TRANSFORMING THE NATION'S ELECTRICITY SYSTEM

THE SECOND INSTALLMENT OF THE QUADRENNIAL ENERGY REVIEW

January 2017

QUADRENNIAL ENERGY REVIEW

TRANSFORMING THE NATION'S ELECTRICITY SYSTEM: THE SECOND INSTALLMENT OF THE QER

January 2017

Preface

Presidential Memorandum

The White House

January 9, 2014

Presidential Memorandum -- Establishing a Quadrennial Energy Review

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

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Section 1. Establishing the Quadrennial Energy Review Task Force.

(a) There is established the Quadrennial Energy Review Task Force (Task Force), to be co-chaired by the Director of the Office of Science and Technology Policy and the Director of the Domestic Policy Council, which shall include the heads of each of the following, or their designated representatives:

(i) the Department of State;

(ii) the Department of the Treasury;

(iii) the Department of Defense;

(iv) the Department of the Interior;

(v) the Department of Agriculture;

(vi) the Department of Commerce;

(vii) the Department of Labor;

(viii) the Department of Health and Human Services;

(ix) the Department of Housing and Urban Development;

(x) the Department of Transportation;

(xi) the Department of Energy;

(xii) the Department of Veterans Affairs;

(xiii) the Department of Homeland Security;

(xiv) the Office of Management and Budget;

(xv) the National Economic Council;

(xvi) the National Security Staff;

(xvii) the Council on Environmental Quality;

(xviii) the Council of Economic Advisers;

(xix) the Environmental Protection Agency;

(xx) the Small Business Administration;

(xxi) the Army Corps of Engineers;

(xxii) the National Science Foundation; and

(xxiii) such agencies and offices as the President may designate.

(b) The Co-Chairs may invite independent regulatory agencies with energy-related responsibilities, including the Federal Energy Regulatory Commission and the Nuclear Regulatory Commission, to participate in the Task Force, as determined to be appropriate by those agencies.

(c) The Co-Chairs shall regularly convene and preside at meetings of the Task Force and shall determine its agenda. Under the direction of the Co-Chairs, the Task Force shall:

(i) gather ideas and advice from State and local governments, tribes, large and small businesses, universities, national laboratories, nongovernmental and labor organizations, consumers, and other stakeholders and interested parties; and

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Sec. 2. The Quadrennial Energy Review Report.

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Sec. 3. Outreach.

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Sec. 4. General Provisions.

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Table of Contents

List of Figures

List of Tables

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

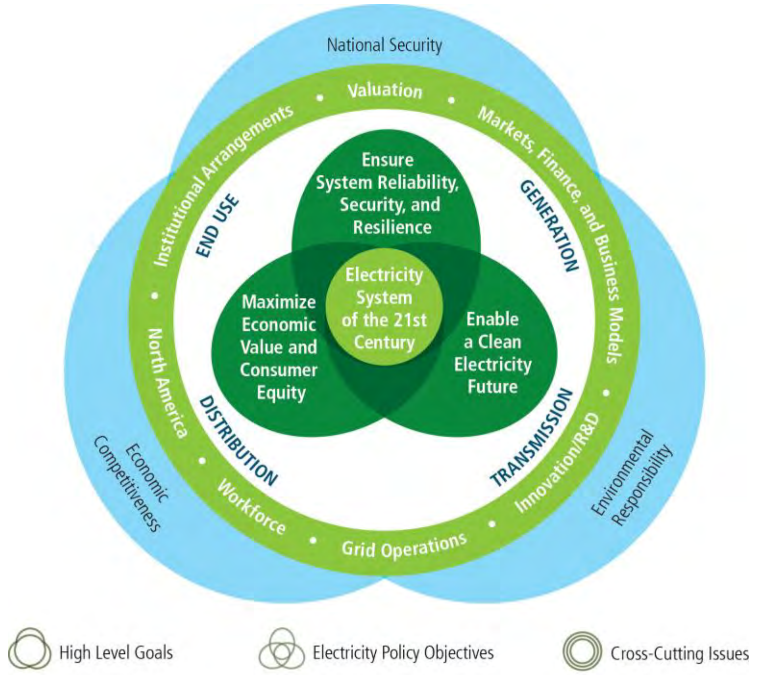


Figure S-1. A comprehensive set of interactions and overlapping objectives and goals must be analyzed to inform policies that will enable the electricity sector of the 21st century. Analysis in QER 1.2 is organized around a set of national goals, integrated objectives, and cross-cutting issues.

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.

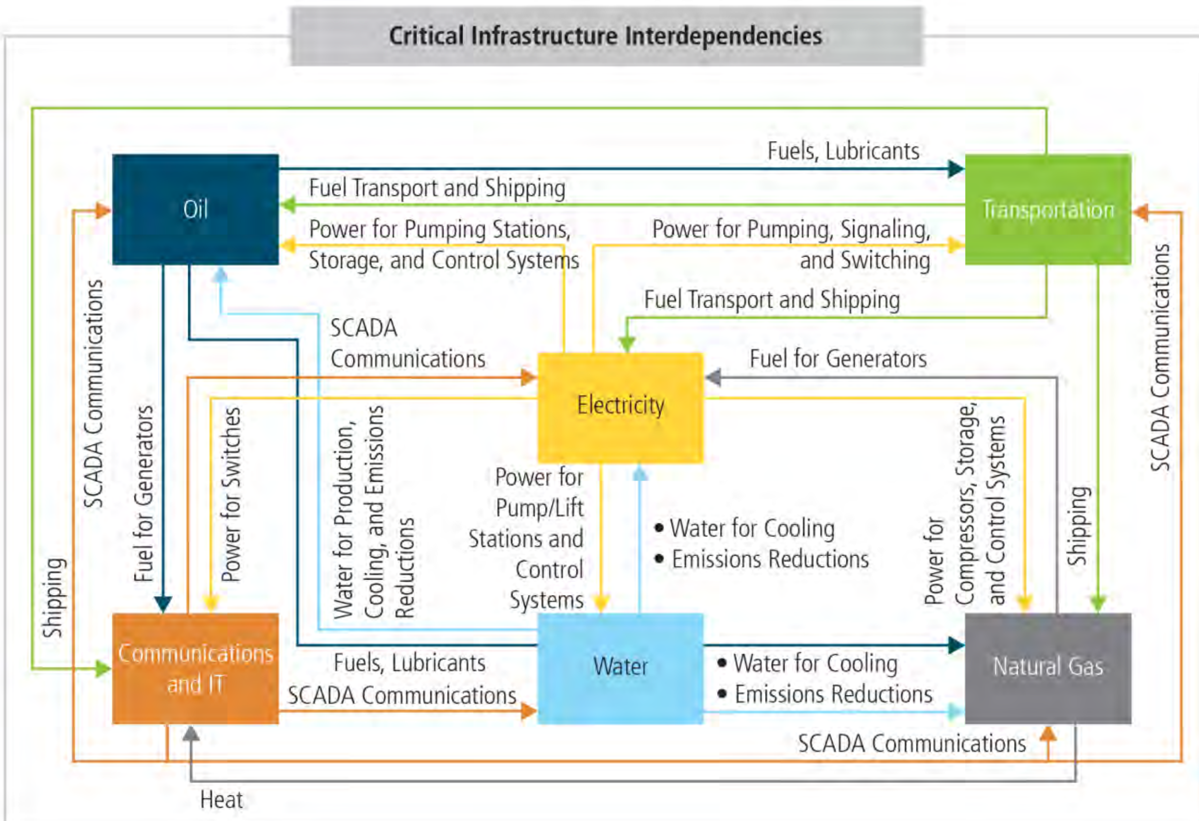
This summary also includes brief summaries of select recommendations to modernize and transform the electricity sector. Specific descriptions of and rationale for the 76 QER recommendations are in the 21st Century Electricity System chapter. The QER also includes an Appendix with an Electricity System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

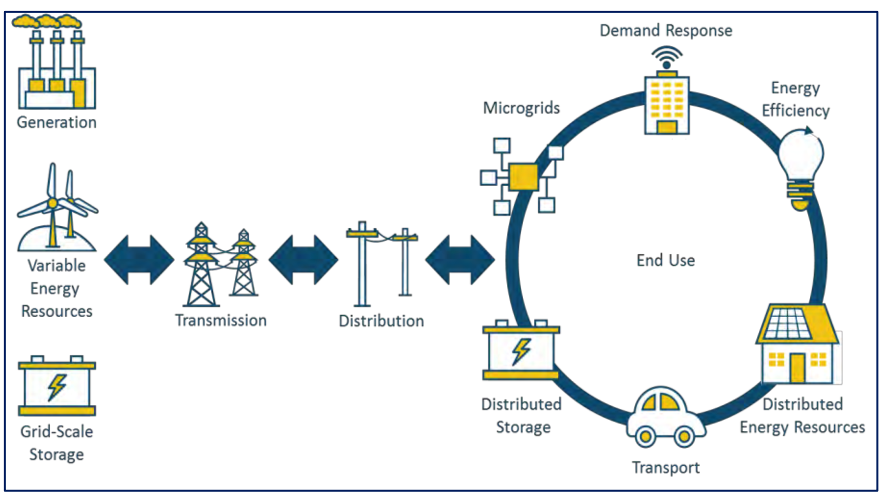
Workforce Challenges. Realizing the full potential of shifts in generation technologies, operations tools, and industry structure will require an electricity industry workforce capable of adapting and evolving to meet the needs of the 21st century electricity sector. A skilled workforce that can build, 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.

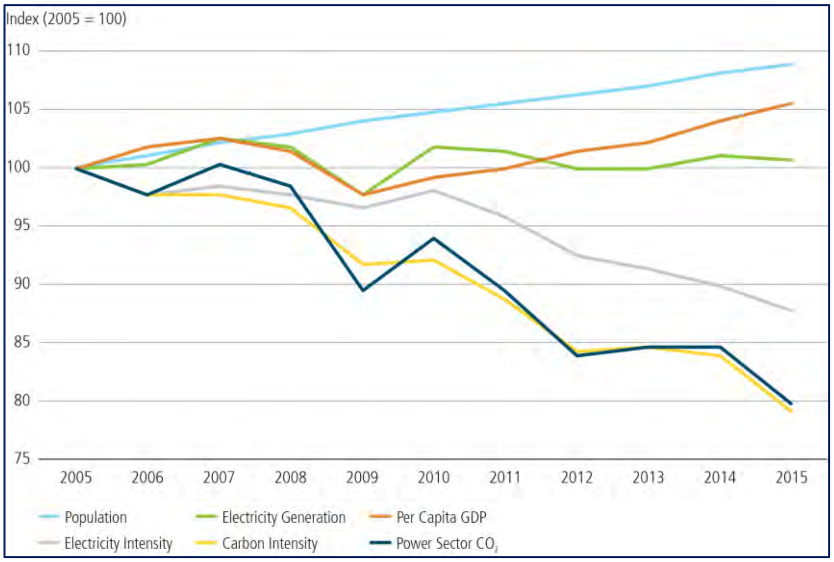
Key Findings

- 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

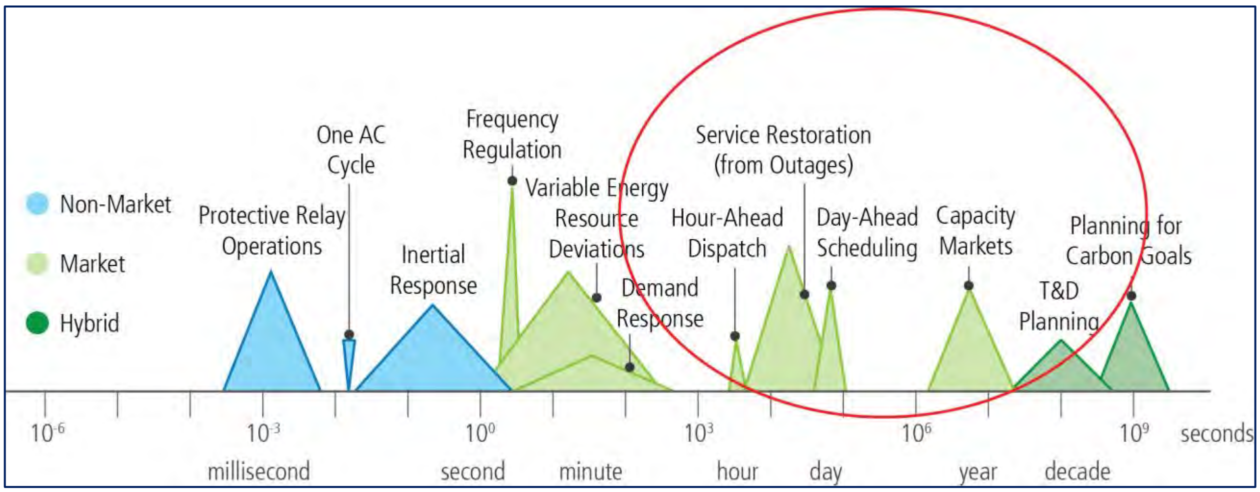
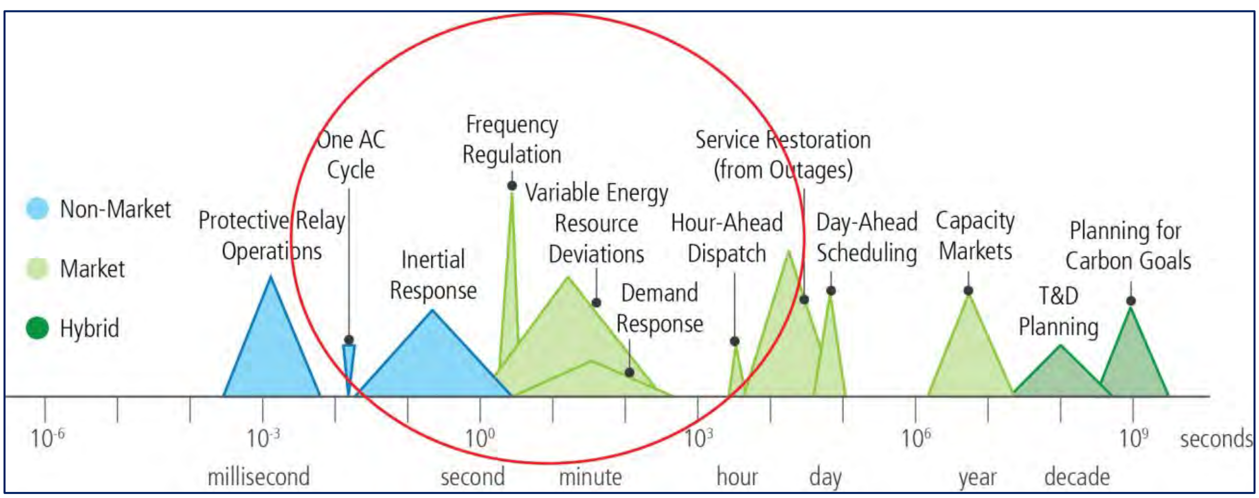


Figure S-5b. Changing Time Scales for Grid Operators Managing Two Way Electricity Flows



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.

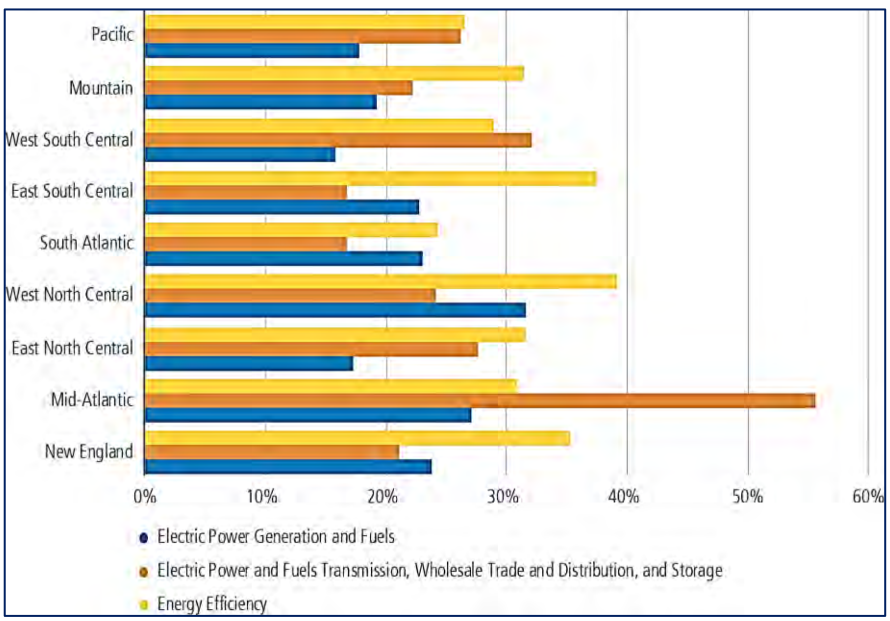
- Information and communications technologies are increasingly utilized throughout the electric system and behind the meter. These technologies offer advantages in terms of efficient and resilient grid operations and opportunities for consumers to interact with the electricity system in new ways. They 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.

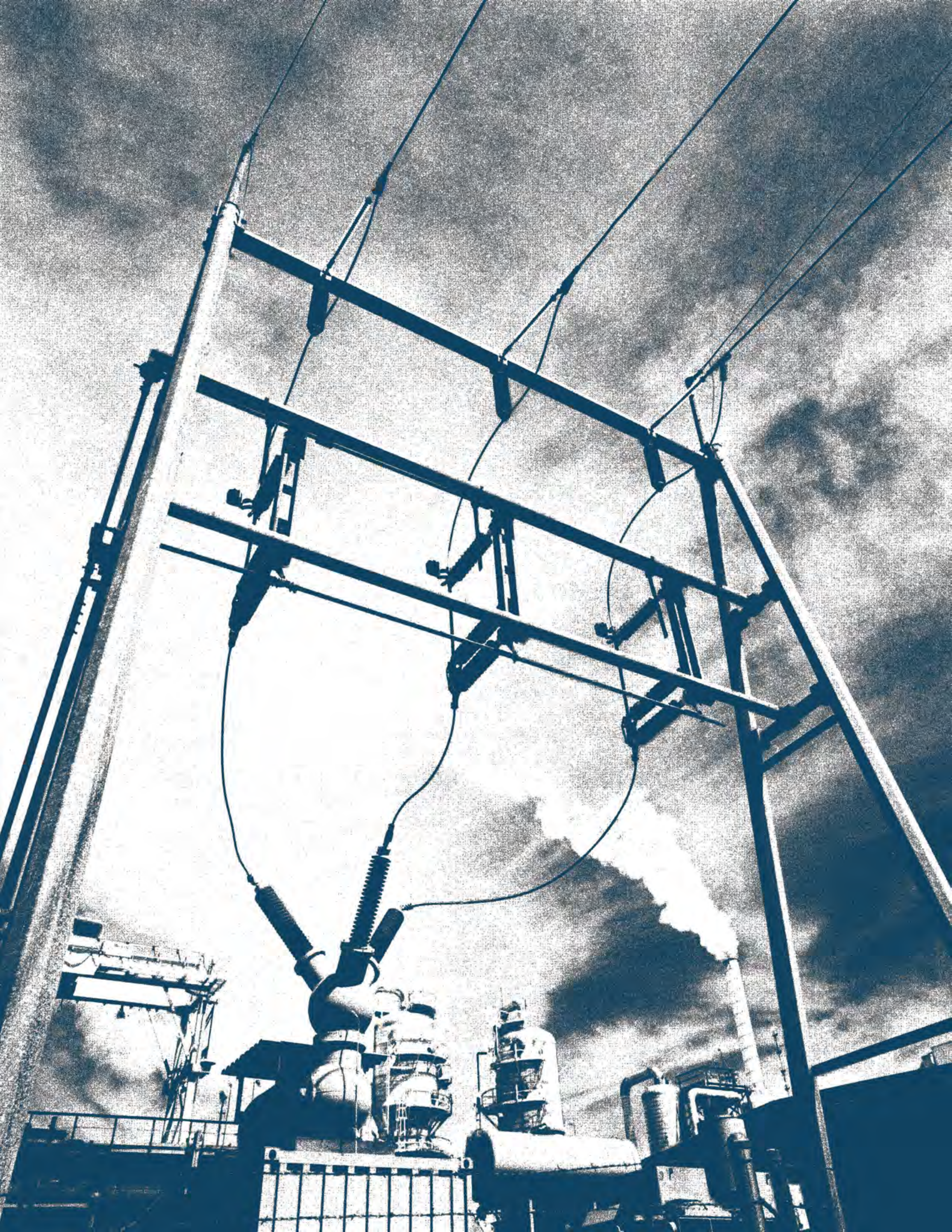
Enhance Electricity Integration in North America

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.



