity-dependent critical infrastructures represent core lifeline networks that supports the American economy and society. These critical networks are increasingly converging, sharing resources and synergistic interactions via common architectures (see Figure S-2).

Figure S-2. Critical Infrastructure Interdependencies



Key critical infrastructure interdependencies represent the core underlying framework that supports the American economy and society. The financial services sector (not pictured) is also a critical infrastructure with interdependencies across other major sectors supporting the U.S. economy.

Rapidly Evolving Context

The QER 1.2 identifies a number of key trends that will shape the future electricity sector, including: the changing generation mix; low load growth; increasing vulnerabilities to severe weather/climate change; the proliferation of new technologies, services, and market entrants; increasing consumer choice; emerging cyber/physical threats; aging infrastructure and workforce; and the growing interdependence of regulatory jurisdictions. Each topic is introduced here and discussed in more detail in Chapter 1, Transforming the Nation's Electricity Sector: The Second Installment of the QER.

Increasing Importance of "Internet of Things" (IoT) and Digitization. IoT is *"sensors and actuators embedded in physical objects—from roadways to pacemakers—[that] are linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet."* The rapid growth of IoT is both a manifestation and key enabler of this major change in the economy. Electricity enables this information-intense economy, while at the same time gaining new value through digitization and interconnectedness.

Increased Productivity, Lower Load Growth. Since the 1950s, growth in U.S. electric consumption has gradually slowed each decade due to a number of factors, including moderating population growth, improvements in the energy efficiency of buildings and industry, market saturation of certain major appliances, and a shift in the broader economy to less energy-intensive industries. Looking forward to 2040, electricity use is projected to grow slowly.

Decarbonizing the Electricity System. U.S. electricity system emissions declined since 2005 by 20 percent, largely due to a slowing of electricity demand growth and the accelerated deployment of lower-carbon generation. Low natural gas prices have led to substantial substitutions of lower-emitting gas for high-emitting coal. The electricity sector has been and—depending on the interplay of technology innovation, market forces, and policy—is likely to continue to be the first mover in economy-wide GHG emissions reductions. This is in part because the electricity sector has the broadest and most cost-effective abatement opportunities of any sector, including multiple zero-carbon and low-carbon generation options—such as nuclear, hydropower, solar, wind, geothermal, biomass, and fossil generation with carbon capture and storage—as well as many operational and end-use efficiency opportunities. It will also play a major role in the levels of decarbonization needed from other sectors such as transportation.

National Security Vulnerability. Without access to reliable electricity, much of the economy and all electricity-enabled critical infrastructures are at risk. These include our national security and homeland defense networks, which depend on electricity to carry out their missions to ensure the safety and prosperity of the American people. As U.S. policies establish new pathways to enhance economic competitiveness and environmental objectives, it is also essential that these policies work in concert with national security objectives.

Growing Importance of Back-up Generation. The loss of significant economic value from even short power outages places a very high premium on *customer as opposed to system reliability* and has helped to create a growing market for back-up generation to meet individual customer needs. Such back-up solutions sometimes have multiple components to ensure necessary redundancy.

Information Technology and the Electricity System. Information and Communications Technology (ICT) as well as grid control technologies for electricity systems—both large and small scale—have evolved, enabling increased interconnection and capture of economies of scale and scope. The electricity industry's early adoption of analytical and computer techniques to coordinate the generation and transmission of power facilitated increased interconnection and inter-utility power transfers.

A Smarter Grid. The "smart grid" refers to an intelligent electricity grid—one that uses digital communications technology, information systems, and automation to detect and react to local changes in usage, improve system operating efficiency, and in turn reduce operating costs while maintaining high system reliability. Smart meter infrastructure, sensors, and communication-enabled devices and controls give electricity consumers and utilities new abilities to monitor electricity consumption and potentially lower usage in response to time, local distribution, or price constraints. Smart meters also provide a number of other benefits, including enhanced outage management and restoration, improved distribution system monitoring, and utility operational savings.

Changing Generation Profile. The national generation mix has realigned over the past few decades and is likely to continue changing. The U.S. generation fleet is transitioning from one dominated by centralized generators with high inertia and dispatchability to one that is more "hybridized," relying on a mixture of traditional, centralized generation, and variable utility-scale and distributed renewable generation.

Aging Infrastructure. Like any infrastructure, the physical components of the electricity system are constantly aging. The continual maintenance and replacement of electricity system infrastructure components provides an important opportunity to modernize the electricity system.

Two-way Flows. For over 100 years, the electricity system has been operated through one-way flows of electricity and information. The generation and smart grid technology innovations described earlier can reduce grid costs and improve efficiency, as well as save time and effort. These technologies have also enabled an electricity system where two-way flows are possible and more common, and where digitization is a key enabler of a new range of services, including increased flexibility, higher system efficiency, reduced energy consumption, and increased consumer options and value.

Customer Engagement, New Business Models, and the Emerging Role of Aggregators. Throughout the electricity industry's development, the electricity customer was viewed as "load"—the aggregate accumulation of demand that utilities served, supported by a "ratepayer." This view of customers as load and ratepayer, largely passive because there were no real alternative options to utility service, was operative through the early 1980s. Changes in the electricity sector starting in the mid-1980s, however, have prompted utilities and emerging competitors to slowly shift their "customer as load" views to a point of view that is more customer-centric.

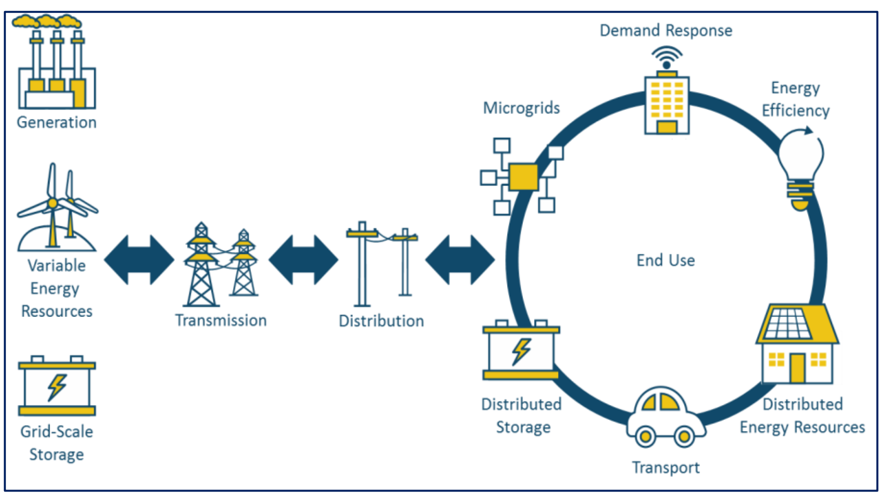
Workforce Challenges. Realizing the full potential of shifts in generation technologies, operations tools, and industry structure will require an electricity industry workforce capable of adapting and evolving to meet the needs of the 21st century electricity sector. A skilled workforce that can build, operate, and manage a modernized grid infrastructure is an essential component for realizing the full value of a modernized electricity sector.

Extreme Weather. The increased severity of extreme weather events over time has been a principal contributor to an observed increase in the frequency and duration of U.S. power outages between 2000 and 2012. Many weather-related threats to the electricity system are increasing in frequency and intensity and are also projected to worsen in the future due to climate change.

The Electricity Sector: Maximizing Economic Value and Consumer Equity

This chapter discusses the role of the electricity sector in creating economic value. The electricity sector has been an economic engine for the United States for over a century, providing reliable and competitively priced electricity that is critical for the United States' productivity. The vast majority of American consumers—encompassing households, businesses, and institutions—enjoy reliable and affordable electricity that enables a modern economy and a high standard of living. Consumers can now both produce and consume power and increase efficiency through advanced distribution infrastructure, and increasingly can provide energy, capacity, and ancillary services. This changing relationship between consumers and the grid is further

Figure S-3. Emerging 21st Century Electricity Two-Way Flow Supply Chain



driving the convergence of systems, business models, services, policies, and new technologies in a development feedback loop.