I Transforming the Nation's Electricity System: The Second Installment of the QER

[illegible]

Conceptual Framework for Electricity Sector Policy Considerations

Thomas Edison's observation that electricity had the potential to "reorganize the life of the world" was prescient. Electricity is now foundational to modern life and has enabled enormous value creation over the last 130 years—from Edison's Pearl Street Station, to Insull's grid, to the electrification of rural America, to the build-out of the Nation's grid after World War II, to today's vast and complex interconnected power grid.[1]

[illegible] *The electricity system is 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.*

[illegible]

The U.S. Electricity System: Operating and Economic Statistics

In the United States, there are around 7,700 operating power plants[2] that generate electricity from a variety of primary energy sources; 707,000 miles of high-voltage transmission lines;[3] more than 1 million rooftop solar installations;[4] 55,800 substations;[5] 6.5 million miles of local distribution lines;[6] and 3,354 distribution utilities[7] delivering electricity to 147 million customers.[a, 8] The total amount of money paid by end users for electricity in 2015 was about $400 billion.[9] This drives an $18.6 trillion U.S. gross domestic product and significantly influences global economic activity totaling roughly $80 trillion.[10]

1.1 Electricity from Generation to End Use: Quadrennial Energy Review 1.2

[illegible]

[illegible]

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[a] [illegible]

[illegible]

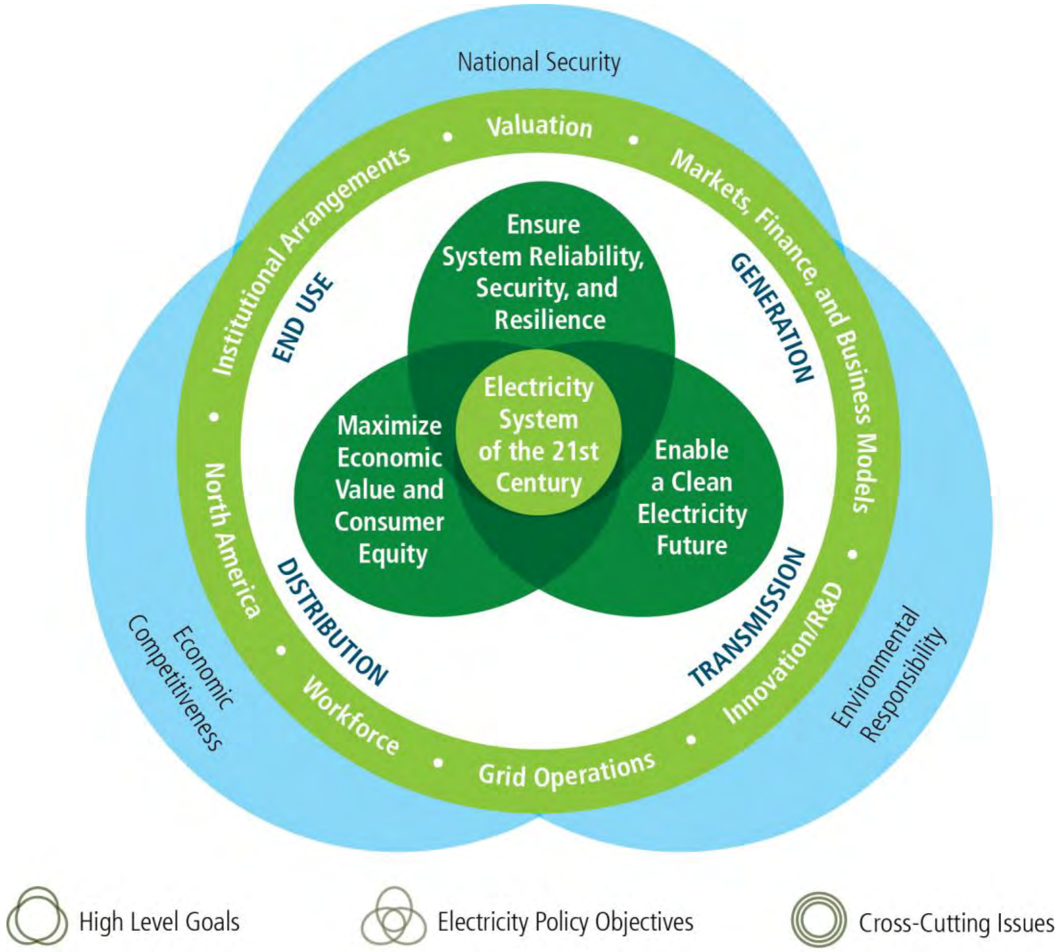
[illegible]

1.1.1 National Goals for a 21st Century Electricity Sector

[illegible]

[illegible]

Figure 1-1. Goals, Objectives, and Organization of QER 1.2



The organization of QER 1.2 reflects the comprehensive set of interactions and overlapping goals and objectives for enabling the electricity system of the 21st century.

[illegible]

1.1.1.1 Economic Competitiveness and the Electricity System

[illegible]

[illegible]

1.1.1.2 Environmental Responsibility and the Electricity System

[illegible]

[illegible]

1.1.1.3 National Security and the Electricity System

[illegible]

1.1.2 Turning National Goals into Actionable Priorities for Electricity System Transformation: Integrated Objectives for QER 1.2

[illegible] *integrated objectives* [illegible]

1.1.2.1 Maximize Economic Value and Consumer Equity

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1.1.2.2 Enable a Clean Electricity Future

[illegible]

[illegible]

[illegible]

1.1.2.3 Ensure Electricity Reliability, Security, and System Resilience

[illegible]

[illegible]

[illegible]

Addressing Climate Change Is an Environmental, Economic, and National Security Imperative

The accumulated evidence of decades of climate science clearly shows that humans are impacting the climate system in new and damaging ways, primarily through the emissions of greenhouse gases (GHGs). Since the widespread adoption of fossil fuels during the Industrial Revolution, human activities have been emitting carbon dioxide (CO_2) faster than the Earth has been removing and storing it. The 17 warmest years on record have occurred in the last 18 years,[14] with 2015 being the warmest year on record and 2016 will likely set yet another record.[15, 16]

Humans experience the climate system not as global, annual averages, but through the climate effects on local weather. Localized impacts can make dry places dryer; wet places wetter; and areas exposed to tropical storms more at risk for high winds, heavy rain, and flooding. What were once rare extreme heat events are already becoming commonplace. Sea-level rise and coastal erosion, coupled with more powerful storms, have destroyed infrastructure and damaged tourism along the East Coast of the United States. Flooding of inland rivers has damaged Midwestern and Northeastern cities. Also, the Arctic, which has been warming at more than twice the rate of lower latitudes,[17] is experiencing infrastructure damage from thawing permafrost; shrinking sea ice (with impacts on coastal erosion and subsistence hunting); and a longer, more destructive wildfire season.

The electricity supply system is a major contributor to U.S. GHG emissions and creates other stresses on the environment as well. Minimizing impacts on the climate, air, water, land, ecosystems, and worker and public safety must be priorities for the electric system, including power plant construction, operation, and decommissioning, as well as transmission and distribution of the electricity, no matter its source. These topics are covered in Chapter III, *Building a Clean Electricity Future*.

The long residence time of CO_2 in the atmosphere establishes an urgent need to act to mitigate the impacts of climate change; even if all CO_2 emissions stopped immediately, the global mean surface temperature would continue to rise and the associated impacts would be felt around the globe for decades to come. In the electric sector, increasing temperatures can increase demand for cooling and warmer water supplies can challenge water-cooled electric generation facilities. Resilience and adaptation are the means by which the United States can reduce these harms, and the electric sector will need to become more resilient and adapt to a changing climate. A discussion of adaptation and resilience are further discussed in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

1.1.3 Crosscutting Issues Important to Achieving National Goals and 21st Century Grid Modernization

[illegible]

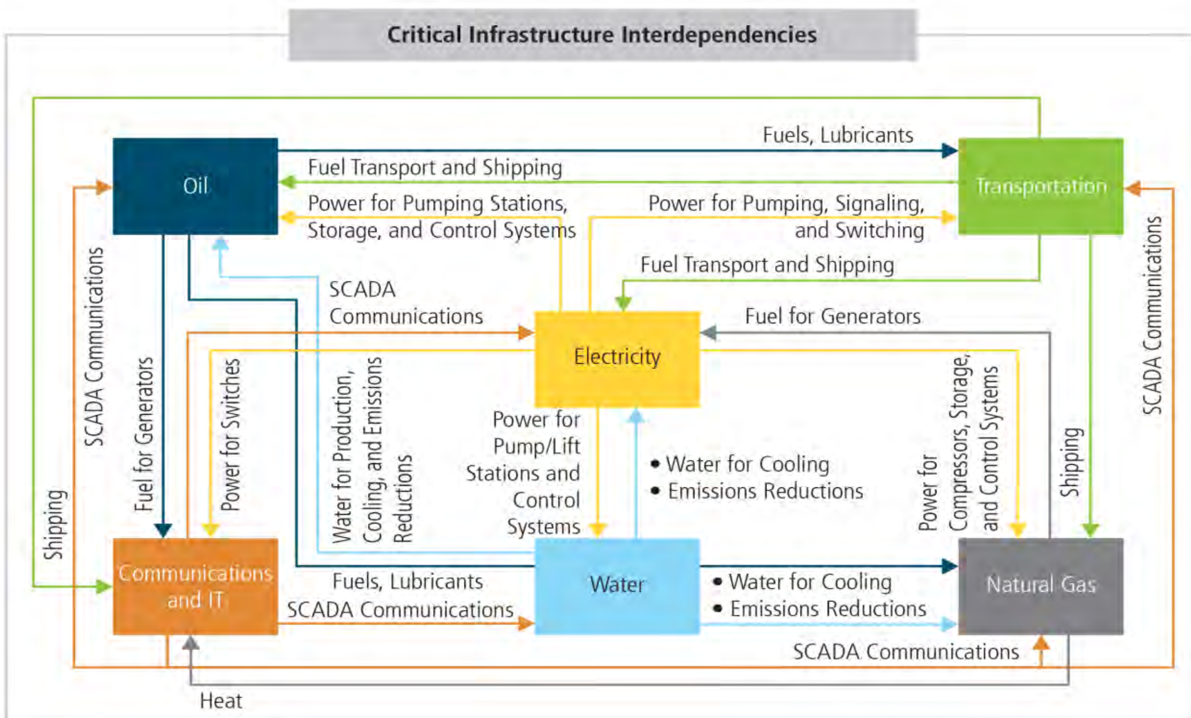
1.2 The Nation's Critical Infrastructures Depend on Electricity

[illegible]

[illegible]

[illegible]

Figure 1-2. Critical Infrastructure Interdependencies[21]



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.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1.3 Electricity-Connected Systems and Digitization Create Significant Economic Value

[illegible] *electricity-information nexus* [illegible]

1.3.1 Value of the Electricity-Dependent "Internet of Things"

[illegible]

[illegible]

Table 1-1. National Data Centers Are Electricity Dependent[40]

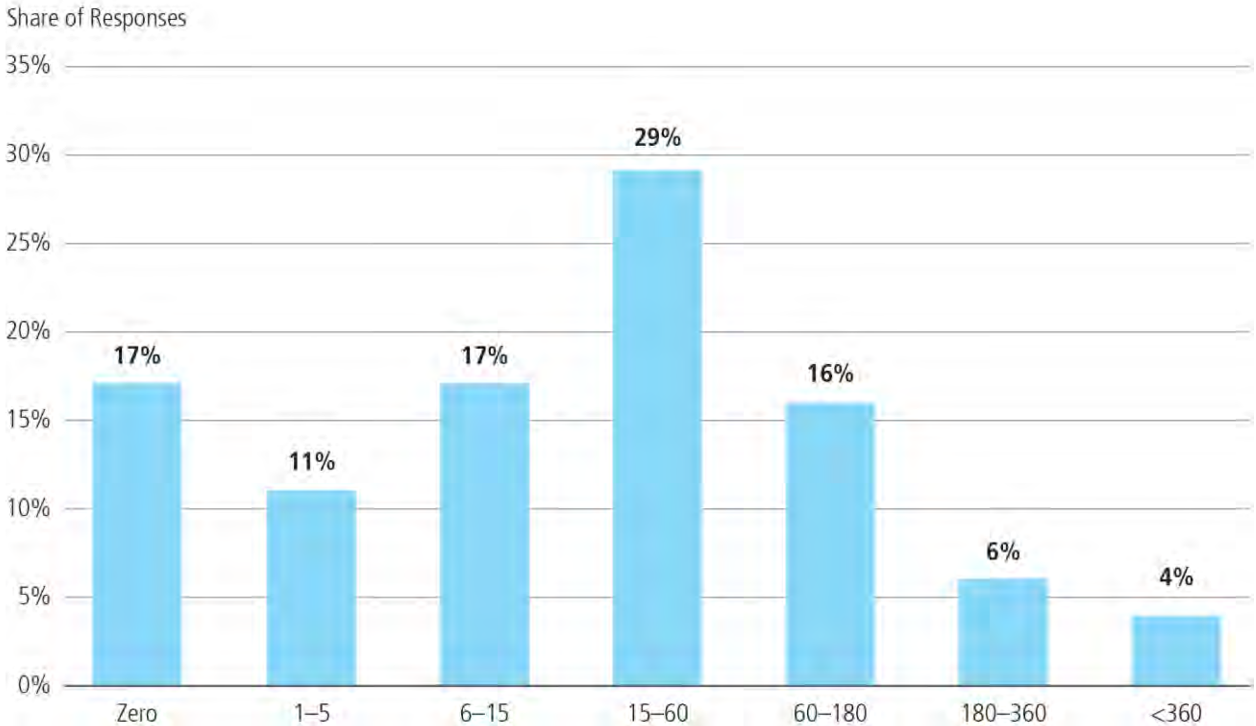
Large Data Centers (>20K square feet)	Nationwide
Number	9,500
Size	~320 million square feet
Server count	8 million
Power load	4 gigawatts
Storage	160 million terabytes
Energy consumption	37 billion kilowatt-hours
Back-up power description (Tier III+ only)	• ñRedundant and maintainableò • Fully redundant power path to all equipment (2N substation to server) • Dual utility power feed • Vendor-owned substation • 10s of back-up gensets (diesel, natural gas) • Generally designed for 72-hour outage

Commercial data centers are an important economic segment that supports much of the internet, business activity, and e-commerce activity. These data centers also require available and reliable electricity service and invest significant money in on-site generation and back-up systems to ensure power availability.

[illegible]

[illegible]

Figure 1-3. Company Survey: Approximately How Many Minutes of IT Downtime Can Occur before Business Is Negatively Impacted?[44]



When the grid goes down, data centers face significant risks as backup power does not always work. The key is to try to minimize the likelihood of grid power outages. Local power grid reliability should be a factor considered when choosing data center locations.

[illegible] *customer as opposed to system reliability* [illegible]

[illegible]

[illegible]

[illegible]

1.3.1.1 Information and the Electricity Sector

Figure 1-4. Electric Utility Control Systems Past to Present[54]

The image on the left depicts an early electricity control system. The image on the right shows a typical control system today.

1.3.2 Digitization Creates Value for the Electricity Sector

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1.3.3 A "Smarter Grid" Is Essential for Grid Modernization and Transformation

[illegible]

[illegible]

> **IT-OT Integration Opportunity: Smart Metering**
>
> Smart metering has traditionally been part of the operational technology (OT) world. Automated meter reading and automated meter management solutions originated in OT and are now connected to the information technology (IT) world. Billing, on the other hand, is typically an IT solution. With integrated systems, end-to-end smart metering (meter-to-bill) bills can be based on exact readings and no longer on estimates.
>
> Customer relationship management, also part of the IT world, plays a vital role in this scenario. With end-to-end smart metering, when a customer contacts a call center to complain about quality of service (e.g., overvoltage), the operator can contact the customer's smart meter in real time to check the historical data stored locally. In addition, new contracts can modify tariffs in the meter in near-real time.

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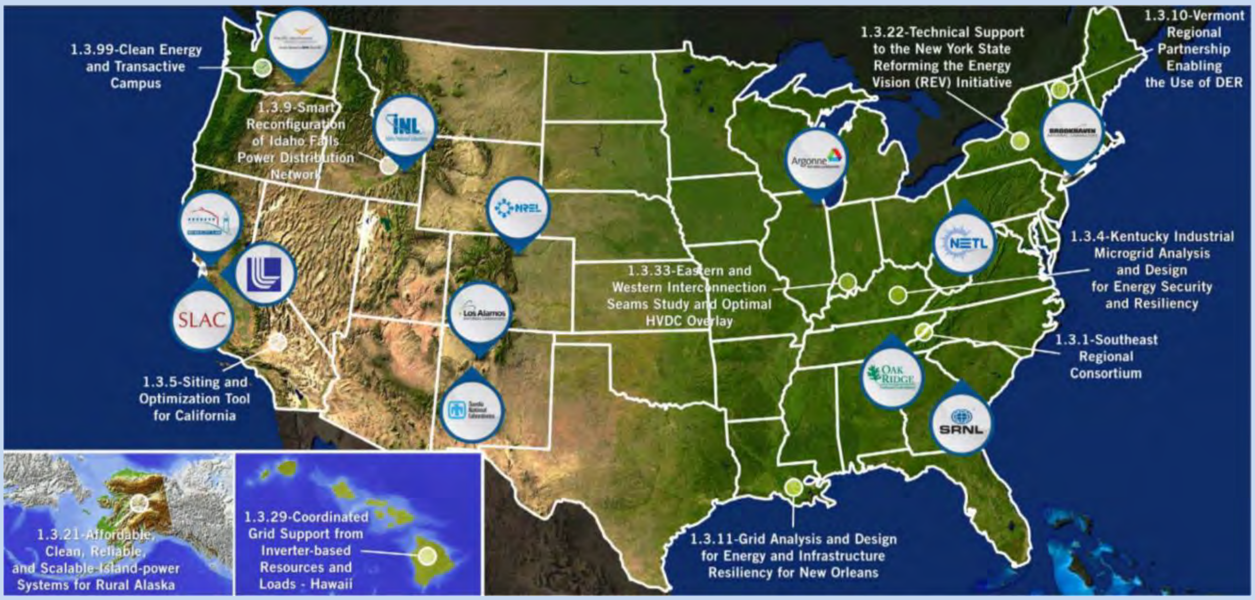
[illegible]

[illegible]

Department of Energy Grid Modernization Initiative

The Grid Modernization Initiative (GMI) is a crosscutting Department of Energy (DOE) effort through which the Department works with public and private partners to develop concepts, tools, and technologies needed to modernize the Nation's grid infrastructure. This work leverages DOE's core capabilities in modeling, computation, systems integration, cybersecurity, and energy storage to help improve system reliability, integrate diverse sources of electricity, advance energy technologies, and provide a critical platform for U.S. competitiveness and innovation in the global economy. In January 2016, the Grid Modernization Laboratory Consortium (GMLC) started 29 regional projects that foster local approaches to grid modernization while contributing to a diverse and balanced national grid.