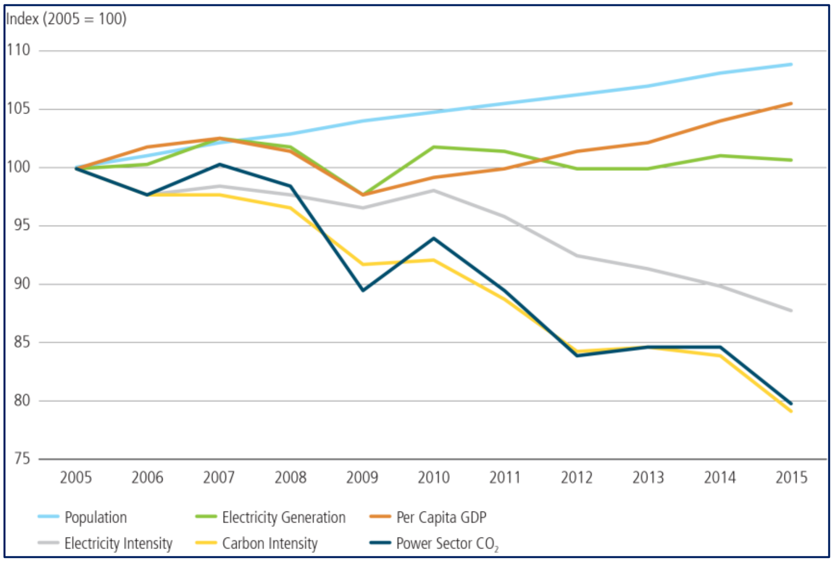
Key Findings

- Advanced metering infrastructure has had a significant impact on the nature of interactions between the electricity consumer and the electric system, allowing two-way flow of both electricity and information and enabling the integration of assets behind the meter into the larger electric grid.
- Interconnection standards and interoperability are critical requirements for seamless integration of grid-connected devices, appliances, and building energy management systems, without which grid modernization and further energy efficiency gains may be hindered.
- Evolving consumer preferences for electricity services are creating new opportunities.
- The convergence of the electric grid with information and communications technology creates a platform for value creation and the provision of new services beyond energy.
- There is enormous potential for electric end-use efficiency improvement based on (1) technical analyses, and (2) the differences in energy efficiency performance between states and utilities with and without ambitious electric end-use efficiency policies and programs.
- Tribal lands and American territories have the highest rates of un-electrified homes—more than half of a million homes. The extreme rurality of some tribal communities coupled with high levels of poverty present an economic challenge for the electric utilities trying to serve them.
- Optimization of behind-the-meter assets will require the design of coordination, communication, and control frameworks that can manage the dispatch of these devices in a way that is both economical and secure, while maintaining system reliability.
- Mobile, internet-connected devices foster new ways of consumer engagement, as well as enable consumers to have more efficient and real-time management of their behind-the-meter assets.
- Consumers and third party merchants that produce electricity can provide economic, environmental, and operational benefits.
- New grid services, modern technologies, and evolving system topologies and requirements are straining traditional methods of valuation. Appropriate valuation of the grid services by various technologies is technically and administratively challenging and may depend on spatial and temporal variables unique to different utilities, states, and regions.
- Currently, about 90 percent of the residential electricity consumption, 60 percent of commercial, and 30 percent of industrial is used in appliances and equipment that are subject to Federal minimum efficiency standards implemented, and periodically updated by, the Department of Energy. Between 2009 and 2030, these cost-effective standards are projected to save consumers more than $545 billion in utility costs, reduce energy consumption by 40.8 quads, and reduce carbon dioxide emissions by over 2.26 billion metric tons.
- Miscellaneous electric loads (MELs), devices that are often inadequately addressed by minimum standards, labeling and other initiatives, are expected to represent an increasing share of total electricity demand, particularly for the residential and commercial sectors.
- Connected devices and energy management control systems are decreasing in cost and improving in functionality, although their market penetration is still low, particularly in residences and small–to-medium-sized commercial buildings. These new technologies and systems, and the broader ‘Internet of Things’ provide a wide range of options for consumers to manage their energy use, either passively using automated controls, or through active monitoring and adjustment of key systems.
- Energy management control systems with communication capabilities are increasing opportunities for demand response services in support of grid operations. Third-party aggregators and other business models are facilitating the expanded use of demand response, but the regulatory environment remains unsettled in many states.
- Lower-income households use less energy, but pay a considerably higher fraction of their after-tax income for electricity services.
- Insufficient broadband access in rural areas could inhibit the deployment of grid modernization technologies and the economic value these technologies can create.

Building a Clean Electricity Future

A clean electricity system reduces air and water pollution, lowers GHG emissions and limits the impacts to the ecosystem in areas such as water and land use. Addressing climate change will require the United States to greatly reduce our carbon emissions, while simultaneously addressing new grid management challenges that have arisen due to recent trends in electricity generation and demand, the changing climate, and the national security implications of grid dependency. Keeping this context in mind, this Chapter explores the essential elements of a clean electricity system, and identifies the policy, market and technology innovations needed to achieve it. In short, we have made substantial progress in reducing the environmental impact of the electricity system, but much work remains.

Figure S-4. Trendlines in CO_2 Emissions Drivers, 2005–2015



Key Findings

- A clean electricity system reduces air and water pollution, lowers GHG emissions and limits the impacts to the ecosystem in areas such as water and land use.
- Deep decarbonization of the electricity system is essential for meeting climate goals; this has multiple economic benefits beyond those of environmental responsibility.
- The United States is the largest producer and consumer of environmental technologies. In 2015, the U.S. environmental technology and services industry employed 1.6 million people, had revenues of $320 billion, and exported $51 billion worth of goods and services.
- Though the U.S. population and economy have grown, between 1970 and 2014, aggregate emissions of common air pollutants from the electric power sector dropped 74 percent even as electricity generation grew by 167 percent.
- U.S. carbon dioxide (CO_2) emissions from the power sector have substantially declined. Between 2006 and 2014, 61 percent of these reductions are attributed to switching from coal- to gas-fired power generation and 39 percent to increases in zero-emissions generation.
- The increasing penetration of zero-carbon variable energy resources (VERs) and deployment of clean distributed energy resources (DERs) (including energy efficiency) are critical components of a U.S. decarbonization strategy.
- It is beneficial to a clean electricity system to have many options available as many of the characteristics of clean electricity technologies complement each other.
- Currently, 29 states and D.C., have a Renewable Portfolio Standard and 23 states have active and binding Energy Efficiency Resource Standards (EERSs) for electricity. States that have actively created and implemented such electricity resource standards and other supporting regulatory policies have seen the greatest growth in renewables and efficiency.
- The integration of variable renewables increases the need for system flexibility as the grid transitions from controllable generation and variable load to more variable generation and the need and potential for controllable load. There are a number of flexibility options such as demand response (DR), fast ramping natural gas generation, and storage.