Figure 1-5. Grid Modernization Laboratory Consortium Locations and Regional Projects[71]



Thirteen DOE National Laboratories collaborate with regional partners on national grid modernization goals throughout the U.S. Projects vary widely, with some of these projects displayed in the figure above and detailed further in Table 1.2 below.

Table 1-2. Sample Grid Modernization Initiative Projects[72]

Project	Summary	Partners
Kentucky Industrial Microgrid Analysis and Design for Energy Security and Resiliency *Oak Ridge National Laboratories, Sandia National Laboratories*	[illegible]	[illegible]

Project	Summary	Partners
Midwest Interconnection Seams Study *National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory*	[illegible]	[illegible]
Grid Analysis and Design for Resiliency in New Orleans *Sandia National Laboratories, Los Alamos National Laboratories*	[illegible]	[illegible]

Grid modernization projects vary widely in scope and region. Three of these projects are summarized above.

[illegible]

[illegible]

1.4 Electricity Systems and Grid Management Are Facing New Challenges

[illegible]

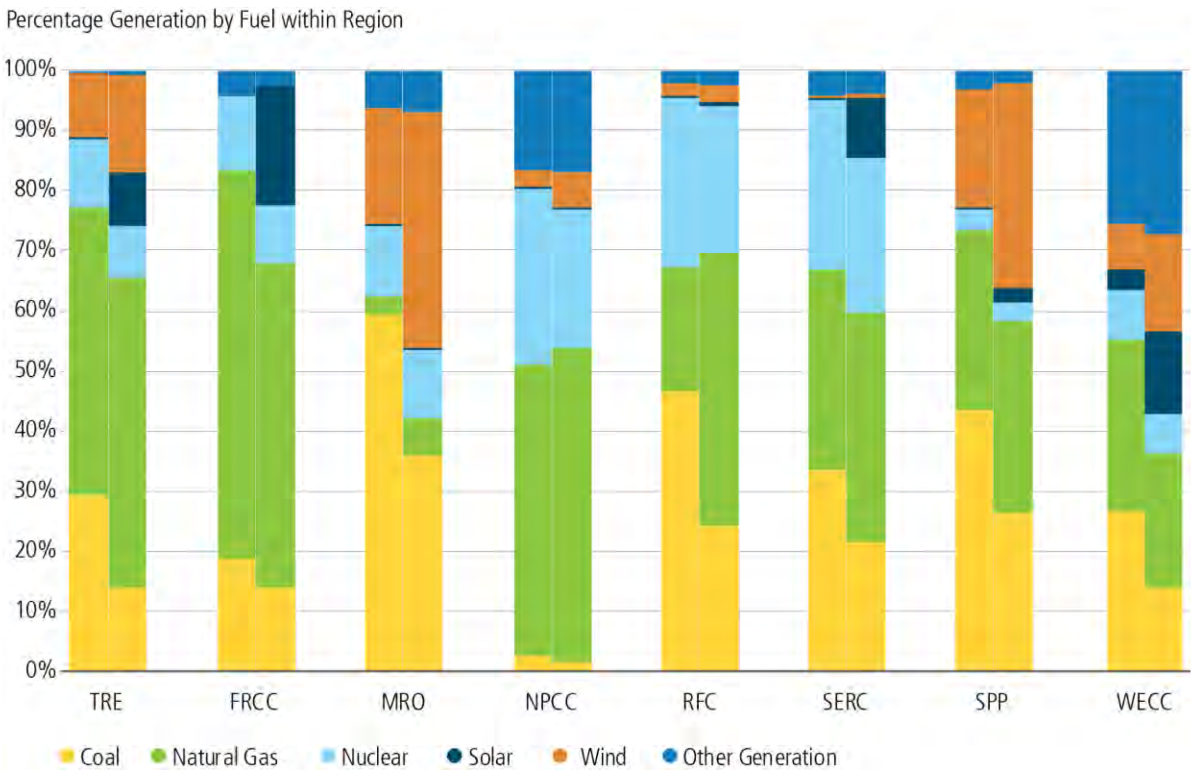
[illegible] *Ensuring Electricity System Reliability, Security, and Resilience.*

1.4.1 The Changing Generation Profile

[illegible]

[illegible]

Figure 1-6. Comparison between Generation Fuel Mix in 2016 and 2040 by North American Electric Reliability Corporation Region[75]

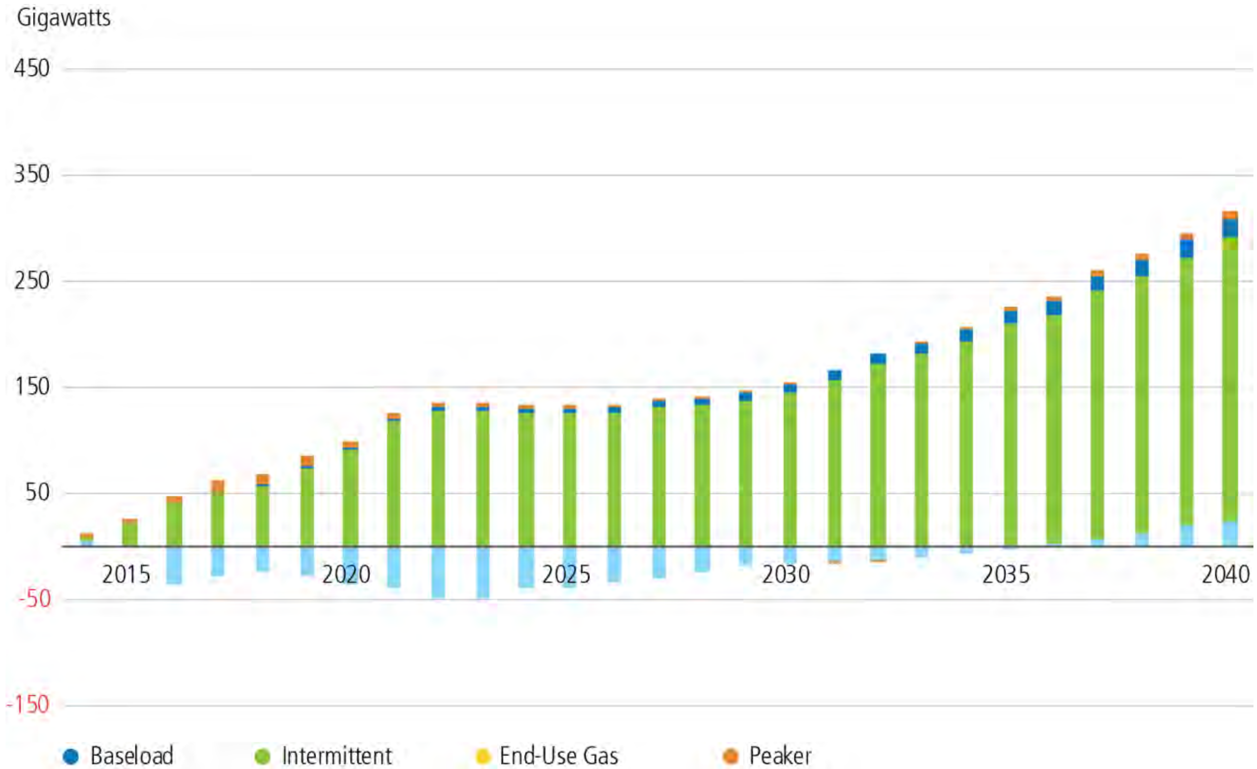


Based upon EIA's AEO 2016 business-as-usual modeling results, the regional variations in generation fuel of 2015 are projected to continue through 2040. Solar generation is expected to play a significant part in Texas (TRE), Florida (FRCC) and the Southeastern U.S. (SERC) and the Western States, particularly the Southwest and California (WECC). Wind generation is anticipated to be largely concentrated in the upper Midwest (MRO), New England (NPCC), and the Western States (WECC). The upper Midwest (MRO), Reliability First Corporation (RFC) region, and Southwest Powerpool (SPP) is expected to decrease their coal generation capacities, but will still retain over 20% of their generation capacity from coal. Hydropower accounts for the largest portion of "Other Generation" in New England and WECC.

1.4.1.1 Information Needs for Load Management Increase with High VER/DER Penetration

1.4.1.2 Role of Baseload Generation

Figure 1-7. Cumulative Utility-Scale Net Capacity Additions, 2015 to 2040[84]



Under business-as-usual assumptions, retirements in baseload capacity are projected to fully offset additions in baseload capacity between 2015 and 2026, where baseload is considered coal, nuclear, and natural gas combined-cycle plants. Variable renewables (wind and solar) capacity is expected to increase throughout the entire time period. Natural gas combustion turbine (peaker) capacity is expected to decline modestly beginning in 2021. By 2027, natural gas net capacity is projected to increase modestly, driven by natural gas combined-cycle plants. Capacity of natural gas-fired combined heat and power plants begins to ramp up in the latter decade of the projection period.

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

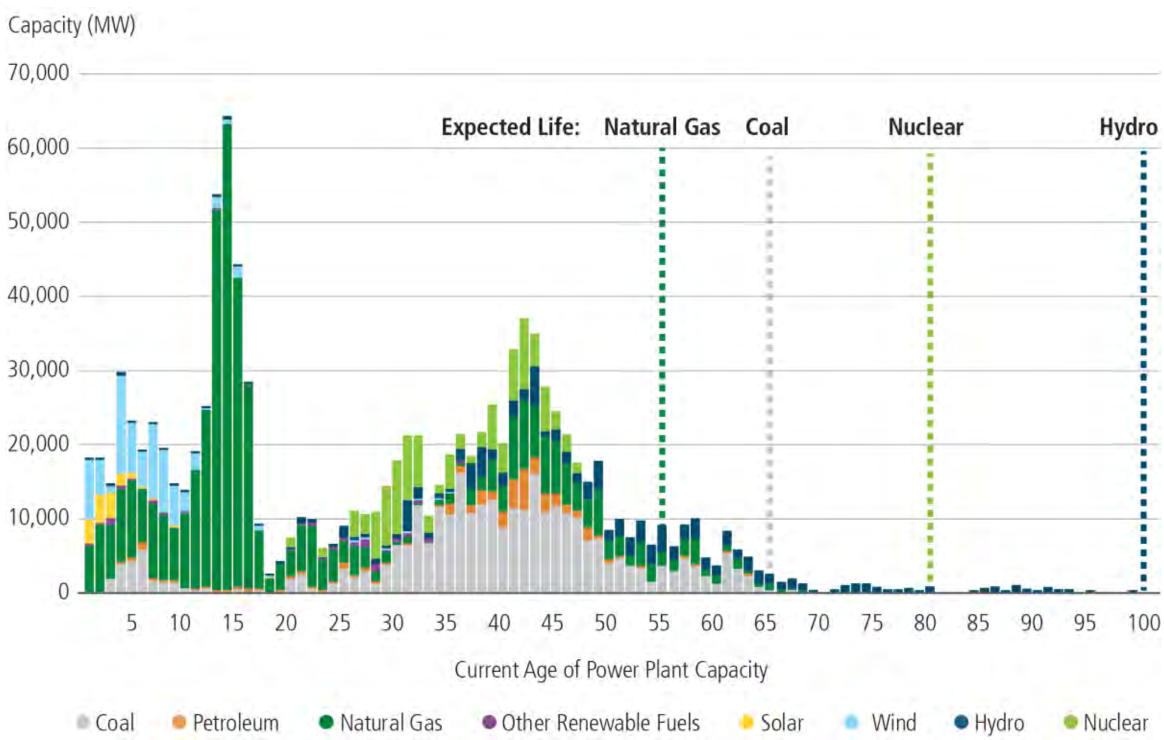
[illegible]

1.4.2 Aging Infrastructure: Challenges and Opportunities

[illegible]

[illegible]

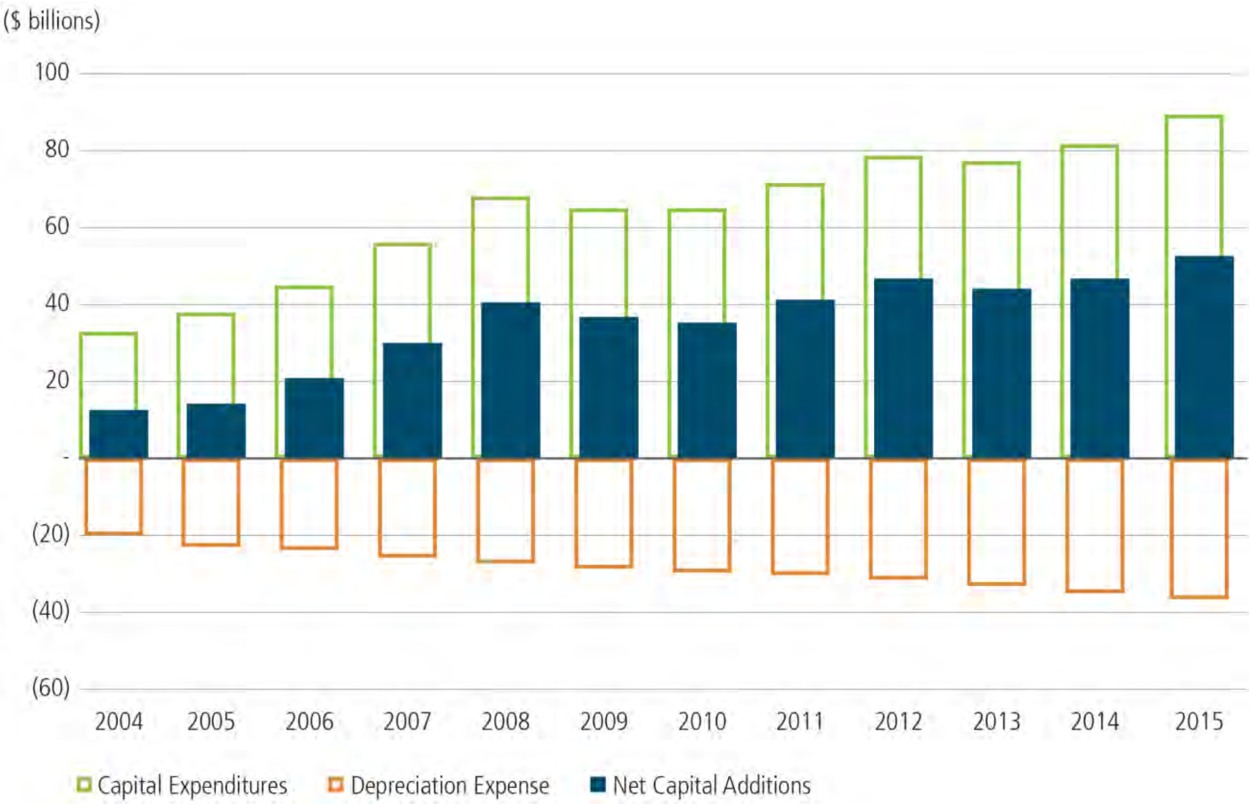
Figure 1-8. Current Age and Expected Life of Generation Fleet by Nameplate Capacity, 2015 [89]



Much of the U.S. generation fleet is 11ï 20 or 41ï 50 years old, with plants over the age of 50 being dominated by coal and hydropower. Much of the U.S. generation fleet is 11ï 20 or 41ï 50 years old. Plants over the age of 50 years are dominated by coal and hydropower. Plants under 20 years of age are dominated by natural gas and wind. Hydropower has the oldest fleet, followed by coal, nuclear, petroleum, and biomass. Expected life of the current fleet ranges from 55 years for natural gas to 100 years for hydropower generation.

[illegible]

Figure 1-9. Utility Operating Company Annual Capital Expenditures, Depreciation, and Net Capital Additions, 2004–2015[90]



Utility investment in capital (in green) has routinely outstripped depreciation expenses (in red) over the last decade, leading to positive and growing net capital additions (in blue). This means that utilities are adding property, plants, and equipment at a faster rate than they are losing it to wear and tear or obsolescence.

1.4.3 New Technologies Enable Two-Way Electricity Flows and Change Grid Management

[illegible]

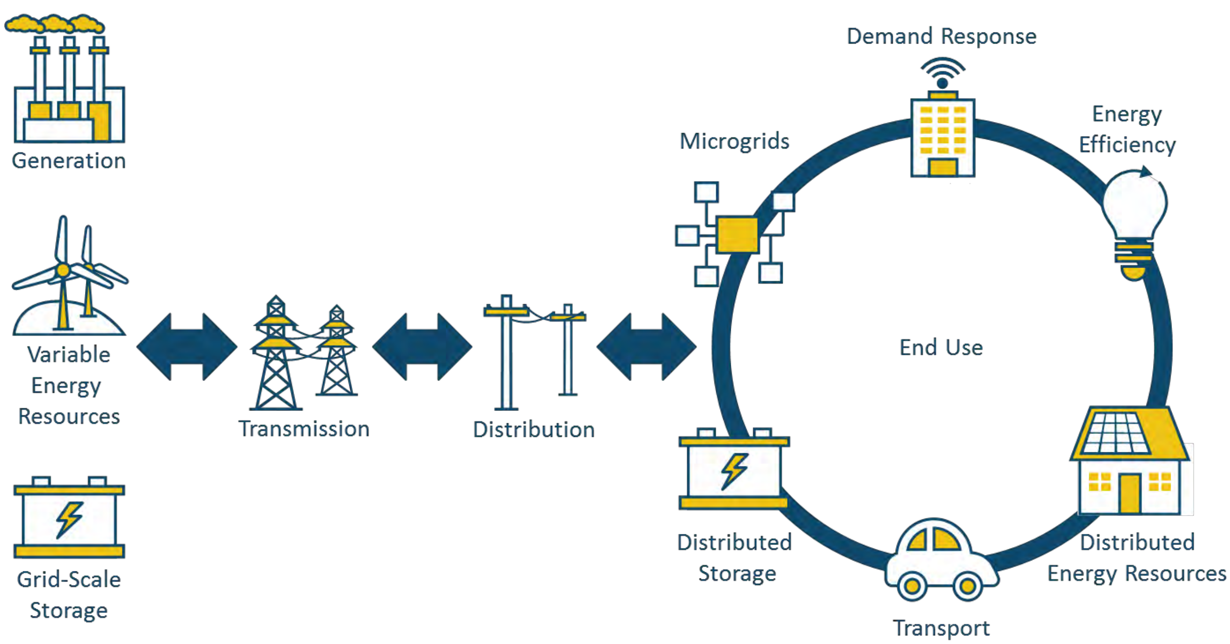
[illegible]

Figure 1-10. Traditional One-Way Flow Electricity Supply Chain[91]

The power grid was traditionally designed to move electricity from large generators to end users. Arrows represent power flows.