- Energy efficiency is a cost-effective component of a clean electricity sector. The average levelized cost of saved electricity from energy efficiency programs in the United States is estimated at $46/MWh, versus the levelized cost of electricity for natural gas combined-cycle generation, with its sensitivity to fuel prices, at $52 to $78/MWh.
- Electricity will likely play a significant role in the decarbonization of other sectors of the U.S. economy as electrification of transportation, heating, cooling, and industrial applications continues. In the context of the Quadrennial Energy Review (QER), electrification includes both direct use of electricity in end use applications as well as indirect use whereby electricity is used to make intermediate fuels such as hydrogen.
- Realizing GHG emissions reductions and other environmental improvements from the electricity system to achieve national goals will require additional policies combined with accelerated technology innovation
- Improving understanding of the electricity system and its dynamics through enhancements in data, modeling, and analysis is needed to provide information to help meet clean objectives most cost-effectively.
- Decades of federal, state, and industry innovation investments have significantly contributed to recent cost reductions in renewable energy and energy efficiency technologies.
- Innovation in generation, distribution, efficiency, and demand response technologies is essential to a low carbon future. Innovation combined with supportive policies can provide the signal needed to accelerate deployment of clean energy technologies, providing a policy pull to complement technology push.
- Nuclear power currently provides 60 percent of U.S. zero-carbon electricity, but existing nuclear merchant plants are having difficulty competing in restructured electricity markets due to low natural gas prices and flat or declining electricity demand. Since 2013, six nuclear power reactors have shut down earlier than their licensed lifetime, and eleven[1] others have announced plans to close in the next decade. In 2016, two states, Illinois and New York, put policies in place to incentivize the continued operation of existing nuclear plants.
- Enhanced oil recovery (EOR) operations in the United States are commercially demonstrated geologic storage, and could provide a market pull for the deployment of carbon capture, utilization, and storage (CCUS).
- Federal laws currently limit the ability of regulated utilities to utilize federal tax credits in the same manner as private and unregulated developers. Publicly owned clean energy projects cannot benefit from the clean energy tax credits because tax equity investors cannot partner directly with tax exempt entities to monetize tax credits.
- Low-income and minority communities are disproportionately exposed to air quality and water quality issues associated with electric power generation. Compared to the U.S. population overall, there is a greater concentration of minorities living within a three-mile radius of coal- and oil-fired power plants. In these same areas, the percentage of the population below the poverty line is also higher than the national average.
- Some energy technologies that reduce greenhouse gas emissions, such as carbon capture, utilization, and storage (CCUS), concentrated solar power, and geothermal generation, have the potential to increase energy's water intensity; others, such as wind and photovoltaic (PV) solar power, can lower it. Dry cooling can reduce water intensity but may increase overall GHG emissions by decreasing generation efficiency. Though there can be a strong link between energy and water efficiency in energy technologies, many research, development, demonstration, and deployment (RDD&D) funding criteria do not incorporate water use or water performance metrics. Designing technologies and optimizing operations for improved water performance can have both energy and water benefits.
- There is currently no centralized permanent-disposal facility for used nuclear fuel in the United States, so this radioactive material is stored at reactor sites in 35 states awaiting development of consolidated storage facilities and/or geologic repositories.
- Coal combustion residues, such as coal ash and scrubber slurry, are the second most abundant waste material in the United States, after household waste.

[1] Note that six of these reactors (the New York and Illinois reactors) are expected to remain open with the passage of Clean Energy Standards (CESs) in those states.

- There is a range of decommissioning needs for different types of power generation facilities.

Ensuring Electricity System Reliability, Security, and Resilience

This chapter addresses a range of possible risks to the electricity system and the broader economy and suggests options to mitigate and prepare for these risks. Traditional electricity system operations are evolving in ways that could enable a more dynamic and integrated grid. The growing interconnectedness of the grid's energy, communications and data flows creates enormous opportunities; at the same time, it creates the potential for a new set of risks and vulnerabilities. Also, the emerging threat environment, particularly with respect to cybersecurity and increases in the severity of extreme weather events, poses challenges for the reliability, security, and resilience of the electricity sector, as well as to its traditional governance and regulatory regimes.

Figure S-5a. Time Scales of Traditional Grid Operations

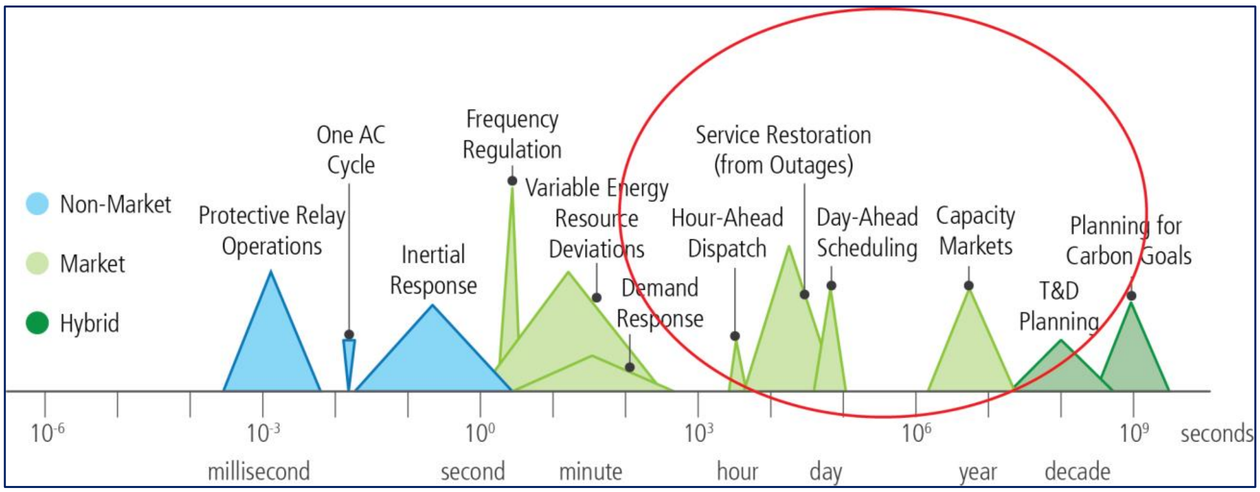
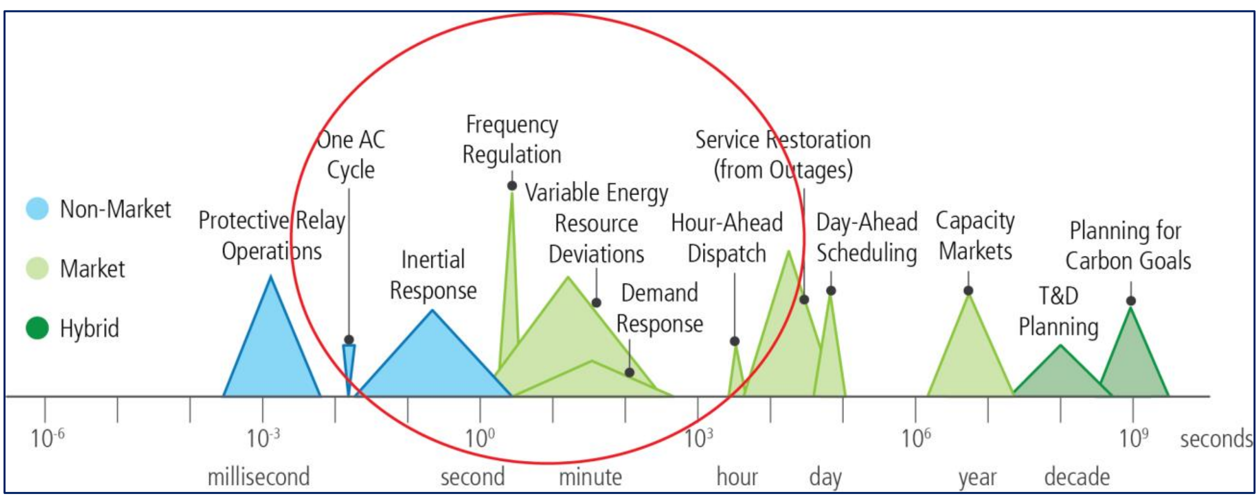


Figure S-5b. Changing Time Scales for Grid Operators Managing Two Way Electricity Flows