[illegible]

Figure 1-11. Emerging 21st Century Electricity Two-Way Flow Supply Chain[92]



The emerging 21st century power grid will incorporate responsive resources, storage, microgrids, and other technologies that enable increased flexibility, higher system efficiency, reduced energy consumption, and increased consumer options and value, as discussed in Chapter II, *The Electricity Sector: Maximizing Economic Value and Consumer Equity*. Arrows represent power flows. Figure 1-11 also depicts key factors that are disrupting traditional modes of grid management and operations, discussed in greater detail in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

[illegible]

[illegible]

1.4.4 Customer Engagement, New Business Models, and the Emerging Role of Aggregators

[illegible]

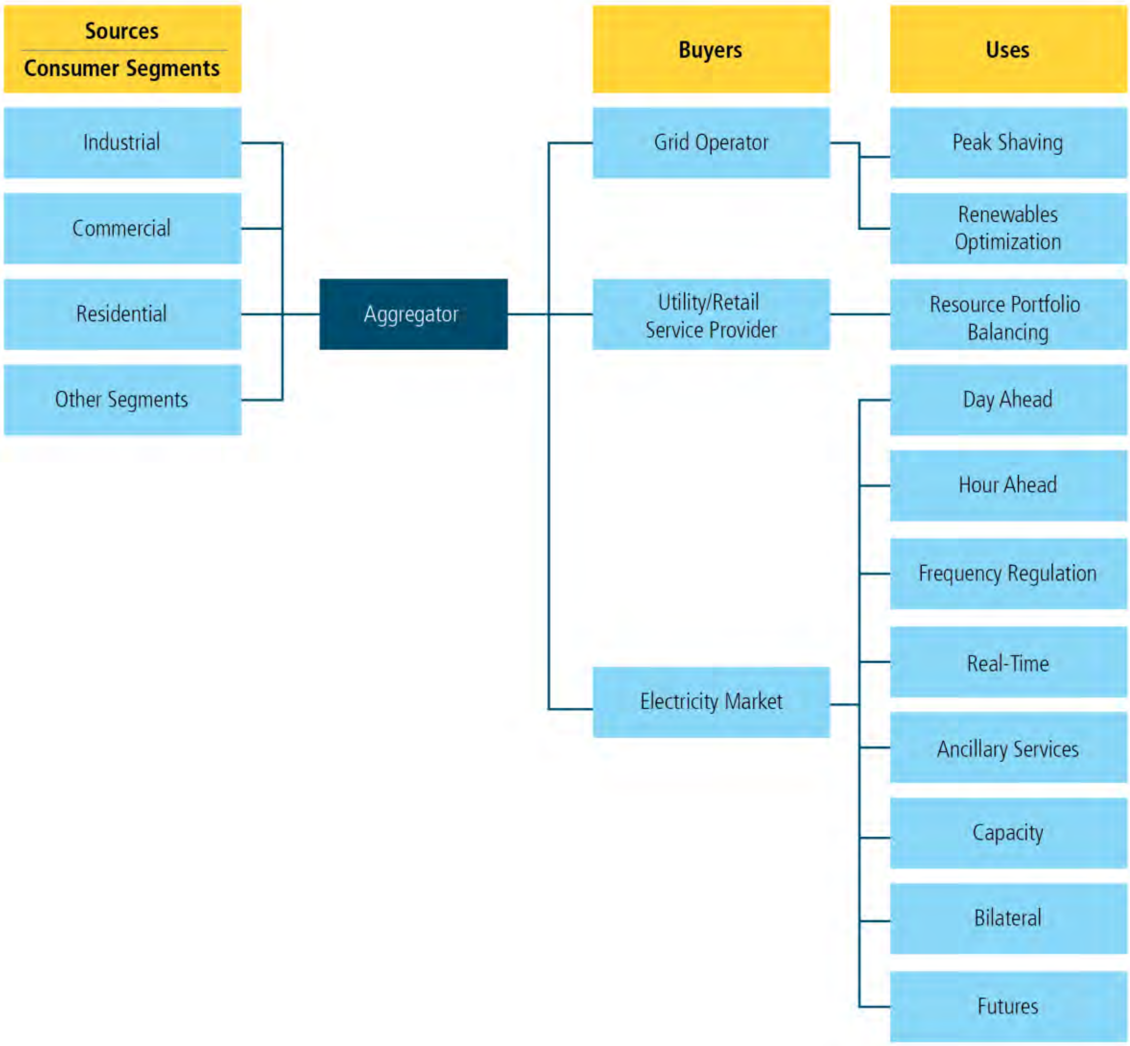
[illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity.*

[illegible]

[illegible]

[illegible]

Figure 1-12. Aggregator Sources, Markets, and Services



Aggregators develop "load portfolios" from various combinations of consumer segments. There are three principal buyers for aggregator services: utility grid operators, utility retailers, and utilities interacting with other wholesale market participants to serve day-ahead, hour-ahead, and real-time markets (which include frequency regulation and other essential reliability services). Aggregators sell DR products for use by utilities across all three buyer types using specific utility-offered DR programs, or through negotiated DR contracts with aggregators.

[illegible]

[illegible]

1.4.5 Workforce Retirements, New Skillsets, and Shifting Regional Needs Pose Challenges for a Changing Electricity Sector

[illegible]

[illegible]

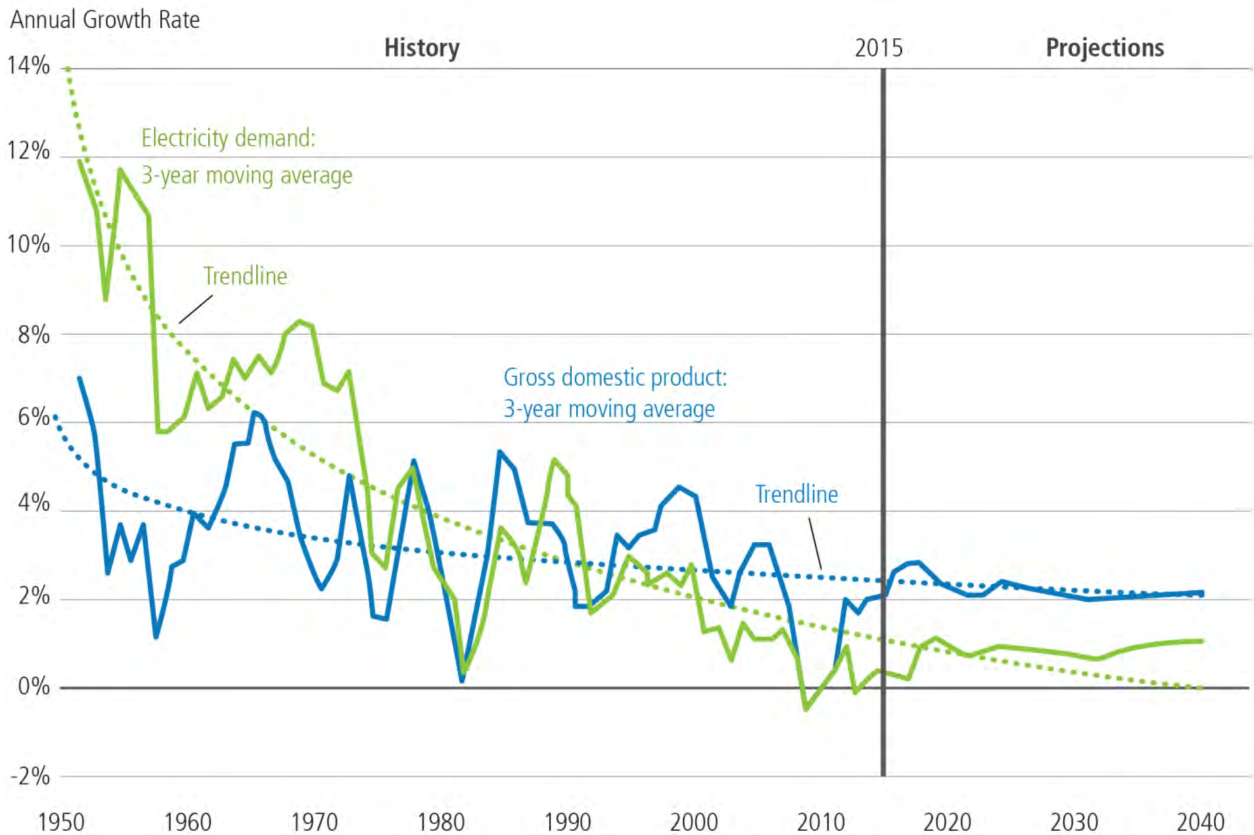
[illegible]

1.5 The Electricity Sector Is Enabling a More Productive Economy and Reducing Carbon Emissions

[illegible]

[illegible]

Figure 1-13. U.S. GDP and Electricity Demand Growth Rates, 1950–2040[111]



U.S. electricity demand growth has slowed since the 1950s and is projected to remain flat through 2040, based upon business-as-usual assumptions. Though national GDP has slowed over the same time period, electricity growth has slowed significantly more than GDP.

[illegible]

1.5.1 Decarbonizing the Electricity System

[illegible]

[illegible] *Building a Clean Electricity Future*[illegible]

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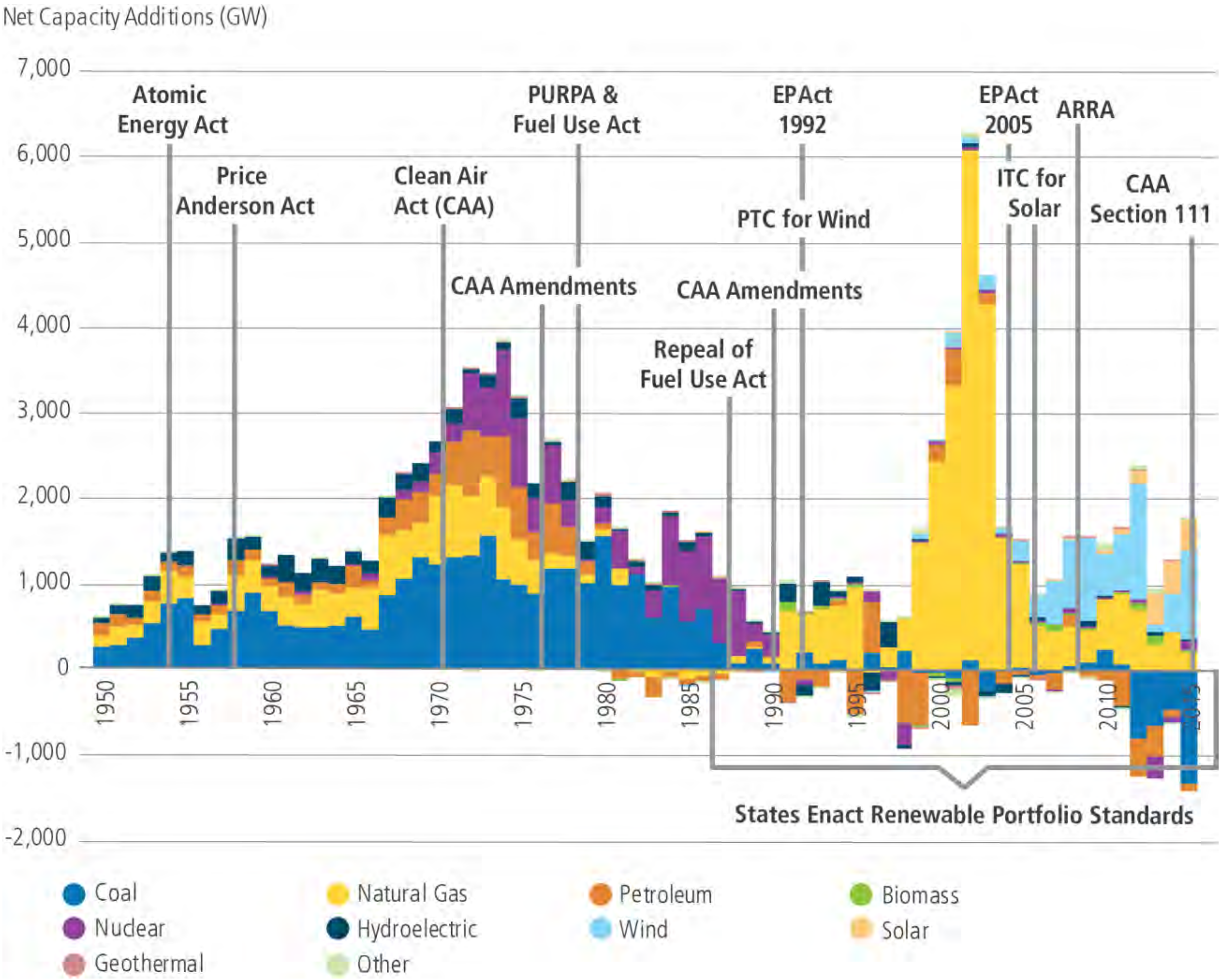
[illegible]

Figure 1-14. Net Generation Capacity Additions, 1950–2015[115]



Capacity additions of different generation technologies came in waves that were largely influenced by policy, fuel costs, and technology development. The 1930s and 1940s fostered the development of hydropower; nuclear power was widely deployed in the 1970s after nuclear research for peaceful uses was allowed; natural gas additions peaked in the 2000s; and non-hydro renewables are quickly growing in the 21st century. Note that the deployment of these generation technologies followed enabling Federal policies and technology development—e.g., nuclear power reactors and natural gas combined-cycle turbines—by several decades.

[illegible]

[illegible]

[illegible]

[illegible]

1.6 Electricity Dependency Is a National Security Vulnerability

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

1.6.1 The Threat Environment Is Changing

[illegible] *Ensuring Electricity System Reliability, Security, and Resilience.*

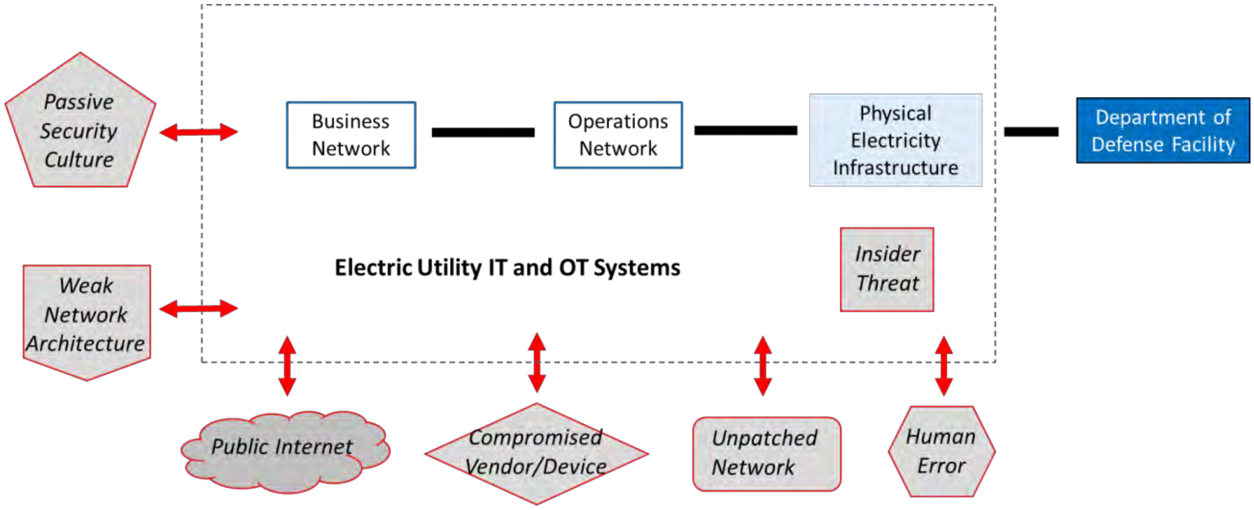
[illegible]

[illegible] *advanced persistent threats* [illegible]

[illegible]

[illegible]

Figure 1-15. Example Cyberattack Vectors for an Electric Utility [124]



There are many ways to communicate with a control system network and components using a variety of computing and communications equipment. Key vulnerabilities include unpatched networks, unvetted vendor access, access to the public Internet, and insider threats.

1.6.2 Homeland Security Requires a Resilient Power Grid

[illegible]

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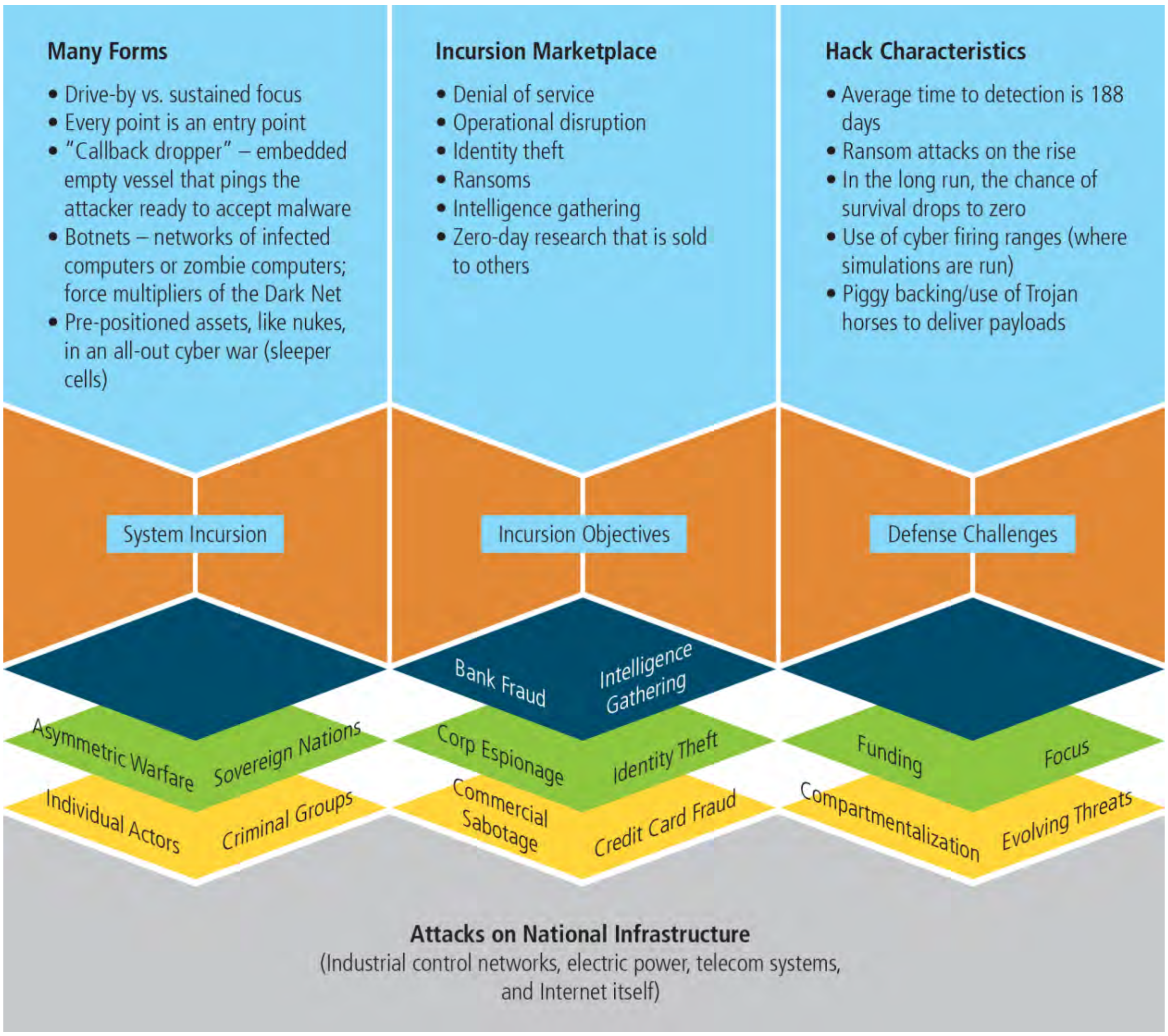
Figure 1-16. Summary of the Cybersecurity Characteristics and Risks Confronting Smart Grid Deployment



Cyber threats have different objectives: typically, incursions by sovereign attackers are warfare-oriented whereas incursions by groups and individuals are driven by pecuniary interests such as corporate espionage, credit card fraud, and ransom. Sovereign and non-sovereign hacking exhibit similar characteristics and patterns, which inform efforts to defend against attacks. *Note: Intended to be illustrative, not comprehensive.*

1.6.3 Electricity Has Significant Value for the National Defense

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]

[illegible]

Back-Up Power for Security

In 2011, the Department of Energy and the Department of Defense announced collaboration on 18 fuel cell back-up power generation projects at eight U.S. defense installations. Compared with diesel generators, which are often used for back-up power, fuel cells use no petroleum, are quieter, require less maintenance than either generators or batteries, and can easily be monitored remotely to reduce maintenance time. These projects address interdependencies that are at risk the longer the duration outage, but provide back-up power to computing, telephone, and lighting functions of the military installations they serve.

[illegible]

1.6.4 DOE's Growing Role in Protecting the Electricity System as a Critical National Security Asset

[illegible] *A 21st Century Electricity Sector: Conclusions and Recommendations* [illegible]

[illegible]

[illegible]

[illegible]

1.7 The Federal Role in Modernizing and Transforming the Grid

[illegible]

The Electricity System and the Role of the Federal Government

The Federal Government and U.S. electricity system have a complex and longstanding relationship that has enhanced the Nation's economy, security, and environmental sustainability. This relationship is forged through legislative and administrative actions that cover issues related to markets, financing, environmental and health impacts, and workers' health and safety.

The earliest Federal intervention into the electric system was the encouragement of utility interconnections during World War I to better supply the surging demand. The Federal Power Commission (FPC), the first Federal agency with regulatory authority over aspects of the Nation's electric industry, was created in 1920 by the Federal Water Power Act to license hydroelectric projects on Federal lands or navigable waters. The powers of the FPC were expanded by the Federal Power Act of 1935, to include the regulation of wholesale sales and transmission of electricity in interstate commerce. The Public Utility Holding Company Act of 1935 charged the Security and Exchange Commission with rationalizing the corporate structure of the electric industry, which had become very concentrated in a small number of holding companies.

During the great depression, the Federal Government developed numerous hydroelectric facilities to harvest America's vast hydroelectric potential. This development resulted in the formation of Federal entities to market and transport that power, including the Bonneville Power Administration and the Tennessee Valley Authority. The Rural Electrification Administration, created by the Rural Electrification Act of 1936, gave loans and helped rural organizations develop electric cooperatives, many of which received power from the various Federal hydropower projects.

The Federal Government's role in promoting the science of producing electricity began with nuclear energy. The development of nuclear energy was a side benefit of the weapons program. The Nation's system of National Labs also grew out of the weapons program and has provided useful research to the industry ever since. Development of nuclear power was aided by the Price-Anderson Nuclear Industries Indemnity Act of 1957, which limited liability of commercial reactors and thereby facilitated their inclusion into the utility generation mix. The Federal Government's role in nuclear energy also included licensing nuclear plants with appropriate environmental review.

The electric industry is subject to a wide variety of environmental laws, covering air and water pollutants as well as the disposal of solid wastes associated with electricity production. The focus of environmental laws has changed over time. For example, initial concerns over air quality focused on "criteria" pollutants such as particulates, nitrogen oxides, and sulfur dioxide, and then expanded in 1990 to pollutants causing acid rain. More recently, the Environmental Protection Agency has promulgated health-based regulations on mercury emissions and adopted regulations on greenhouse gas emissions that cause global warming. The Federal Government has played an important role in changing the nature of electric markets. The Public Utilities Regulatory Policies Act of 1978 required utilities to purchase power from non-utility generators, at their avoided costs, thereby creating new markets for independent generation. These markets were further enhanced by provisions of the Energy Policy Act of 1992, as well as by regulations promulgated by the Federal Energy Regulatory Commission (FERC), that provided transmission access for wholesale market participants. Ultimately, the move to competitive wholesale power markets enabled retail competition policies—allowing end-use customers to select among competing electricity suppliers—adopted by some states. Increasingly, FERC (the successor to the FPC) has recognized the need to protect customers from the exercise of market power by policing anticompetitive behavior in the organized markets.

As the markets have transformed, the Federal Government has continued to lead and participate in market transformations. The Department of Defense has recognized the important role of renewable energy in achieving its mission of protecting the American people. The Department of Homeland Security is playing an important role in increasing cybersecurity and physical security. The Department of Energy is playing an important role as a facilitator and leader of research on the future of the grid and ways to remove technical impediments to getting there. The National Institute of Standards and Technology is developing standards to enable a 21st century grid. FERC is exploring market rules that will enable participation of a broader array of resources, as well as many customer-sided options.

1.7.1 Innovation Is Essential

[illegible]

[illegible] *Building a Clean Electricity Future.*

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1.7.2 Jurisdictional Relationships and Limitations

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II The Electricity Sector: Maximizing Economic Value and Consumer Equity

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Maximizing Economic Value and Consumer Equity: Summary of Key Findings

- Advanced metering infrastructure has had a profound impact on the nature of interactions between the electricity consumer and the electricity system, allowing a 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 who 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 residential, 60 percent of commercial, and 30 percent of industrial energy consumption are 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, 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, as well as 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 that these technologies can create.

2.1 Maximizing Economic Value and Consumer Equity

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2.2 The 21st-Century Energy Consumer

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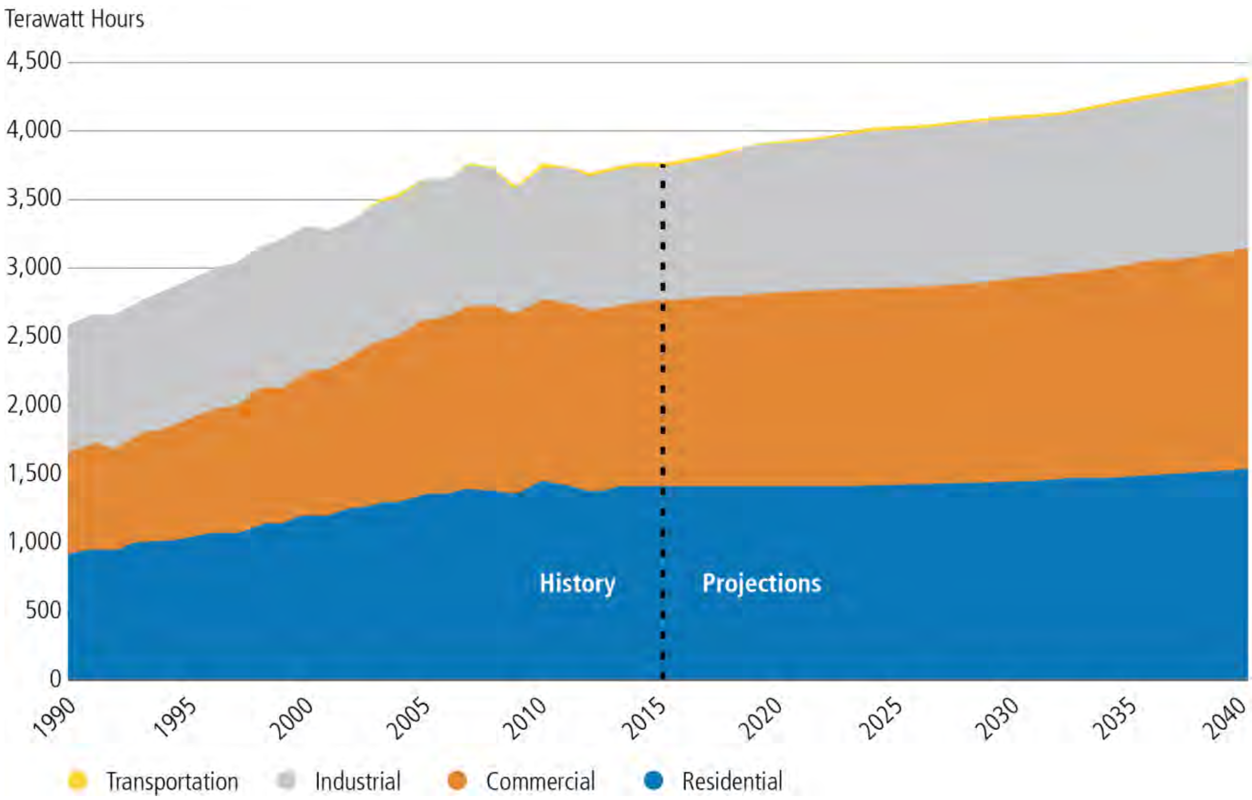
Figure 2-1. U.S. Electricity Consumption Projections to 2040[3]



In 2014, the residential sector consumed the most electricity of any sector (1,415 terawatt-hours [TWh], 38 percent of total consumption), followed by the commercial sector (1,358 TWh, 36 percent of total consumption), and the industrial sector (959 TWh, 26 percent of total consumption), with transportation using just 7.6 TWh (less than one percent of total consumption). Overall, electricity consumption is expected to grow by about 18 percent between 2014 and 2040, based on business-as-usual assumptions.

2.2.1 Industrial Consumers of Electricity: Price-Sensitive, On-Site Generation

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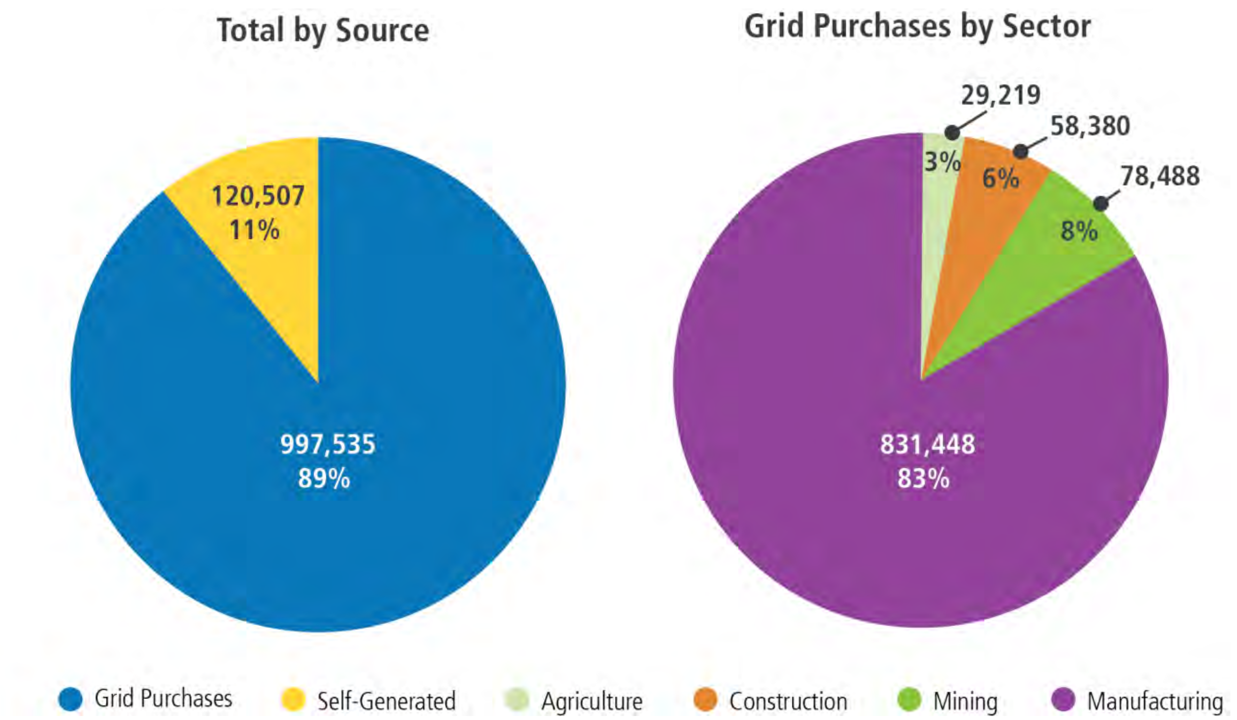
Figure 2-2. U.S. Industrial Electricity Consumption in 2014 (Million Kilowatt Hours)[9]



The left chart shows the industrial sector's purchased electricity consumption, combined heat and power self-generation by source, and the right chart shows purchased electricity by industrial subsector.

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2.2.2 Commercial Consumers: Optimizing Building Design, Lighting and Space Conditioning

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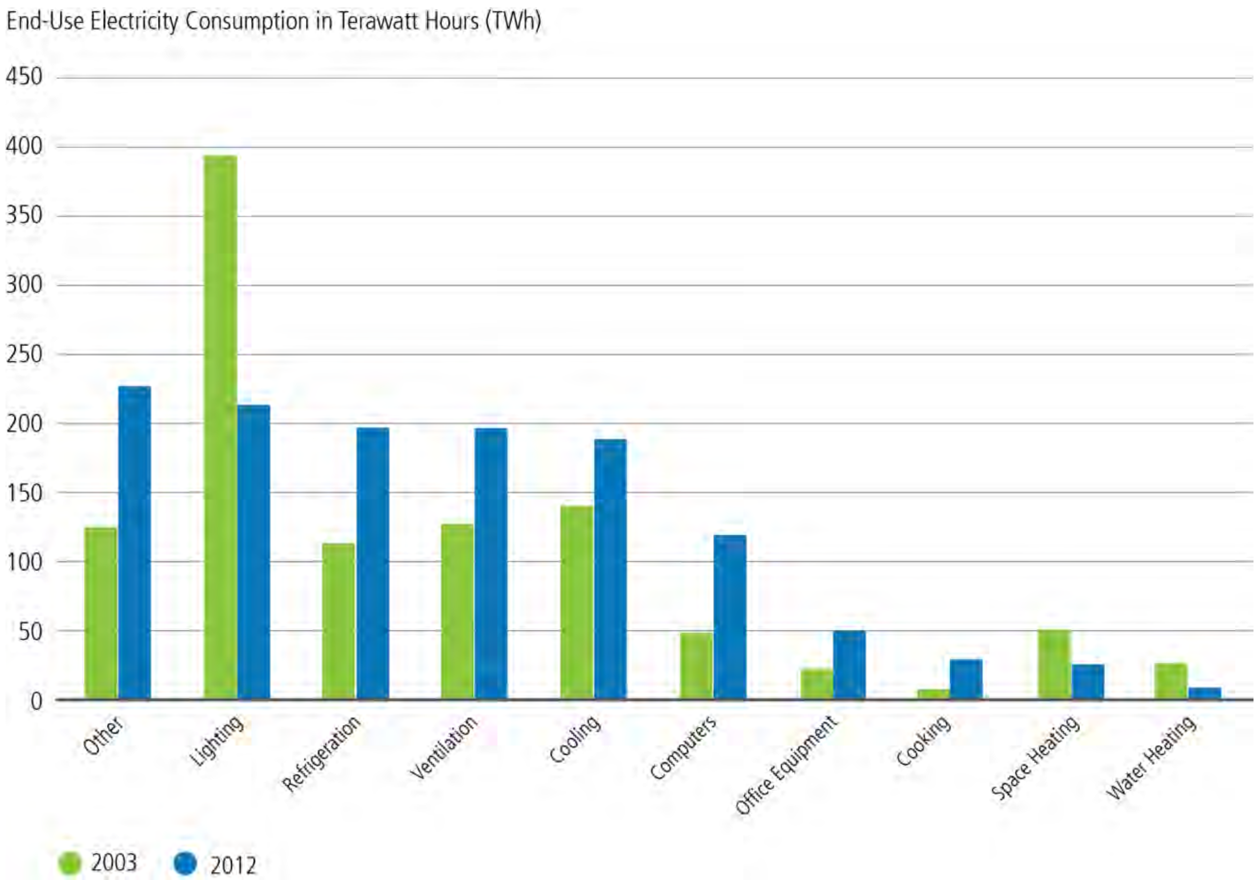
Figure 2-3. Comparison of Commercial End-Use Electricity Consumption between 2003 and 2012 [23] [24]



Consumption across most end uses is increasing, including MELs, refrigeration, computing, and cooling. Lighting and space heating consumption have each decreased by about 50 percent between 2003 and 2012.

2.2.2.1 "Dispatchable" Smart, Green Buildings

[illegible]

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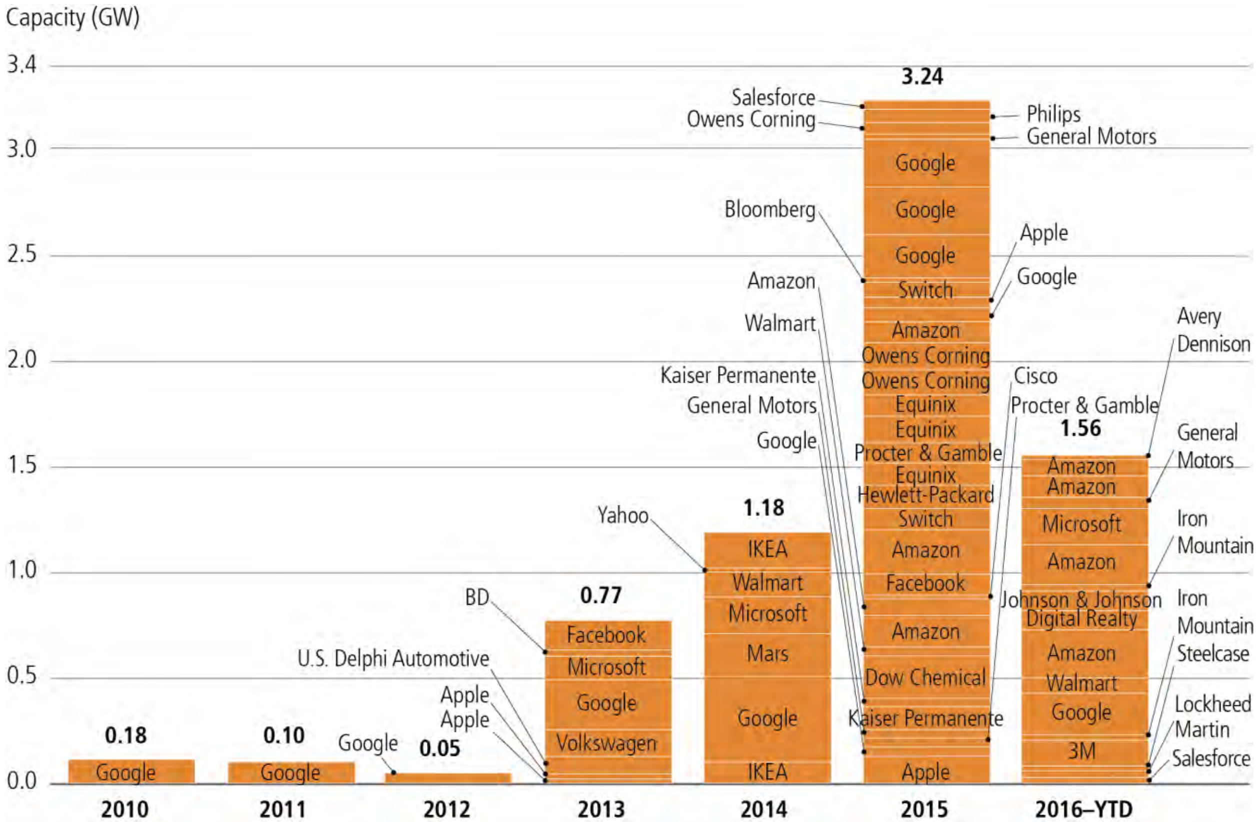
2.2.2.2 Meeting Sustainability Goals through Direct Procurement of Renewable Energy

[illegible]

Figure 2-4. Corporate Procurement of Renewable Energy-Based Electricity 2010–2016[32]



Large corporate customers (including commercial and industrial sectors) can specify the type of generation underlying the electricity provided through procurement contracts, including PPAs, Green Tariffs and Project Ownership. Corporate procurements represent an important new mechanism for developing renewable energy projects. Last updated December 15, 2016.