Key Findings

- The reliability of the electric system underpins virtually every sector of the modern U.S. economy. Reliability of the grid is a growing and essential component of national security. Standard definitions of reliability have focused on the frequency, duration, and extent of power outages. With the advent of more two-way flows of information and electricity, communication across the entire system from generation to end use, controllable loads, more variable generation, and new technologies such as storage and advanced meters, reliability needs are changing, and reliability definitions and metrics must evolve accordingly.
- The time scales of power balancing have shifted from daily to hourly, minute, or second-to-second to millisecond to millisecond at the distribution end of the supply chain; with the potential to impact system frequency and inertia and/or transmission congestion. The demands of the modern electricity system has required, and will increasingly require, innovation in technologies (e.g., inverters), markets (e.g., capacity markets), and system operations (e.g., balancing authorities).
- Electricity outages disproportionately stem from disruptions on the distribution system (over 90 percent of electric power interruptions), both in terms of the duration and frequency of outages; this is largely due to weather-related events. Damage to the transmission system, while infrequent, can result in more widespread major power outages that affect large numbers of customers with significant economic consequences.
- As transmission and distribution system design and operations become more data-intensive, complex, and interconnected, the demand for visibility across the continuum of electricity delivery has expanded across temporal variations, price signals, new technology costs and performance characteristics, socio-economic impacts, and others. However, deployment and dissemination of innovative visibility technologies face multiple barriers that can differ by the technology and the role each plays in the electricity delivery system.
- Data analysis is an important aspect of today's grid management, but the granularity, speed, and sophistication of operator analytics will need to increase, and distribution- and transmission-level planning will need to be integrated.
- The leading cause of power outages in the United States is extreme weather, including heat waves, blizzards, thunderstorms, and hurricanes. Events with severe consequences are becoming more frequent and intense, due to climate change, and have been the principal contributors to an observed increase in the frequency and duration of power outages in the United States.
- Grid owners and operators are required to manage risks from a broad and growing range of threats. These threats can impact almost any part of the grid (e.g., physical attacks), but some vary by geographic location and time of year. Near-term and long-term risk management is increasingly critical to the ongoing reliability of the electricity system.
- The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities, juxtaposed against the slower-moving deployment of defense measures. Mitigation and response to cyber threats are hampered by inadequate information-sharing processes between government and industry, the lack of security-specific technological and workforce resources, and challenges associated with multi-jurisdictional threats and consequences. System planning must evolve to meet the need for rapid response to system disturbances.
- Other risk factors stem from the increasing interdependency of electric and natural gas systems as natural gas–fired generation provides an increasing share of electricity. However, coordinated long-term planning across natural gas and electricity can be challenging since the two industries are organized and regulated differently.
- As distributed energy resources (DERs) become more prevalent and sophisticated—from rooftop solar installations to applications for managing building electricity usage—planners, system operators, and regulators must adapt to the need for an order of magnitude increase in the quantity and frequency of data to ensure the continuous balance of generation and load.
- Demand response technologies and programs offer a particularly flexible grid resource that is capable of improving system reliability, reducing the need for capital investments to meet peak demand, reducing electricity market prices, and improving the integration of variable renewable energy resources. It can be used for load reduction, load shaping, and management of consumption to help grid operators mitigate the impact of variable and distributed generation on the transmission and distribution systems.

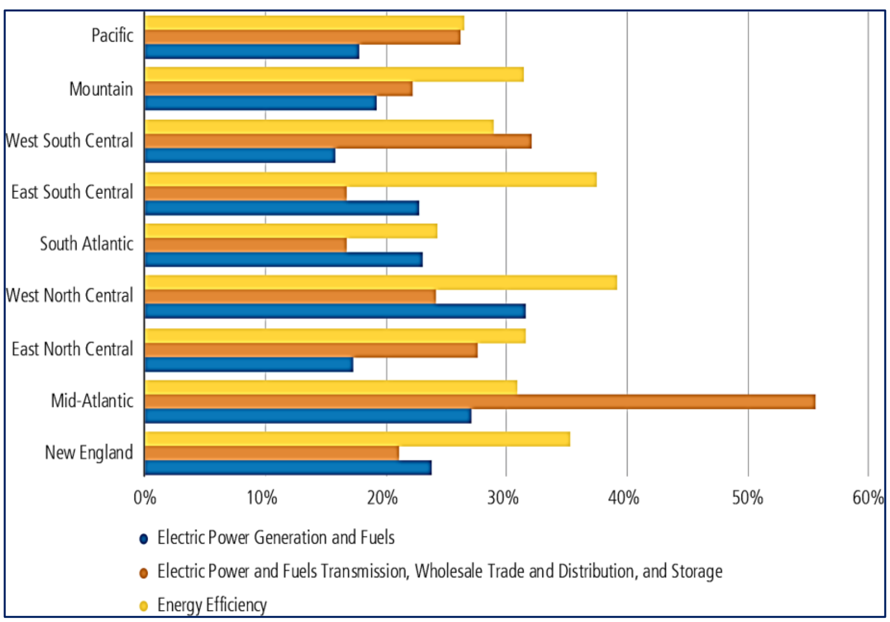
- Information and communications technologies are increasingly utilized throughout the electric system and behind the meter. These technologies offer advantages in terms of efficient and resilient grid operations and opportunities for consumers to interact with the electricity system in new ways. They also expand the grid's vulnerability to cyber attacks by offering new vectors for intrusions and attacks, making cybersecurity a system-wide concern.
- There are no commonly used metrics for measuring grid resilience. Several resilience metrics and measures have been proposed; however, there has been no coordinated industry or government initiative to develop a consensus on or implement standardized resilience metrics.
- Low-income and minority communities are disproportionately impacted by disaster-related damage to critical infrastructure. These communities with fewer resources may not have the means to mitigate or adapt to natural disasters and disproportionately rely on public services, including community shelters, during disasters.

This chapter was developed in conjunction with the closely-related and recently-published "Joint United States-Canada Electric Grid Security and Resilience Strategy."

The Electricity Workforce: Changing Needs, New Opportunities

This chapter provides an overview of current and projected employment in and related to the electricity sector, and it discusses options to assist workers and develop a workforce that has the skills to build, maintain, and operate the electricity system of the future. The broader changes in the electricity industry have created both new opportunities and new challenges for the electricity industry workforce, including new workforce opportunities in the renewable energy industry and information and communications technologies, and the challenges of the skills gap for deploying and operating new technologies, the shift in the geographic location of jobs, and the need to recruit and retain an inclusive workforce. The electricity industry is the dominant consumer of coal, natural gas, and renewable energy technologies, so changes in electricity industry demand for these resources can cause regional and sectoral dislocations in these industries. Each industry has distinctive workforce skills requirements and geographic concentrations, so employment gains in one industry do not always translate to opportunities for those workers affected by employment loss in other industries that may be geographically distant and require different skills.

Figure S-6. Percentage of Employers Reporting Very High Hiring Difficulty by Census Region and Subsector (Q4 2015)



Key Findings

- Over 1.9 million people are employed in jobs related to electric power generation and fuels, while 2.2 million people are working in industries directly or partially related to energy efficiency.
- Job growth in renewable energy is particularly strong. Employment in the solar industry has grown over 20 percent annually from 2013 to 2015. From 2010 to 2015, the solar industry created 115,000 new jobs. In 2016, approximately 374,000 individuals worked, in whole or in part, for solar firms, with more than 260,000 of those employees spending most of their time on solar. There were an additional 102,000 workers employed at wind firms across the Nation. The solar workforce increased by 25 percent in 2016, while wind employment increased by 32 percent.
- The oil and natural gas industry experienced a large net increase in jobs over the last several years, adding 80,000 jobs from 2004 to 2014. Unlike coal production, natural gas production is projected to increase over the coming decades under a business-as-usual scenario, sustaining natural gas industry employment.
- Employment in the natural gas industry is regionally and temporally volatile; 28,000 jobs were lost between January 2015 and August 2016. Shifts in locations pose challenges for employees and the economies of the areas where they live and work.
- Between 1985 and 2001, coal production increased 28 percent as industry employment fell by 59 percent due to efficiencies gained by shifting production from Appalachia to the West. In 2015, annual coal production was at its lowest level since 1986, and it is forecast to continue declining over the coming decades.
- Aside from a minor employment increase from 2000 to 2011, 141,500 domestic coal jobs were lost between 1985 and 2016, and the industry shrank by 60 percent. Today, the coal mining industry employs about 53,000 people.
- Despite ongoing economic challenges in the Appalachian region, the non-highway appropriated budget for the Appalachian Regional Commission (ARC), a federally-funded regional economic development agency, has fallen from roughly $600 million in the early 1970s to around $100 million in the 1980s and remained roughly constant until 2016. The ARC budget recently increased from $90 million in fiscal year 2015 to nearly $150 million in fiscal year 2016.
- The Abandoned Mine Lands Reclamation Fund's (AML Fund's) inability to fully support the reclamation of lands disrupted by the coal mining industry has the potential to leave communities in regions with declining local revenues with polluted and unsafe lands and few means to repair the damage. The AML Fund's increased ability to support coal mine reclamation would provide local employment opportunities and help coal communities transition to new industries.
- The continued fiscal difficulties of coal miner pensions threaten the solvency of the Pension Benefit Guaranty Corporation, a Federal agency that insures private-sector pension funds and is funded out of insurance premiums paid by member funds.
- Proliferation of information and communications technology and new technologies like distributed generation, smart home devices, and electric battery storage have led to new businesses and employment opportunities, which will require a wide array of new skills.
- The electricity industry will need a cross-disciplinary power grid workforce that can comprehend, design, and mange cyber-physical systems; the industry will increasingly require a workforce adept in risk assessment, behavioral science, and familiarity with cyber hygiene.
- A dip in the number of electricity industry workforce training programs in the 1980s contributed a shortage of middle and upper management positions in the sector today, creating a workforce gap as the large number of baby boomers retire.
- Workforce retirements are a pressing challenge. Industry hiring managers often report that lack of candidate training, experience, or technical skills are major reasons why replacement personnel can be challenging to find—especially in electric power generation.
- Electricity and related industries employ fewer women and minorities than the national average, but have a higher proportion of veterans. Only 5 percent of the boards of utilities in the United States in