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2.2.3 Federal Agencies

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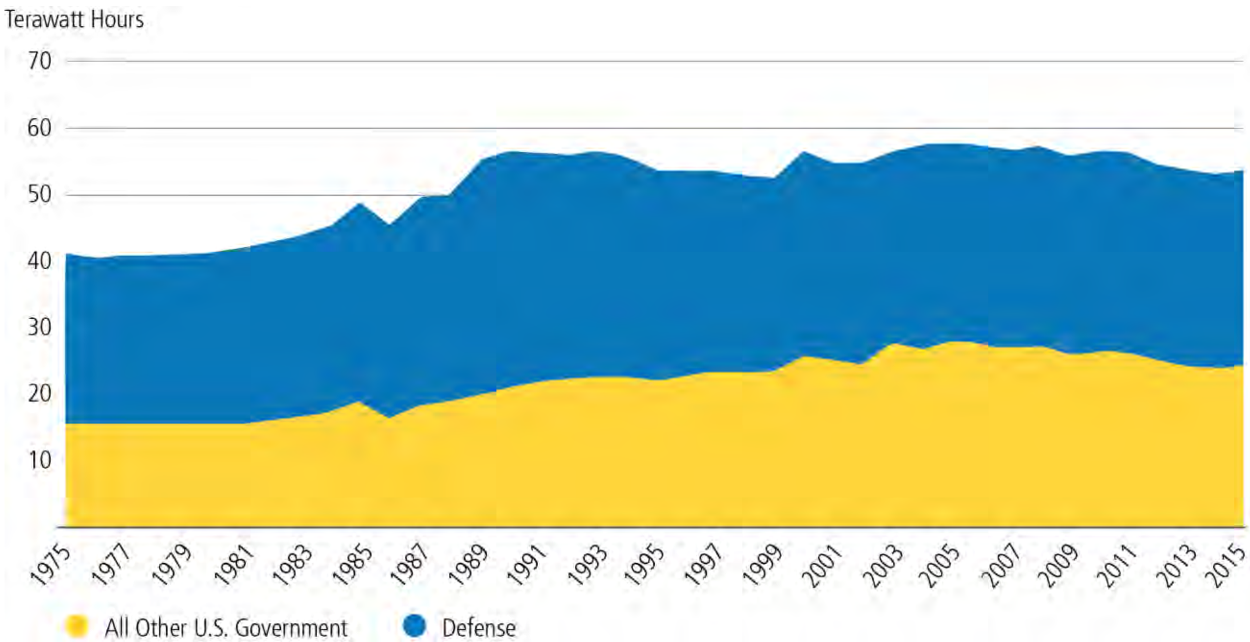
2.2.3.1 Department of Defense is Single Largest Consumer of Electricity

Figure 2-5. Electricity Use by the U.S. Government and Department of Defense, 1975–2015[43]



DOD uses more electricity than the rest of the U.S. Government combined. This relationship has remained relatively steady for the past 40 years.

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2.2.4 Municipalities, Universities, Schools, and Hospitals

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2.2.4.1 Municipal Water Efficiency Opportunities

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2.2.5 Residential Consumers

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2.2.5.1 Energy Management through DR, Automation, and Smart Homes

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2.2.5.2 Consumer Preferences for New Technologies and Services

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A central question for state electricity regulators, consumer advocates, and electric utilities is how to balance the utility's obligation to provide safe, reliable, and affordable energy to all consumers with a growing desire for more products and services from a smaller subset of consumers.

[illegible]

[1] [illegible] *Building a Clean Electricity Future* [illegible]

[2] [illegible]

Retail Electric Choice Markets

In the late 1990s and early 2000s, some state legislatures passed legislation opening the retail electricity market to firms beyond the incumbent distribution utility. Currently, 14 states and the District of Columbia have programs that allow end-use customers to buy electricity from competitive retail suppliers.[k, 76] Under this structure, the regulated distribution utility still manages and provides the distribution of electricity through wires, with retail marketers procuring and selling the commodity itself. State retail open-access policies typically apply only to investor-owned utilities, though some states conditionally require it for electric cooperatives as well. States with retail open access typically do not require it for public power utilities, leaving competition policy to their local governing boards. Some states, such as Michigan, cap retail open access as a percentage of electricity sales (i.e., alternative retail electric supplies, besides the incumbent distribution utility, can provide up to 10 percent of retail electric sales).

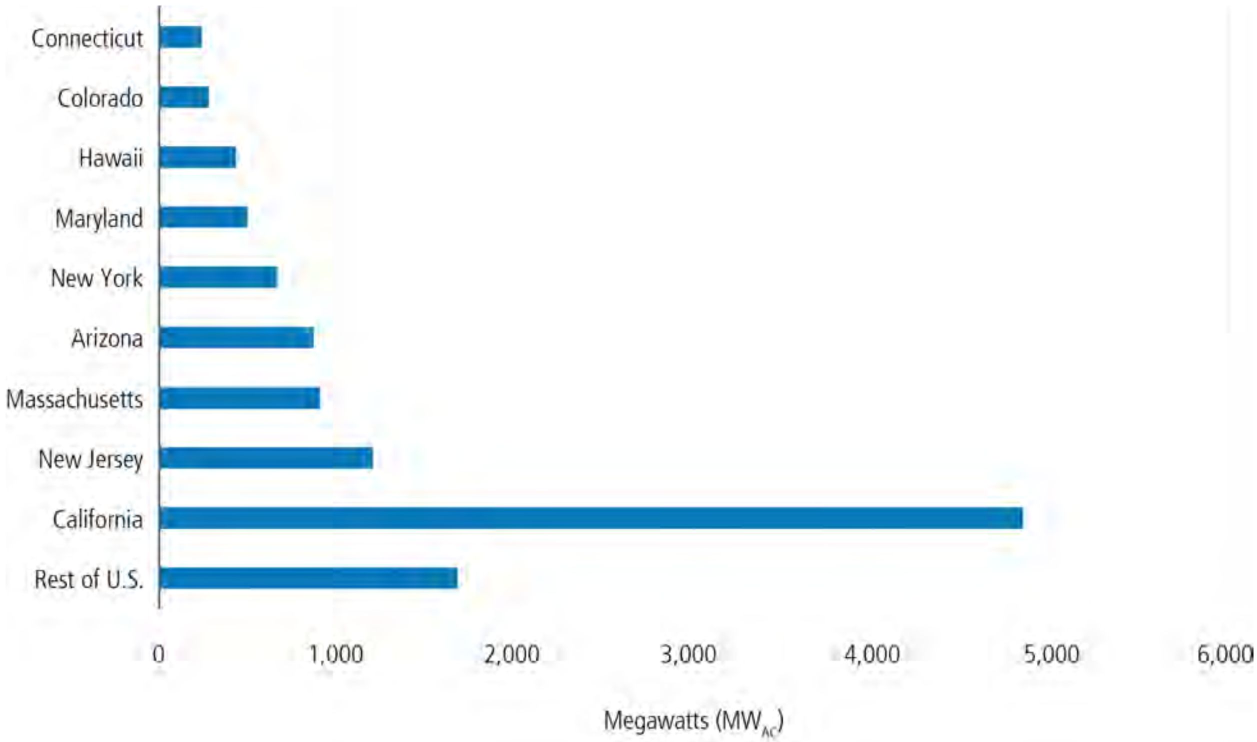
The outcome of retail electric choice has been mixed. Retail choice has introduced dynamic pricing programs and new services, and it has encouraged the growth of renewable energy. However, electricity prices in areas with retail choice have been more variable and possibly even higher than in areas without it.[77, 78] Most states with retail choice also rely on the distribution utility that serves as the default energy commodity provider, with administratively determined rates for customers who choose not to participate in the retail market.

2.2.5.3 Distributed Generation: A Consumer Choice

[illegible]

k [illegible] *2016–2017 Annual Directory and Statistical Issue* [illegible]

Figure 2-6. Distributed Solar PV Capacity, Top 10 States, As Of August 2016 (in MW Alternating Current [AC])[79]



Distributed solar PV capacity is unevenly distributed in the US. As of August 2016, roughly a third of capacity was installed in California, followed by New Jersey and Massachusetts.

2.2.5.4 Small-Scale Distributed Storage

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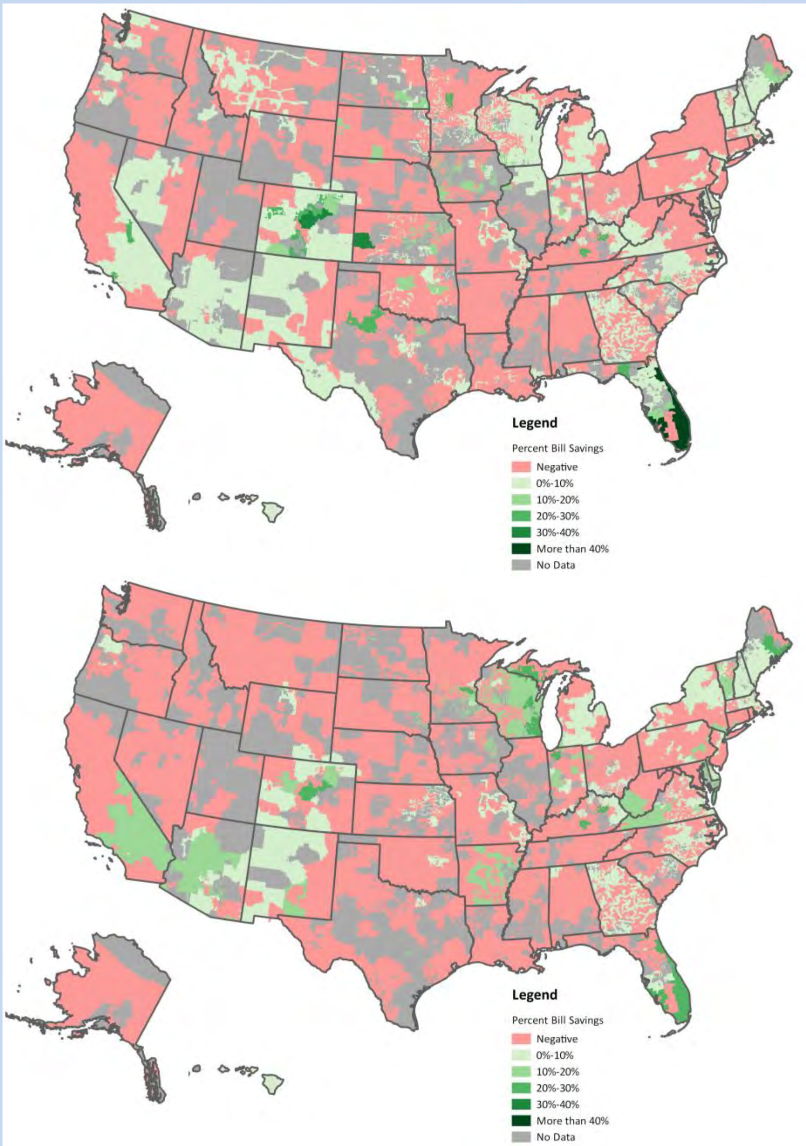
Residential Electricity Bill Savings from Distributed Electric Storage[90]

This project analyzed over 45,000 utility rates for more than 4,500 utilities covering all regions of the country.[91] To identify the electricity bill savings opportunities from the use of distributed energy storage (DES), two operational strategies are modeled:

- Flattened: Flatten the load profile to minimize demand changes
- Arbitrage: Reduce energy use during peak and increase energy use during off-peak periods to take advantage of time-of-use rate designs

Figure 2-7. Gross Residential Customer Electricity Bill Savings for the Flattened and Arbitraged Demand Profiles. Top: Bill Savings from Flattened Load Profiles; Bottom: Bill Savings from Arbitraged Load Profiles[92]



Estimated electricity bills for residential customers with Distributed Energy Storage ranged from showing no savings to a greater than 40% reduction in electricity bills. The opportunities for customers to save on their electricity bills are geographically similar for the flattened and arbitraged demand profiles, but appear to lack geographic correlation with urban or rural areas. Each service territory may have several utility rates applicable to that area, so only the largest electricity bill savings available are shown in the figure (where data exist).

This analysis found that customer investment in DES can provide electricity bill savings for over 80 million residential customers. However, electricity bill savings opportunities are geographically heterogeneous and highly dependent on local rate structures, and the savings in all cases are significantly lower than the normalized cost of the DES. Furthermore, the electricity bill savings that customers realize are not commensurate with the net system benefits that DES provides as estimated by current technical literature. The shortfall between net system benefits, or the social value of DES, and customer electricity bill savings, or the private value of DES, suggests that traditional utility rate design does not adequately reflect the net benefits that a customer with DES provides the system, and additional remuneration methods may be needed to bridge that shortfall.

2.2.5.5 Challenges to Electricity Affordability

[illegible]

[illegible] *energy burden,* [illegible] *all* [illegible] *for low-income households energy burden averaged 8.3 percent* [illegible]

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[illegible] *Electricity End Uses, Energy Efficiency, and Distributed Energy Resources Baseline* [illegible]

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2.2.5.6 Access to Distributed Energy Resources and New Energy Services for All Consumers

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2.2.6 Electricity Issues in Small, Rural, and Islanded Communities

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2.2.6.1 Powering Isolated Communities in Alaska

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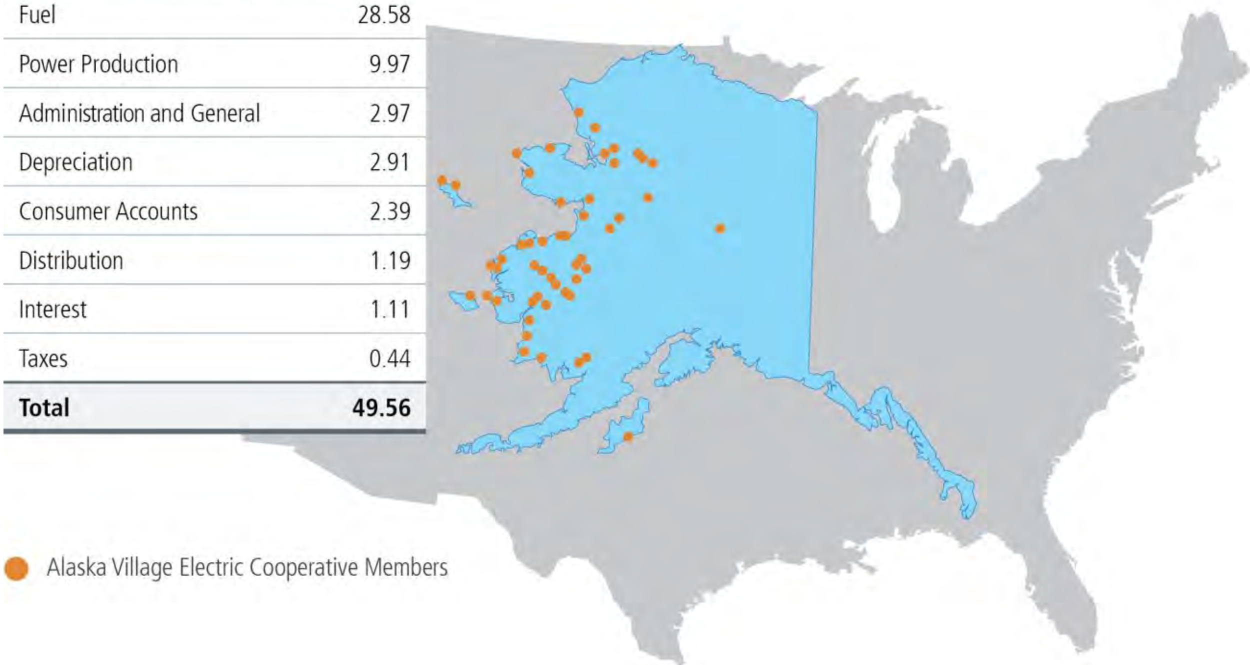
Figure 2-8. Electricity Costs in Rural Alaska[125]

Average Alaska Village Electric Cooperative Village Electricity Cost (¢/kWh)

Fuel	28.58
Power Production	9.97
Administration and General	2.97
Depreciation	2.91
Consumer Accounts	2.39
Distribution	1.19
Interest	1.11
Taxes	0.44
Total	**49.56**



The Alaska Village Electric Cooperative serves more than 50 small communities dispersed across large distances and in remote regions with harsh climatic conditions. These factors contribute to average electricity prices being approximately five times the U.S. national average.

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2.2.6.2 Innovative Rural Electric Co-Op Programs

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2.2.7 Electricity as a Driver of Economic Growth in Tribal Communities

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2.3 Maximizing the Value of Energy Efficiency

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Figure 2-9. Multiple Benefits of Energy Efficiency Improvements[150]

Energy efficiency improvements include energy and non-energy benefits for individual participants, the electricity system, and society as a whole.