2015 include women, and approximately 13 percent of board members among the top 10 publicly owned utilities were African American or Latino. Underrepresentation in or lack of access to science, technology, engineering, and mathematics educational opportunities and programs contribute to the underrepresentation of minorities and women within the electricity industry.

- From 1995 to 2013, the number of injuries per 100 employee-years in the electricity utility industry decreased from 4.7 to 1.3. However, line workers continue to experience hazardous working conditions. In 2014, electrical power line installers and repairers suffered 25 fatal work injuries—a rate of 19 per 100,000 full-time equivalent workers, which is over five times the national work fatality rate.
- While data on energy sector workforce are improving, there are still major shortcomings in the data availability, precision, and categorization of energy sector jobs.

Enhancing Electricity Integration in North America

This chapter details the interconnectivity of the United States, Canada, and Mexican electric systems and opportunities for enhancing integration. The potential for electricity integration to provide economic benefits and support the development of more modern and resilient energy infrastructure has been a longstanding theme for North American diplomacy. Earlier this year at the North American Leaders' Summit, President Barack Obama, President Enrique Peña Nieto and Prime Minister Justin Trudeau signed a statement agreeing to collaborate on cross-border transmission projects in order to achieve the mutual goal of advancing clean and secure power. The extensive electricity integration that already exists between the United States and Canada, and the potential to increase existing integration between the United States and Mexico, suggests that North America has much to gain from collaborative planning, strategy, and cooperation in the power sector.

Figure S-7. Border Crossings of Electric Transmission Lines

Key Findings

- Integration of the power systems of Canada, Mexico, and the United States historically occurred by gradual, ad hoc, and regional adjustments implemented by an array of regional public and private stakeholders, reflecting the complex and fragmented jurisdictions in all countries. Many opportunities for enhanced integration have included a collection of stakeholders and were pursued on a sub-regional basis.
- One model for shared power sector governance is demonstrated by the reliability planning under the North American Electric Reliability Corporation (NERC); however, this engagement has been limited to Canada, the United States, and the Baja California region of Mexico.
- Canada, Mexico, and the United States governments have all made significant climate commitments and indicated a desire to shift towards greater renewable energy penetration. Greater cross-border integration could be a tool to maximize gains from the deployment of clean energy generation, but the complexity and current asymmetry of national and subnational policy frameworks may impede implementation.
- The design of domestic U.S. clean energy policies, both at the federal and state level, have implications for cross-border trade and continental emissions reductions. Currently, there are significant disparities between U.S. states' policies for recognition or exclusion of international clean energy imports.
- Continued study of the context and levels of integration of each subregional cross-border interconnection will allow for a deeper understanding of which policies have shaped current levels of cross-border trade (Table 7-1).
- Canada has additional hydropower resources which could be exported to the United States to provide a reliable source of firm, low-carbon energy. There are concerns among stakeholders that increased imports of Canadian hydropower could reduce U.S. renewable energy competitiveness; however, there are examples of arrangements where Canadian hydropower decreases curtailments of U.S. renewable resources.
- Trade has been increasing across the North American bulk power system, but cross border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.
- Under a low carbon future scenario, current modeling results show that transmission with Canada becomes increasingly important for sustaining emissions reductions, and has a significant impact on the generation mix in border regions.
- While many electricity system models exist for the United States (and in some cases, the United States and Canada), detailed modeling tools to explore the economic, social, and/or reliability impacts of electricity trade across all of North America are currently insufficient to inform opportunities for enhancing integration.
- While extensive integration between the United States and Canada can inform the potential for increased future U.S.-Mexico integration, these situations are fundamentally dissimilar in four main ways: lack of a dominant exporting country on the U.S.-Mexican border, the different regional approaches to integration on the U.S. side, the nascent regulatory framework in Mexico, and the lack of parity in open access transmission agreements and reliability coordination between the United States and Mexico. The United States and Mexico agreed to a set of principles for electricity integration in early January 2017.
- Mexico's ongoing electricity utility industry reforms could have significant impacts on the future of cross-border integration. The reforms are focused on the overall goal of competitiveness, with the twin objectives of reducing electricity costs and developing more clean energy. A transition in Mexico from oil to natural gas in electricity generation could have significant impacts in the manufacturing sector, reducing electricity prices, boosting manufacturing output and increasing overall GDP for Mexico.
- Mexico's increasing importation of U.S. natural gas could be an economic and environmental opportunity for both sides, by offsetting expensive and high-GHG-emitting diesel generation in Mexico and creating economic opportunities for U.S. exporters. The resulting reduction in electricity costs in Mexico could also boost overall North American competitiveness.
- The Electric Reliability Council of Texas (ERCOT) could benefit from greater integration with Mexico, through access to enhanced imports or as a business opportunity for power exporters.

- California's ambitious clean energy policy provides an opportunity for energy exporters in Mexico, especially in the Baja California region, to supply clean energy, dispatchable power, or ancillary services.

A 21st-Century Electricity System: Conclusions and Recommendations

This chapter highlights many recommendations that are enablers of the modernization and transformation necessary. The recommendations build on the analysis and findings in earlier chapters. Many of the recommendations will provide the incremental building blocks for longer-term, planned changes and activities, undertaken in conjunction with state and local governments, policy-makers, industry and other stakeholders. The policy, research and investment choices made today will establish critical pathways for decades.

Recommendations in Brief

QER 1.2 provides 76 recommendations divided into six sections. The first section addresses recommendations that are crosscutting, addressing all three high level goals national security, economic competitiveness and environmental responsibility. Following this section in the QER, three sections make more specific recommendations that will help meet the strategic objectives: maximizing economic value and consumer equity; building a clean electricity future; and ensuring grid reliability, security, and resilience. There are also recommendation sections on the electricity sector workforce and on enhancing electricity integration in North America. These recommendations are summarized here, with full details in Chapter 7.

Key Crosscutting Recommendations to Support the Security and Reliability of the Electricity System

Protect the Electricity System as a National Security Asset. The Federal Power Act provides a statutory foundation for an electricity reliability organization to develop reliability standards for the bulk power system. Pursuant to this authority, FERC has certified NERC as the Electric Reliability Organization. Under this arrangement, NERC and FERC have put into place a comprehensive set of binding reliability standards for the bulk power system over the past decade, including standards on cybersecurity and physical security. However, the Federal oversight authority is limited: FERC can approve or reject NERC-proposed reliability standards, but it cannot author or modify reliability standards.