[150] [illegible] *Assessing the Multiple Benefits of Clean Energy: A Resource for States* [illegible]

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[illegible] *Building a Clean Electricity Future* [illegible]

2.3.1 Miscellaneous Electric Loads Will Be Growing Share of Electricity Demand in Future

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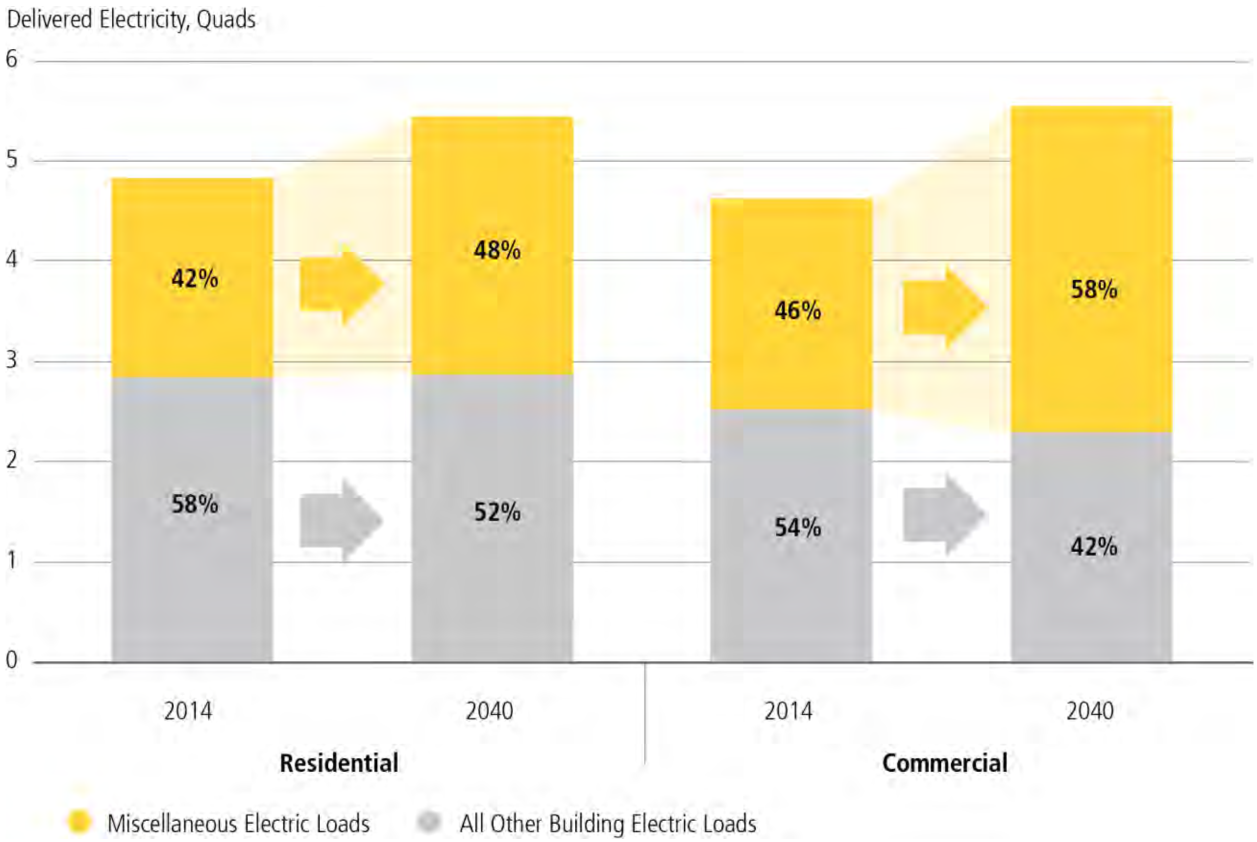
Figure 2-10. Share of Miscellaneous Electric Loads Compared to All Other Building Electric Loads, Residential and Commercial Sectors, 2014 and 2040[155]



Compared to other loads, MELs are projected to increase significantly in their share of total delivered electricity in residential and commercial buildings. MELs represent a broad range of electric loads outside of a building's core end uses of heating, ventilation, air conditioning, lighting, water heating, and refrigeration. Projections are based upon the business-as-usual assumptions in the EPSA Base Case.

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2.3.2 Energy Efficiency Codes and Standards Help Reduce Consumption and Save Money

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2.3.3 State and Local Energy Policies and Programs Deliver Efficiency

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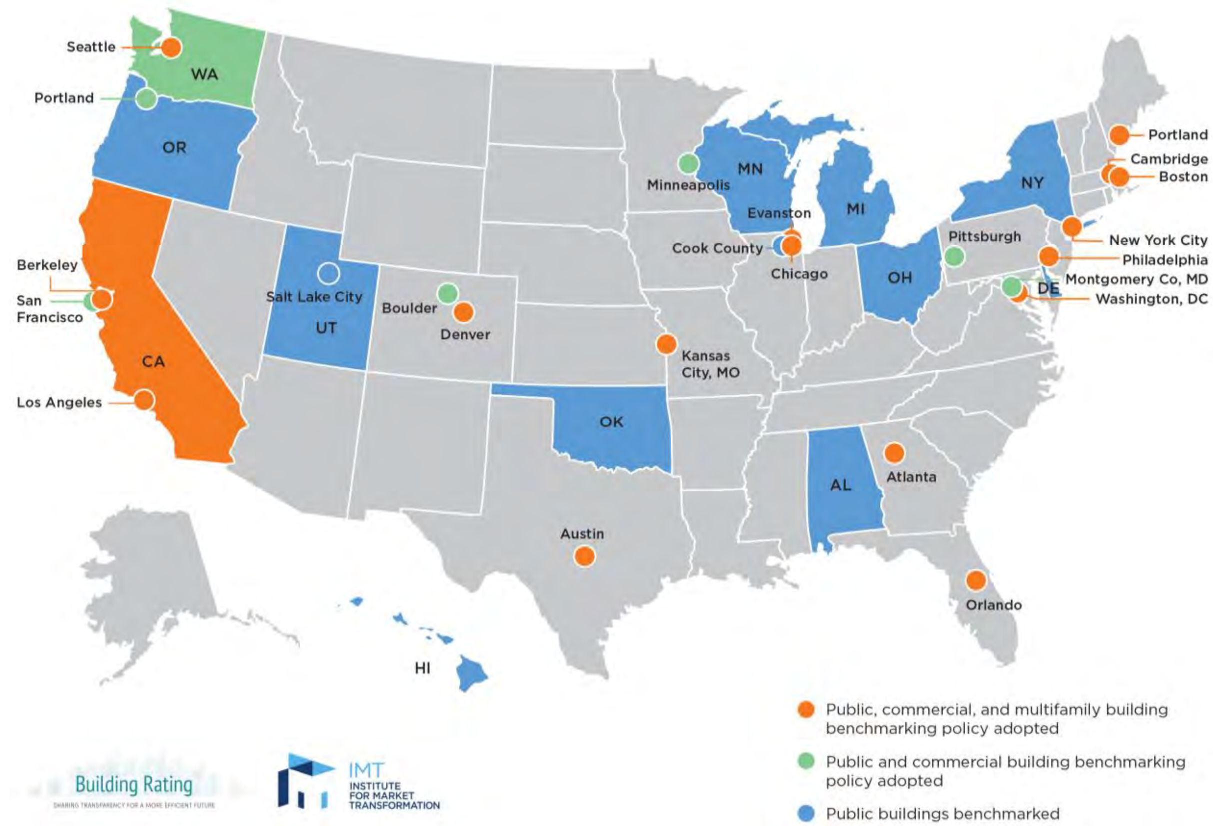
[illegible] *Building a Clean Electricity Future* [illegible]

Figure 2-11. U.S. Building Benchmarking and Disclosure Policies[158]



A growing number of states and communities are adopting building information transparency policies. These include building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), and point-of-sale disclosure or upgrades (or both).

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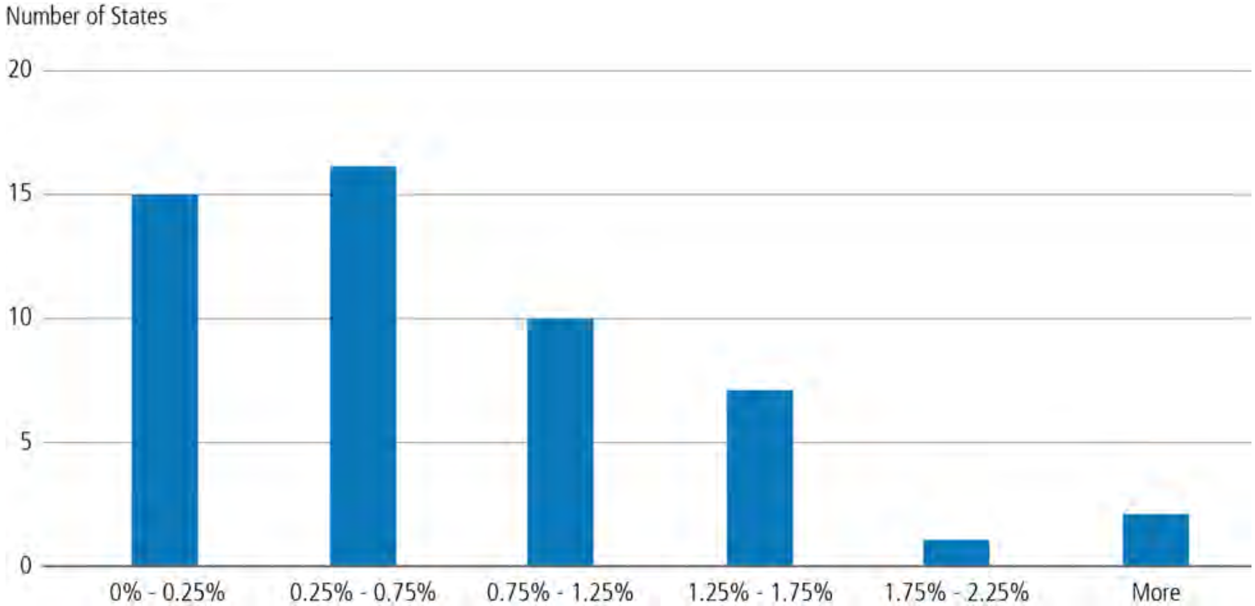
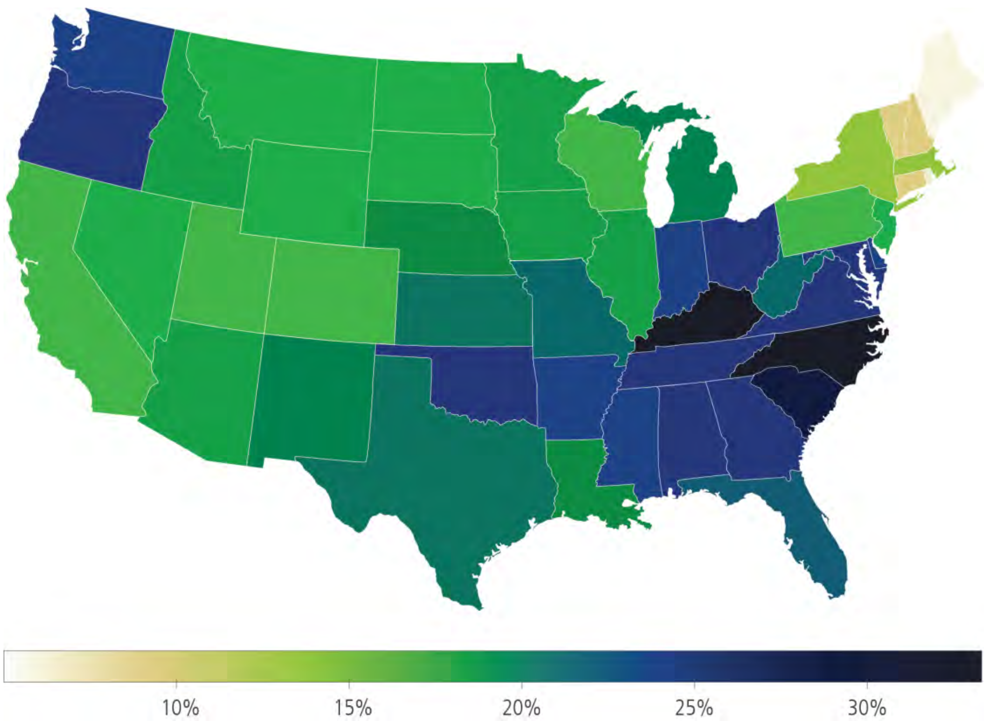
Figure 2-12. Percent Electricity Savings in 2014 from Energy Efficiency Programs Funded by Utility Customers[165]



Nearly a third of states are achieving savings of at least 1 percent per year and another third of states are saving between 0.25 percent and 0.75 percent of retail sales. On average national savings reported in 2014 from utility and public benefits electricity programs were equal to 0.7 percent of sales.

[illegible]

Figure 2-13. Potential Electricity Savings from Residential Energy Efficiency Upgrades, by State[176]



Modeling indicates that homeowners in most States can reduce their electricity consumption by 15 to 30 percent after implementing net present value positive energy efficiency measures, compared to current consumption.

Zero Energy Buildings

In concept, zero energy homes (and zero energy buildings [ZEBs] in generalẁ) are ñenergy-efficient buildings where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.ò Other definitions use site-energy-based criteria—a less-stringent definition than source-based, which includes the site energy plus the energy used to provide and distribute it. And, others use time-dependent, valuation-based definitions, which seek to assign a valuation of energy produced or consumed to better reflect the actual costs of energy, as adopted by the California Public Utilities Commission. The difficulty in meeting ZEB criteria varies between definitions. Furthermore, the cost-effectiveness of ZEBs depends highly on the age and type of building, location (climate), incentives (e.g., utility rebates), electricity rate and structure, and the cost of renewable energy generation.

Recent studies demonstrate that many new ZEBs in the commercial sector can be cost-effective, with overall costs falling within the same range as conventional, new construction projects. The explicit goal of net-zero energy throughout the design process is critical to minimizing construction costs. In California, for example, many commercial buildings are technically feasible to be ZEB using a time-dependent, valuation-based definition. However, several building categories, such as sit-down restaurants, hospitals, and large offices cannot reach ZEB designation using rooftop solar—though they might reach that designation using parking lot PV systems. Having available roof space for onsite PV is often a challenge. Contracting with offsite renewable energy systems or participating in virtual net-metered or community-scale solar projects provide greater flexibility for buildings to be ZEB or ZEB-ready. This is an active area of policy discussion.

Other barriers to the adoption of ZEBs are the lack of integrated design practices, cost barriers, lack of skilled and knowledgeable workforce in design and construction, additional design and construction cost, improper building management, user behavior, and integration of solar PV, either as part of the building construction process or as a parallel step during that process.

Policy that encourages zero-energy homes increases demand for not only energy efficiency but also other distributed energy resources, such as DG and battery storage. High levels of market penetration could have significant impacts on the grid, reducing overall grid electricity consumption. More distributed energy resources driven by zero-energy targets can potentially lead to higher levels of DR. California has announced a target of making all new residential buildings net-zero energy by 2020. It is likely that a significant fraction of existing residential buildings would struggle to attain zero energy onsite due to roof angles, poor insulation, insufficient roof area (particularly in the case of high-rise buildings), and other factors. This may place a premium on finding a way to procure offsite sources to offset whatever amount of site energy remains.

Using government-owned buildings, especially schools, to demonstrate the multiple benefits that ZEBs can help realize (such as improved student health and reduced operating costs) could lead to more widespread adoption of such building construction, renovation, and management practices. For example, one study showed that improved heat pump air conditioning in relocatable classrooms could simultaneously reduce the energy needed for heating, ventilation, and air conditioning by 50ï 70 percent and significantly improve indoor air quality. More studies are needed on the cost-effectiveness of new ZEBs, considering an integrated package of energy efficiency measures rather than analysis of discrete measures, as well as a better understanding of the cost-effectiveness of ultra-low energy or ZEB retrofits. Some of the key adoption issues that need to be resolved for ñshared solarò or offsite renewable generation include a lack of uniformity and standardization of consumer contracts, rate design, and program structure, and the need for a framework to track and match offsite renewable resources to specific buildings claiming an offset. Thus, an analysis of the policy choices, impacts, and cost implications of ZEBs would be helpful.

ẁ ¢KŜ ǘŜǊY ÎŜǊƻ ŜyŜǊƎè ōdzƛƭŘƛƴƎ ó½9.ú dzǎŜŘ KŜǊŜ ƛǎ Õƻy̓ǎƛŘŜǊŜŘ ǘƻ KI·ØŜ ǘKŜ ǎI·Y̓Ŝ Y̓ŜI·y̓ƛƴƎ I·ǎ ǎƛY̓ƛƭI·ǊǘŜǊYǎ ǎdzǑK I·ǎ ÎŜǊƻ yŜǘ ŜyŜǊƎè ōdzƛƭŘƛƴƎ ó½b9.ú ƻǊ yŜǘπÎŜǊƻ ŜyŜǊƎè ōdzƛƭŘƛƴƎ ób½9.úφ

2.4 Maximizing Value of Dynamic Consumer Assets

[illegible]

2.4.1 Modern Communications Networks Provide the Backbone for Maximizing Value of Electricity Assets

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.4.2 Customer Engagement

[illegible] *Transforming the Nation's Electricity System: The Second Installment of the QER* [illegible]

[illegible]

Table 2-1. Potential Annual Cost Savings from Customer Engagement Solutions[200]

Value Source	Annual Savings Per Regulated Household
Effective marketing of new offerings	**$4–5**
Reduced cost-to-serve	
Reduced call volume, decreased escalations, etc.	$3–16
Increased adoption of e-billing	$3–5
Improved payment discipline	$1–4
Improved cost-effectiveness of energy efficiency (EE) program portfolio	
EE program cost savings via Behavioral EE	$2–5
EE program cost savings via Thermostat EE	$20–35
Behavioral DR capacity and energy cost savings	
Behavioral demand-response capacity savings	$7–20
Potential aggregate value, $/household, per year	**$40–90**

Customer engagement can provide cost savings to utilities across several functions: program marketing, customer care, energy efficiency, and demand response.

2.4.3 Privacy Concerns Could Limit Utilization of Consumer Data

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.4.4 Demand-Side Options Can Be Used to Avoid Costs of New Infrastructure

[illegible] *Building a Clean Electricity Future* [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.4.5 Aggregation of Individual Consumer Transactions Can Create Economies of Scale and New Business Models

[illegible]

DR aggregation [illegible]

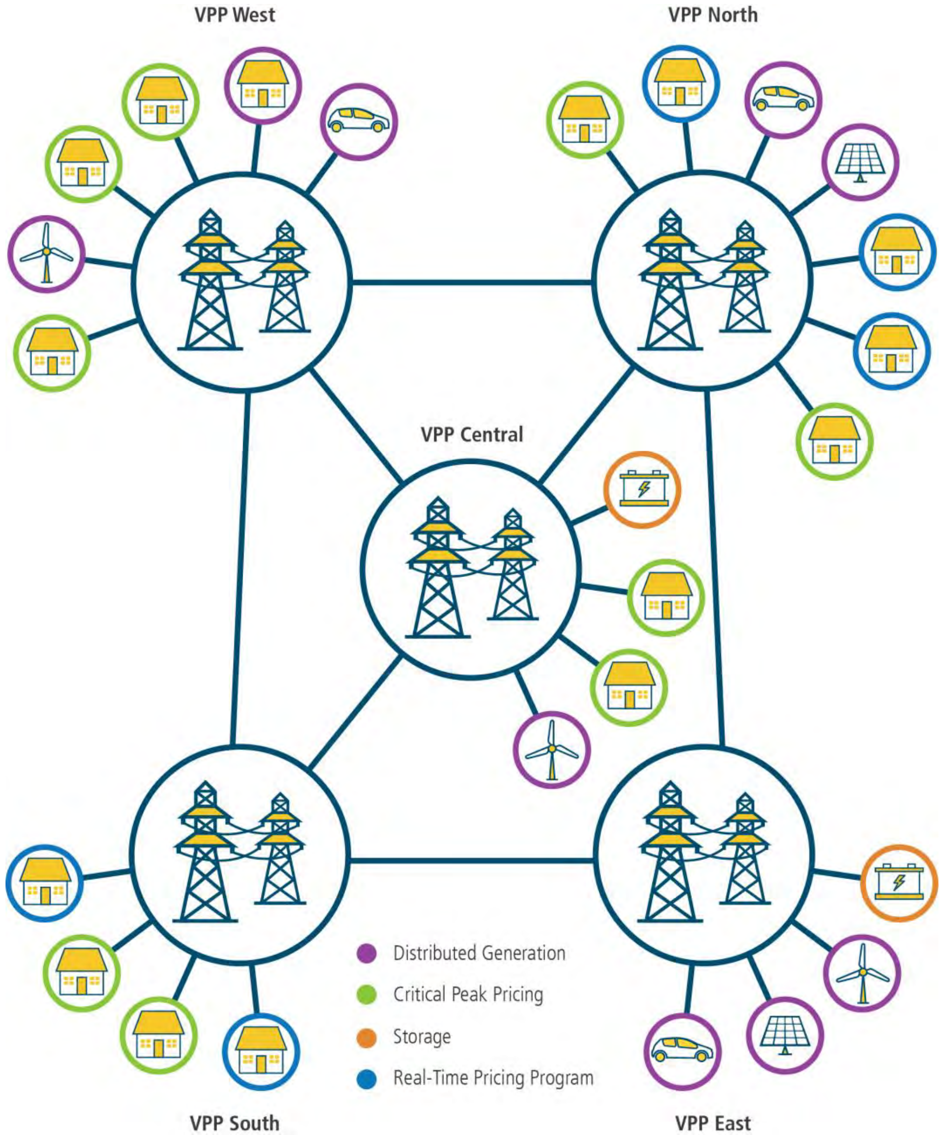
[illegible] *must be compensated* [illegible]

Virtual power plants (VPPs), pioneered in the 1980s in Austin, Texas, are systems that integrate a wide variety of power resources, such as smaller, local renewable or gas-fired generation, energy storage, and energy efficiency DR programs. They do this by aggregating many diverse customers from different customer classes "under one type of pricing, demand response, or distributed energy resource program."[216] Customers are not necessarily grouped by program or type, but they can also be aggregated by another defining characteristic, for example location (

[illegible]

[illegible] *Building a Clean Electricity Future* [illegible]

Figure 2-14. Aggregations of Demand Response and Distributed Generation[219]



Aggregators acting as VPPs collect power and services from distributed resources including community solar, rooftop solar, EVs, distributed storage, and grid-controlled and price-reactive household devices. Aggregators are then able to bid these services collectively into wholesale electricity markets to meet system operation needs.