The nature of a national security threat, however, as articulated in the FAST Act, stands in stark contrast to other major reliability events that have caused regional blackouts and reliability failures in the past. In the current environment, the U.S. grid faces imminent danger from cyber attacks. Widespread disruption of electric service because of a transmission failure initiated by a cyber attack at various points of entry could undermine U.S. lifeline networks, critical defense infrastructure, and much of the economy; it could also endanger the health and safety of millions of citizens. Also, natural gas plays an increasingly important role as fuel for the Nation's electricity system; a gas pipeline outage or malfunction due to a cyber attack could affect not only pipeline and related infrastructures, but also the reliability of the Nation's electricity system.

- **Amend Federal Power Act authorities to reflect the national security importance of the Nation's electric grid**. Grid security is a national security concern—the clear and exclusive purview of the Federal Government. The Federal Power Act, as amended by the FAST Act, should be further amended by Congress to clarify and affirm the Department of Energy's (DOE's) authority to develop preparation and response capabilities that will ensure it is able to issue a grid-security emergency order to protect critical electric infrastructure from cyber attacks, physical incidents, EMPs, or geomagnetic storms. In this regard, Federal authorities should include the ability to address two-way flows that create vulnerabilities across the entire system. DOE should be supported in its development of exercises and its facilitation of the penetration testing necessary to fulfill FAST Act emergency authorities. In the area of cybersecurity, Congress should provide FERC with authority to modify NERC-proposed reliability standards—or to promulgate new standards directly—if it finds that expeditious action is needed to protect national security in the face of fast-developing new threats to the grid. This narrow expansion of FERC's authority would complement DOE's national security authorities related to grid-security emergencies affecting critical electric infrastructure and defense-critical electricity infrastructure. This approach would maintain the productive NERC-FERC structure for developing and enforcing reliability standards, but would ensure that the Federal Government could act directly if necessary to address national security issues.

- **Collect information on security events to inform the President about emergency actions as well as imminent dangers**. DOE should collect targeted data on critical cyber, physical, EMP, and geomagnetic disturbance events and threats to the electric grid to inform decision making in the event of an emergency or to inform the anticipatory authorities in the FAST Act. DOE should concurrently develop appropriate criteria, processes, and definitions for collecting these targeted data using a dedicated information protection program to safeguard utility data consistent with FERC rules. Reporting will be done on a confidential basis. Updating will be required to address evolving threats. DOE will coordinate the development of analytical data-surveillance and data-protection tools with the National Labs, states, universities, industry, Federal agencies, and other organizations as appropriate.
- **Adopt integrated electricity security planning and standards**. FERC should, by rule, adopt standards requiring integrated electricity security planning on a regional basis to the extent consistent with its statutory authority. Such requirements would enhance DOE's effectiveness in carrying out its responsibilities and authorities to address national security imperatives and new vulnerabilities created by (1) two-way flows of information and electricity and (2) the transactive role of customers and key suppliers (such as those providing stored fuel for strategic generators). Important national security considerations warrant careful consideration of how generation, transmission, distribution, and end-user assets are protected from cybersecurity risks. Vulnerabilities of distribution and behind-the-meter assets, which may provide an increasing number of potential entry points for access to utility control systems, are threats that can adversely affect the operation of the transmission system; for these vulnerabilities, a careful review of protections is required. To adequately address and support the security requirements of the FAST Act and DOE's implementation of the FAST Act, this review should be performed on an integrated basis, rather than separating the review into bulk power system and other assets.

  To ensure that there are no unnecessary vulnerabilities associated with state-to-state or utility-to-utility variations in protections, integrated electricity security planning should be undertaken to cover the entire United States, including Alaska, Hawaii, and U.S. territories. FERC should consider having existing regional organizations undertake such planning, as it deems appropriate. FERC should evaluate whether the costs of implementing security measures identified in the integrated electricity security plan are appropriate for regional cost allocation, where such measures are found to enhance the security of the regional transmission electric system.

To the extent necessary, appropriate statutes should be amended to clearly authorize FERC to adopt such integrated electricity security planning requirements. However, FERC should immediately begin to advance this initiative to the maximum extent possible under its current authority by initiating a dialogue, including discussions with DOE and state authorities, and driving consensus on Integrated Electricity Security Plans.

- **Assess natural gas/electricity system infrastructure interdependencies for cybersecurity protections**. DOE, pursuant to FAST Act authorities and in coordination with FERC, should assess current cybersecurity protections for U.S. natural gas pipelines and associated infrastructure to determine whether additional or mandatory measures are needed to protect the electricity system. If the assessment concludes that additional cybersecurity protections—including mandatory cybersecurity protocols—for natural gas pipelines and associated infrastructure are necessary to protect the electricity system, such measures and protocols should be developed and implemented. This work should build on existing assessments, including those underway at the Transportation Security Administration.

Increase Financing Options for Grid Modernization Estimates of total investment requirements necessary for grid modernization range from a low of about $350 billion to a high of about $500 billion. Grid modernization is the platform for the 21st-century electricity system, bringing significant value associated with lower electricity bills due to fuel and efficiency savings, more electricity choices, and fewer and shorter outages. The Federal Government currently plays a role in providing tax incentives for deployment of clean energy technologies, as well as Federal credit assistance to facilitate early deployment of innovative technologies.

- **Expand DOE's loan guarantee program and make it more flexible to assist in the initial deployment of innovative grid technologies and systems**. The design of the current DOE loan guarantee program is focused primarily on financing deployment of innovative generation technologies. Most DOE loan guarantee recipients, for example, are structured as special project entities that can raise equity outside of regulated business structures and can provide credit security in the form of power purchase agreements. This financing model is not amenable to grid modernization financing by regulated entities, especially in cases of some technological uncertainty associated with initial commercial deployments. In addition, there will an ongoing need for innovation in grid technologies beyond the likely availability of current DOE loan guarantee authority. Also, the limitations of the loan program restrict the program to a very small and ever-changing portion of new transmission capacity; more projects and innovation are necessary to transform the grid.

  Modifications to the current DOE Title XVII loan guarantee program are needed to (1) reduce restrictions on numbers/types of projects and timeframes, e.g. in order to adequately address innovative transmission capacity needs, and (2) provide clear statutory authority for lending to other public or public/private entities that support transmission and other grid modernization projects (e.g., state agencies, regional power pools) through on-lending or equity investing. By their nature, transmission projects, especially big projects, involve many entities and jurisdictions. Statutory clarification is needed on indirect lending authorities to such entities for multi-jurisdictional projects.

  Some of the benefits of grid modernization are realized over time, as the electricity system itself is changed by technology and market innovations. Additional funding resources would bridge the gap between investment costs and realization of benefits and would enable utilities to invest in grid modernization. A relatively low-cost permanent Federal financing system could be established by setting up a revolving loan fund with one-time seed capital.

Increase Technology Demonstrations and Utility/Investor Confidence. The future electric grid will require that utilities deploy a wide range of new, capital-intensive technologies. Primary technologies are needed to support increased reliability, security, value creation, consumer preferences, and system optimization and integration at the distribution level. Demonstrating the technical readiness and economic viability of advanced technologies is needed to inspire the confidence of utilities and investors.

- **Significantly expand existing programs to demonstrate the integration and optimization of distribution system technologies.** The complexity of the issues facing distribution systems—including new technologies, the need for systems approaches, and geographical differences in markets and regulatory structures—points to a significant need for multiple "solution sets" to enable two-way electricity flows on distribution systems, enhance value, maximize clean energy opportunities, optimize grid operations, and provide secure communications. Building on existing demonstration programs and reflecting the Administration's commitment to the doubling of Federal clean energy innovation over 5 years as part of its Mission Innovation initiative, DOE should develop a focused, cost-shared program for qualifying utilities to demonstrate advanced distribution system technologies at the community scale, including advanced voltage control/optimization systems; dynamic protection schemes to manage reverse power flows, communications, sensors, storage, switching and smart-inverter networks; and advanced distribution management systems, including automated substations.

  Demonstrations supported by the cost-shared, cooperative agreement program would be specifically designed to inform standards and regulations and increase regulatory and utility confidence in key technologies or technology systems. Under this program, utilities would have to make a positive business case for projects and obtain regulatory approvals for their proposed demonstrations. Preference would be given to multi-utility partnerships with diverse customer profiles and to projects that promote education and training in key academic disciplines that are essential for distribution system transformation. Cybersecurity plans for all projects would be required and supported by programmatic review of plans and deployments.

  Existing DOE programs, including advanced distribution management systems, microgrids, communications and sensors, storage, and cybersecurity, should be leveraged to provide technical assistance regarding technological issues, planning and performance evaluation, and institutional needs. A percentage of funding could be dedicated to small, publicly-owned utilities. The program should be of sufficient size to have a material impact; it should start in fiscal year (FY) 2018 and be ramped up over the time period identified in the Mission Innovation initiative.

Build Capacity at the Federal, State, and Local Levels. The 21st-century electricity system is becoming increasingly transactive, and properly valuing attributes is key to an efficient system. Application of lessons learned that pair economic and system analysis will lead to a power system that cost-effectively serves customers while providing nationally valued public goods, e.g., reliability, resilience, and acceptable environmental performance.

Advances in electricity technologies (i.e., smart grid processes and solutions) require enhanced capabilities in human resources to ensure the cost-effective selection, deployment, and operations of key technologies.

- **Provide funding assistance to enhance analytical capabilities in state Public Utility Commissions and improve access to training and expertise for small and municipal utilities.** Federal support should be provided to states and small utilities to enable them to better manage the increasing complexities in the electricity system, such as integrating variable energy resources; incorporating energy efficiency, demand response (DR), and storage into planning; developing competencies in various technologies; and making investment and security decisions within uncertain parameters. These issues are highly technical and require a new knowledge base and skillset often within the domain of computer sciences, economics, and cybernetics. At the same time, these entities are dealing with the workforce issues of outside recruitment or retirement across the electricity industry, which are referenced in the QER. DOE should build and cultivate much-needed analytical capacity at the state level over a limited period of time by allocating funding to state public utility commissions to allow them to hire new or train existing analysts with more sophisticated and advanced skills and build institutional knowledge. Eligibility for state and local funding should be contingent upon demonstration of consideration for Integrated System Planning, which is outlined in this chapter. DOE should support these analysts through an online interactive education and training platform with access to nationally recognized experts. This platform would also be available and tailored to the needs of small utilities. On a national scale, these actions will serve to sustain system reliability and security and bolster resilience.

- **Create a Center for Advanced Electric Power System Economics**. DOE should provide two years of seed funding for the formation of a center designed to provide social science advice and economic analysis on an increasingly transactive and dynamic 21st-century electricity system. The center should be modeled after the National Bureau of Economic Research and be managed by a university consortium. The consortium will establish and maintain a network of experts in economics, the social sciences, and the electricity system; these experts should be from academia, industry, nonprofit institutions, and the National Laboratories. The center will develop new methods where appropriate, serve as advisor and consultant to stakeholders preparing germane analyses, and foster the advancement of students and professionals who are developing expertise in these disciplines. The focus of the center will include power systems evaluation (e.g., valuation, benefit-cost, and competition analysis).

Inform Electricity System Governance in a Rapidly Changing Environment. The rapid rate of change in the electricity sector today often exceeds the ability of institutions and governance structures to respond in a manner sufficient to meet critical national goals and objectives. This is particularly true in the resolution of jurisdictional disputes over responsible price formation and valuation. Clarification and harmonization of roles and responsibilities for developing pricing can reduce market uncertainty, facilitate the achievement of policy goals, and reduce costs to ratepayers.

- **Establish a Federal Advisory Committee on Alignment of Responsibilities for Rates and Resource Adequacy.** DOE, in collaboration with the National Association of Regulatory Utility Commissioners, should convene a Federal advisory committee that reports to the Secretary or the Secretary's designee to examine potential jurisdictional concerns and issues associated with harmonizing wholesale and retail rates and tariffs. This advisory committee will evaluate and make recommendations (where appropriate) on the way in which the organized markets reflect state policy; pricing mechanisms for maintaining resource adequacy; state and Federal roles in pricing and operation of distributed energy resources (DERs), storage, and microgrids; the role of aggregators; and mechanisms for implementing consumer protection across the various markets and jurisdictions. The advisory committee will represent a broad cross-section of industry and stakeholders. An annual report will be prepared by this advisory committee for the Secretary that identifies the impact of governance issues and recommends solutions.

In the remainder of this Summary, we highlight a few recommendations from a much more extensive set in the full report.

Maximize Economic Value and Consumer Equity

Tailor and Increase Tools and Resources for States and Utilities to Effectively Address Transitions Underway in the Electricity System. States and electric utilities are responsible for making critical decisions regarding how to improve the reliability, affordability and sustainability of the electric grid, and officials from state agencies and utilities provided comments as part of the QER Stakeholder process on the federal role in informing these decisions. Technical assistance, improved regional consideration in program offerings, and new analysis for decision-making, will allow the federal government to respond to the needs of states and utilities in ensuring consumer value and equity in the electricity system of the 21st Century. Recommendations include:

- Improve energy management and demand response in buildings and industry
- Increase Federal support for state efforts to quantitatively value and incorporate energy efficiency, demand response, distributed storage, and distributed generation into resource planning.

Expand Federal and State Financial Assistance to Ensure Electricity Access for Low-income and Under-served Americans. Analysis indicates that electricity costs represent a disproportionate share of total income for low-income Americans. Increased funding for proven, state-administered programs and enhanced data and tools for targeting assistance can reduce this "electricity burden." Ensuring that the costs of the rapid transition of the electricity system are not disproportionately borne by low-income Americans is a top priority; low-income Americans should also be able to share in the benefits from an electricity system transition. Recommendations include:

- Encourage public-private partnerships to underwrite and support clean energy access for low and moderate income households.
- Provide assistance to address rural, islanded, and tribal community electricity needs.

Increase Electricity Access and Improve Electricity-related Economic Development on Tribal Lands. The interdependencies of electricity access, health, economic wellbeing and quality of life underscore the importance of universal access to electricity. While recent data on electricity access on Tribal Lands is limited, there are still areas that lack adequate access to electricity despite the nation's commitment to full electrification dating back to the Rural Electrification Act of 1936. More recent anecdotal evidence suggests that the problem broadly persists. It is a moral imperative that the Federal Government support Tribal leadership and utility authorities to provide basic electricity service for the tens of thousands of Native Americans who currently lack access to electricity and to foster the associated economic development on tribal lands. Federal agencies should also support renewable energy acceleration and economic development opportunities through renewable energy incentives, workforce development, financing program improvements, and improved consultation with Tribes. Recommendations include:

- Support the achievement of full tribal land electrification.
- Support advanced technology acceleration and economic development opportunities for tribal lands.

Strengthen Rural Electricity and Broadband Infrastructure. The Federal government has historically supported the expansion of access to affordable electricity and communications service in rural America, with major initiatives continuing today mainly through the USDA. The lack of access to broadband in rural areas means that these consumers lack access to demand response technologies, such as smart meters, smart thermostats, and other technologies can reduce pollution, help consumers save electricity, improve overall grid resilience and reliability, and enhance economic development. Broadband expansion into these regions would significantly advance grid modernization goals, while providing significant communications, connectivity, and educational benefits to numerous regions of the country. Supporting broadband access in sparsely-populated rural areas, many of which are low-income, is not, however, profitable for the private sector. Federal support would help enhance security, environmental and economic development goals. Recommendations include:

- Leverage utility broadband build-out to expand public broadband access in rural areas.
- Increase opportunities for small and rural utilities to utilize USDA's electricity financing programs

Enable a Clean Electricity Future

Transform the Electricity System through Leadership in National Clean Electricity Technology Innovation. Private sector investment in clean energy technology faces many barriers, e.g. prices do not reflect the costs and benefits of clean energy, investments are made in a highly-regulated environment, and there are high capital costs and the long time horizons for R&D and capital stock turnover in comparison to many other sectors (e.g. IT). Increased investments in electricity technology innovation is essential for transformation of the electricity system. Federal investments have a history of success and have been leveraged by the private sector to create significant economic value; case studies on nuclear energy, shale gas, and solar PV, among many other electricity-related technologies, demonstrate the instrumental role of federal investment in early-stage R&D. Recommendations include:

- Significantly increase federal investment in clean electricity RD&D.
- Implement Regional Clean Energy Innovation Partnerships.

Address Challenges to Large-scale, Centralized Clean Generation. Regardless of the energy source, there are a number of challenges to deploying large centralized power generation facilities. Lower electricity prices, largely related to low-cost natural gas, are reducing the economic viability of other clean generation resources, especially nuclear energy. Nuclear power currently provides 60 percent of zero-carbon generation in the United States. Hydropower is one of the oldest and most established forms of electricity generation, contributing 6 percent of the electricity generated in the U.S. in 2015 and 19 percent of zero-carbon generation. Non-hydropower renewables – including wind, solar, geothermal, and biomass – accounted for about 7 percent of electricity generated in the U.S. in 2015. Each of these technologies face a range of siting constraints, licensing and permitting processes, or environmental concerns, which can be broad and extensive; this can make new, large-scale deployments difficult, in some cases, taking a decade or more to build. A combination of federal coordination, licensing support, analysis of financing opportunities, and RD&D can help address these barriers. Recommendations include:

- Increase funding for the life-extension R&D program to ensure maximum benefits from existing nuclear generation.
- Increase support for advanced nuclear technology licensing at NRC.
- Develop environmental mitigation technologies for hydropower.

Address Significant Energy-water Nexus Issues Affecting – and Affected by – the Electricity Sector. Electricity systems and water systems are in many cases interconnected. Water is a critical requirement for many electricity generation technologies. Two-thirds of total U.S. electricity generation—including many coal, natural gas, nuclear, concentrated solar power (CSP), and geothermal plants—requires water for cooling. In addition, carbon capture, utilization, and storage (CCUS) technologies have significant water demands. Electricity is also required for water and wastewater conveyance, treatment, and distribution. From a full-system perspective, the joint reliance of electricity and water systems can create vulnerabilities (e.g., drought impacts on thermoelectric generation and hydropower), but it can also create opportunities for each system to benefit from well-designed integration. Such challenges and opportunities can be addressed through improved policy integration, data collection, modeling, analysis, RDD&D, and engagement with stakeholders. Recommendations include:

- Launch an electricity-related Energy-Water Nexus Policy Partnership with Federal, state and local partners.

Provide Federal Incentives for a Range of Electricity-related Technologies and Systems. A package of tax incentives targeted at specific market segments can support an all-of-the-above energy strategy by helping to reduce the costs of deploying and using innovative, commercially available energy technologies. The economies of scale and "learning by doing" promoted by such deployments support continued technology cost reductions and greater market competition. Recommendations include:

- Expand the timeframe and the total capacity allowed under the PTC for nuclear generation.
- Provide tax credits for Carbon Capture, Utilization and Storage.
- Increase power purchasing authorities for the Federal Government from 10 to 20 years.

Address a Range of Power Plant Siting Issues. The land use requirements for different types of power generation reflect significant differences between the various types of infrastructure and their operational requirements. Recommendations include:

- Evaluate and develop generation siting best practices.
- Modernize electricity transmission permitting procedures.

Grid Operations and Planning for Electricity System Reliability, Security and Resilience

Support Industry, State, Local, and Federal Efforts to Enhance Grid Security and Resilience. Some types of extreme weather events are projected to increase in frequency and intensity due to climate change. Cyber threats to the electricity system are increasing in sophistication, magnitude, and frequency. Physical threats remain a concern for industry. These challenges could be mitigated through a combination of cost-benefit analyses, standards, and collaboration across industry, state, local, and federal stakeholders. The recommendations build upon and extend current initiatives, such as DOE's Grid Modernization Initiative and Partnership for Energy Sector Climate Resilience. Recommendations include:

- Develop uniform methods for cost-benefit analysis of security and resilience investments for the electricity system.
- Provide incentives for energy storage.
- Support grants for small utilities facing cyber, physical, and climate threats.
- Support mutual assistance for recovering from disruptions caused by cyber threats.
- Support the timely development of standards for grid-connected devices.
- Require states to consider the value of DER, funding for public purpose programs, energy and efficiency resource standards, and emerging risks in integrated resource or reliability planning under PURPA.

Improve Data for Grid Security and Resilience. As the nation increasingly relies on electricity to power the economy and support consumer options and choices, the consequences of electricity outages are rising. The U.S. currently lacks sufficient data on all-hazard events and losses. Such data would help utility regulators, planners, and communities analyze and prioritize security and resilience investments. Recommendations include:

- Enhance coordination between Energy Sector Information Sharing and Analysis Centers (ES-ISACs) and the intelligence communities to synthesize threat analysis and disseminate it to industry in a timely and useful manner.

Encourage Cost-effective Use of Advanced Technologies that Improve Transmission Operations. Permitting and planning are necessary, but complex processes that can slow transmission development and increase costs. Other barriers restrain the use of new technologies that can increase transmission system capacity utilization and improve reliability and security, and other planning priorities. Recommendations include:

- Promote deployment of advanced technologies for new and existing transmission.

Improve EIA's Electricity Data, Modeling, and Analysis Capabilities. EIA provides all levels of stakeholders--government, companies and customers--with data to inform the evaluation and development of policies that affect the electricity grid. More timely and publicly accessible data on how system operations are changing and how efficiency and renewable energy are specifically affecting them would facilitate the development of federal and state policies and investments needed to ensure the reliability, resilience, and security of the grid. Substantially improved electricity transmission data and related analyses by EIA would support significant improvements in the effectiveness of a broad range of government policies and programs, including market design and transmission planning. Recommendations include:

- Expand economic modeling capability for electricity.
- Expand EIA data collection on energy end-use.
- Support EIA's collection of additional data on electricity and water flow for water and wastewater.

Electric Workforce of the 21st Century

Support the Electricity Sector Workforce. The electricity sector is undergoing a number of significant shifts in structure, energy sources, and applications as the industry modernizes and evolves. The full potential of these shifts will, however, only be realized if the electricity sector workforce appropriately adapts and grows to meet the needs of the 21st century electricity system. The federal government has both an interest in development of this workforce. Recommendations include:

- Support Cyber Physical Systems (CPS) curriculum, training, and education for grid modernization and cybersecurity.
- Support Federal and regional approaches to electricity workforce development and transition assistance.

Meet Federal Commitments to Communities Affected by the Transformation of the Electricity Sector. To achieve the transition to the electricity sector of the 21st century smoothly, quickly, and fairly, the Federal government should offer a synthesized package of incentives that address the needs of the most important stakeholders both within and outside of the electricity sector. Many of these needs are addressed through other recommendations on this list, including incentives to reduce the cost of flexible and clean assets, encourage the deployment of new and improved technologies throughout the electricity supply chain, and train workers for 21st century electricity jobs. Recognizing that the shift to the 21st century electricity system can impact communities dependent on 20th century resources, the following recommendations provide transition assistance for communities affected by the multi-decadal decline in coal production. Recommendations include:

- Meet the Federal commitment to appropriate sufficient funding to accomplish the mission of the Abandoned Mine Lands Fund.

Enhance Electricity Integration in North America

Increase North American Cooperation on Electric Grid and Clean Energy Issues: Electric reliability cooperation is needed to strengthen the security and resilience of an increasingly integrated cross-border electricity grid. A clear understanding of the regulatory requirements at the federal and state levels for the permitting of cross-border transmission facilities, sharing of best practices, and exploration of potential future cooperation on grid security issues, will limit uncertainties and improve policy coordination at the multilateral and international levels. Recommendations include:

- Increase U.S. and Mexican cooperation on reliability.
- Advance North American grid security.
- Modernize international cross-border transmission permitting processes.

Conclusion

The electricity sector has been, and will continue to be, an indispensable tool to enable the United States to meet its linked National goals. Thanks to technology innovation and more than a century of development, the electricity system is already an extraordinary national asset. It has supported significant progress towards economic prosperity, equity, environmental responsibility, and security and resilience. The QER identifies many approaches that can build on this success to advance – and accelerate – the electricity system's role in meeting these goals.