Community choice aggregation [illegible]

[illegible] **community solar model** [illegible]

[illegible]

2.4.6 Interconnection and Interoperability Standards

[illegible]

[illegible]

[illegible]

2.5 The Changing Preferences of Electricity Consumers: Impacts on Policies and Regulations

[illegible]

2.5.1 Compensating Providers of Grid Services

[illegible]

2.5.2 Valuation of Grid Services

[illegible]

[illegible]

- **Type of resource:** [illegible]
- **Location:** [illegible]
- **Time:** [illegible]

[illegible]

2.5.3 Rate Designs for Valuing New Services

[illegible]

[illegible]

*Revenue Requirement = (Rate of Return **x** Depreciated Rate Base) + Depreciation*

+ Operations and Maintenance (including Fuel) + Taxes

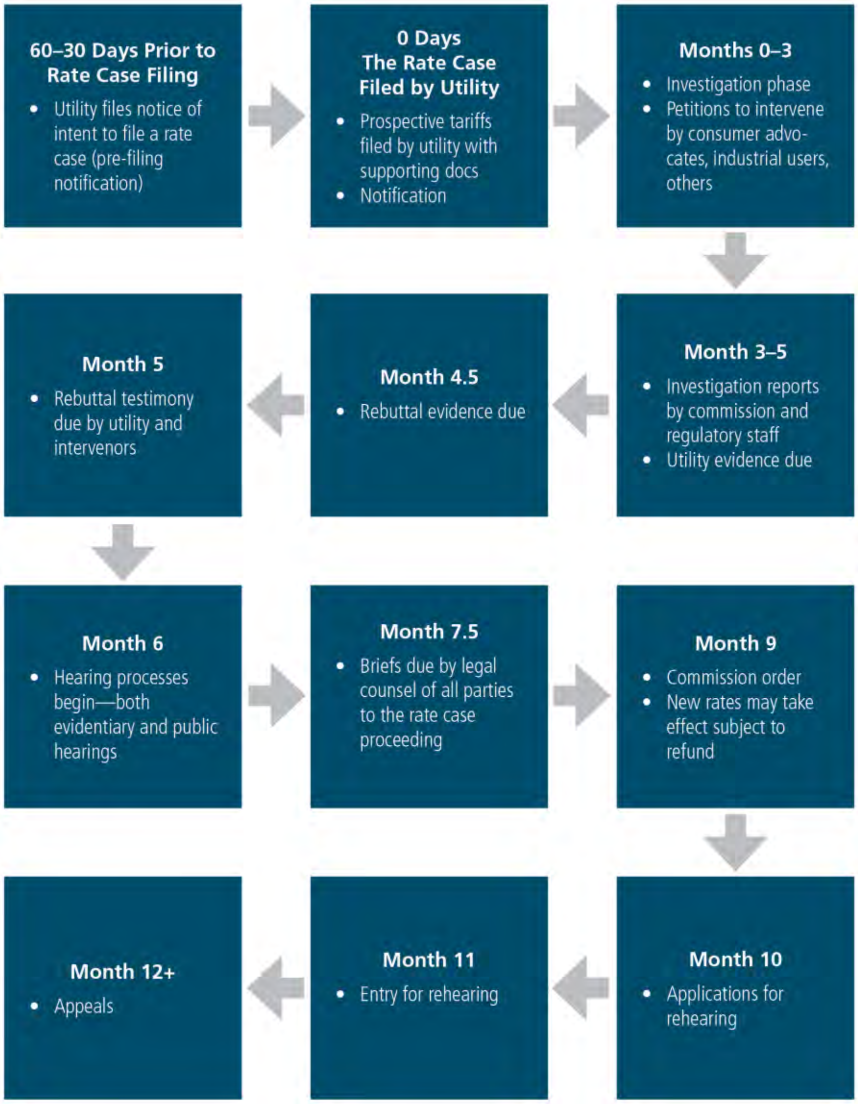
[illegible]

[illegible]

[illegible]

[illegible] *Knoxville v. Knoxville Water Company, 212 U.S. 1 (1909)* [illegible] *Bluefield Water Works & Improvement Company v. Public Service Commission, 62 U.S. 679 (1923),* [illegible]

Figure 2-15. Timeline of a Typical Rate Case Proceeding[236]



Rate cases are lengthy and complex, often lasting a year or more. Depending on how utilities calculate their costs, this often leads to ñregulatory lag,ò wherein rates come into effect long after utilities have made investments. Thus, utilities are typically recovering past, not current, costs.

[illegible] *costs* [illegible] *price or charge* [illegible] *costs*, [illegible] *prices and charges*. [illegible]

1. **Fixed costs** [illegible]

2. **Capacity costs** [illegible]

[illegible]

2. **Variable costs** [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.5.3.1 Time-Varying Rates Can Shift Demand

2.5.3.2 Locational Pricing Difficult to Implement

[illegible]

[illegible]

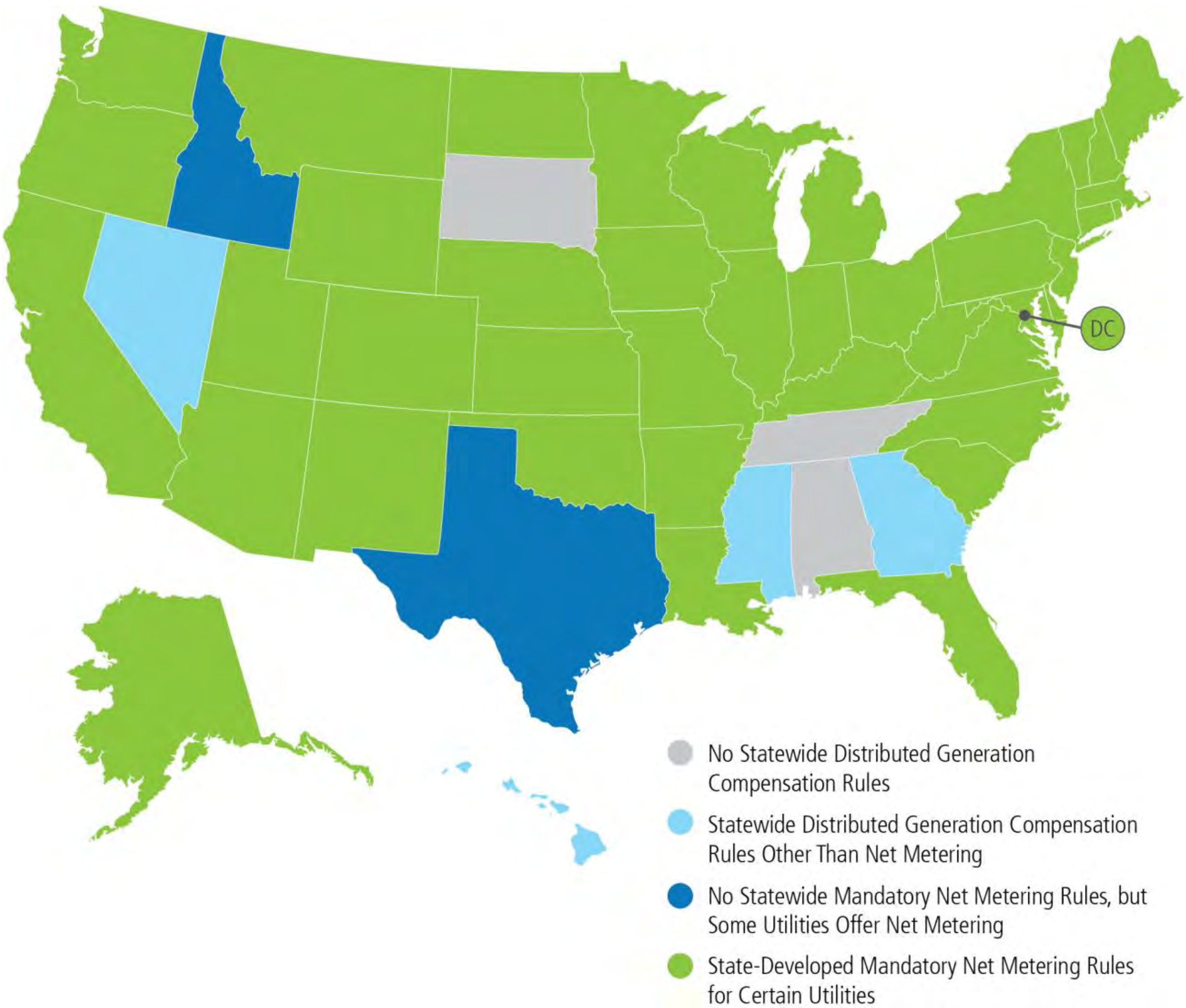
2.5.4 Net Metering for Distributed Generation

[illegible]

[illegible]

[illegible]

Figure 2-16. Current Net Metering and Distributed Generation Compensation Policies [252]



Georgia, Hawaii, Mississippi, and Nevada offer alternative compensation mechanisms for DG such as net billing, which typically provides a rate of compensation for grid exports below the retail rate.

[illegible]

[illegible] *rates* [illegible] *costs* [illegible]

[illegible]

[illegible]

[illegible]

Table 2-2. Alternative Rate Options for Distributed Solar

Structure	Description	Utility Example
Value of Solar	Utilities and other stakeholders attempt to calculate the full social value of distributed PV, including its environmental benefits, and use that to develop a tariff for all electricity exported to the grid from a distributed PV facility.	Austin Energy; Minnesota's statewide value of solar tariff has not yet been implemented.
Net Billing	Distributed PV host receives neither credit nor charge for electricity consumed onsite but receives compensation for exported power at an administratively-determined rate, often set at the cost of procuring utility-scale solar power.	Imperial Irrigation District
Self Supply and Grid Supply	Consumers choose to supply all of their own power, in which case they are excused from some charges but not compensated for any exported electricity. Or, they must buy all of their power at retail rates and sell all of their onsite generation at a lower rate.	Hawaiian Electric Company
Increased Fixed Charges	Net energy metering is maintained, but its value and any associated cost changes from infrastructure upgrades (not counting externalities) are reduced by increasing fixed charges and decreasing volumetric charges.	Wisconsin Utilities

The increasing penetration of rooftop solar and advanced metering is driving and enabling regulatory changes. Regulators and utilities are considering alternative rate options for compensating customers for grid services while continuing to support new technology, maintain infrastructure, and ensure affordability for all customers.

2.5.4.1 Providing Incentives through Ratemaking

[illegible]

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]

[illegible]

2.5.4.2 Providing Resources to Inform Rate Design

[illegible]

- [illegible]
- [illegible]

- [illegible]

[illegible]

[illegible]

2.5.5 Adapting the Distribution Utility Business Model

[illegible]

[illegible]

[illegible]

[illegible]

2.5.5.1 Models for Provision of Demand-Side Services

Table 2-3. Energy Efficiency Business Models[270, 271]

Utility Programs	Utility energy efficiency programs are part of a resource-acquisition process in which a utility plans for resources that it expects to need in order to provide reliable service.
Independent Entities	Some states use independent entities to administer energy efficiency programs. Their purpose is to invest in services and programs that save money and conserve energy. The fee is based on integrated resource plans that consider both environmental and economic costs.
State Agency Administered	Some states, such as New York, employ a blended approach, whereby some the New York State Energy Research and Development Authority implements the efficiency programs, and the utilites implement others.
Market-Based Providers	Some non-utility companies provide value by serving as the interface between customers and the market (e.g., Comverge).
Energy Service Companies	Energy service companies (ESCOs) offer both private provision of energy efficiency services and a vehicle for implementation. They typically use performance contracts in which the ESCO guarantees energy and/or dollar savings for the project, linking ESCO compensation to the performance of the project.

An array of actors in the electricity sector including utilities, private-sector companies, and state agencies offer energy efficiency programs. Energy efficiency programs are available both in wholesale electricity market areas and within regulated vertically integrated utility areas.

2.5.5.2 Models for Integrating Distributed Generation

[illegible]

[illegible]

[illegible]

Table 2-4. Business Models for Distributed Generation

Customer Ownership	The customer finances the installation, keeps any renewable energy credits associated with solar production, enjoys the tax benefits of the investment, and keeps the bill credit from net metering (or revenue stream from an alternative compensation scheme, such as a value-of-solar or feed-in-tariff).
Power Purchase Agreements	PPAs are standard contract vehicles for long-term power purchases from a third-party developer.
Utility Affiliate Model	The utility invests capital in developing DER through an affiliate. Codes of conduct bar affiliates from competing in markets in which their parent (franchised) utilities do business, or subject affiliates to special restrictions and oversight.
Utility Provided Customer-Premises Model	Where allowed, utilities may offer DER systems to customers and, like other utility generation investments, include the capital cost in the rate base. The utility (as opposed to an affiliate) is the supplier.
Aggregators	Aggregators are companies that group customer load or generation assets together to facilitate their participation in the markets.
Utility-Owned DER	Utility-owned DER can be located either on a customer's premises or on utility property.
Utility-Provided DER	Utility-provided DER is, essentially, small-scale, utility-owned generation. This model alleviates the issue of high, upfront and installation costs that leave customers unable to participate.
Third-Party Merchant Model	Independent third parties can connect DER directly to the distribution system with no onsite customer involvement.

Utilities can integrate DG using a variety of business models to accommodate varying local and regional circumstances, market and infrastructure topologies, and consumer preferences.

2.5.5.3 Limitations on the Scope of Utility Activities

[illegible]

[illegible]

[illegible]

[illegible]

- [illegible]
- [illegible]
- [illegible]

[illegible]

2.5.5.4 Nature of Consumer Protection Changing with New Players

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.6 Federal and State Jurisdictional Issues

[illegible]

2.6.1 Distributed Generation

[illegible]

[illegible]

[illegible]

2.6.2 Demand Response

2.6.3 Energy Storage

2.6.4 Potential Tools to Coordinate across Jurisdictions and Align Regulatory Approaches to Emerging Energy Technologies

In many policy areas, FERC has tread softly where it might have a claim of jurisdiction but did not want to preempt state regulation; in these instances, it has chosen to exercise its jurisdiction in line with state policy goals. Several tools are at FERC's disposal to deal with future potential jurisdiction challenges impacting new and emerging technologies and the integration of markets for those technologies.

One way forward is through new frameworks that, for example, could establish rate-setting models that consider revenues from both state and Federal jurisdictions simultaneously. These models would allow resource owners to "stack" revenues from services they provide across state and Federal jurisdictions. It would also guard against the potential for over-recovery and unjust and unreasonable rates. In addition, FERC could explore including costs of additional technologies in rate design.

While rarely used, FERC has authority to establish joint hearings that would permit FERC and the states to hear cases together, but without a joint decisional procedure.[298] FERC can also delegate certain roles to "joint boards" made up of state commissioners (with no Federal representation).[299] More generally, FERC and state commissions can collaborate on policy matters of common interest.

Another possible approach is to redraw the line between Federal and state jurisdictions to better accommodate today's regulatory needs. In particular, this redraw should reflect the broader regional nature of electricity markets and the ability of new and emerging technologies to provide service across both Federal and state jurisdictional lines.[kk]

Another option would be to authorize jurisdictional agreements, which would permit a consensual resolution of potential conflicts between state agencies and FERC. Under this option, an amendment to the FPA would include provisions similar to those in several other Federal statutes[ll] that would authorize FERC and state commissions to enter into agreements that rationalize their respective state and Federal regulatory jurisdiction.

The recommendations based on the analysis in this chapter are covered in Chapter VII (*A 21st-Century Electricity Sector: Conclusions and Recommendations*).

[kk] Note that amendments to the Federal Power Act intended to resolve jurisdictional uncertainty with respect to new technologies or circumstances will themselves be subject to interpretation over time and will have to be applied to ever-changing fact patterns.

[ll] See e.g., National Labor Relations Act of 1935, Pub. L. No. 74-198, §§ 10(a), 14(c), 49 Stat. 449, 453, 457 (codified as amended at 29 U.S.C. §§160(a), 164(c)); Atomic Energy Act of 1954, Pub. L. No. 83-703, § 244, 68 Stat. 919, 958-59 (codified as amended at 42 U.S.C. § 2021 (2005)); Clean Air Act § 111(c), Pub. L. No. 91-604, § 111(c), 84 Stat. 1676, 1684 (1970) (codified as amended at 42 U.S.C. § 7411(c) (1977)).

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III Building a Clean Electricity Future

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Key Findings for Building a Clean Electricity Future

- 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 the reductions in CO_2 intensity were attributed to switching from coal- to gas-fired power generation, and 39 percent were attributed 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 Washington, D.C., have a Renewable Portfolio Standard (RPS), 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 per megawatt-hour (MWh), versus the levelized cost of electricity (LCOE) for natural gas combined-cycle (NGCC) generation, with its sensitivity to fuel prices, at $52 to $78/MWh.[1]
- 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 greenhouse gas (GHG) emissions reductions and other environmental improvements from the electricity system to achieve national goals will require additional policies combined with accelerating 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[a] 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 GHG emissions, such as carbon capture, utilization, and storage (CCUS), concentrated solar power (CSP), 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 residuals (CCRs), such as coal ash and scrubber slurry, are the second most abundant waste materials in the United States, after household waste.
- There is a range of decommissioning needs for different types of power generation facilities.

3.1 Building a Clean Electricity Future

[illegible] "73% of voters support a national energy policy that ensures a secure supply of abundant, affordable, and available energy for the American people in an environmentally responsible manner."[p]

[illegible]

[illegible]

3.2 CO_2 Emissions and the Electricity System

[illegible] year over the past decade, due in part to “slowing population growth, market saturation [illegible] industries.” [illegible]

[illegible] *rate*—[illegible]

[illegible] or’s [illegible]

[illegible] r’s share is projected to increase from 13 percent in 2014 to 14 [illegible]

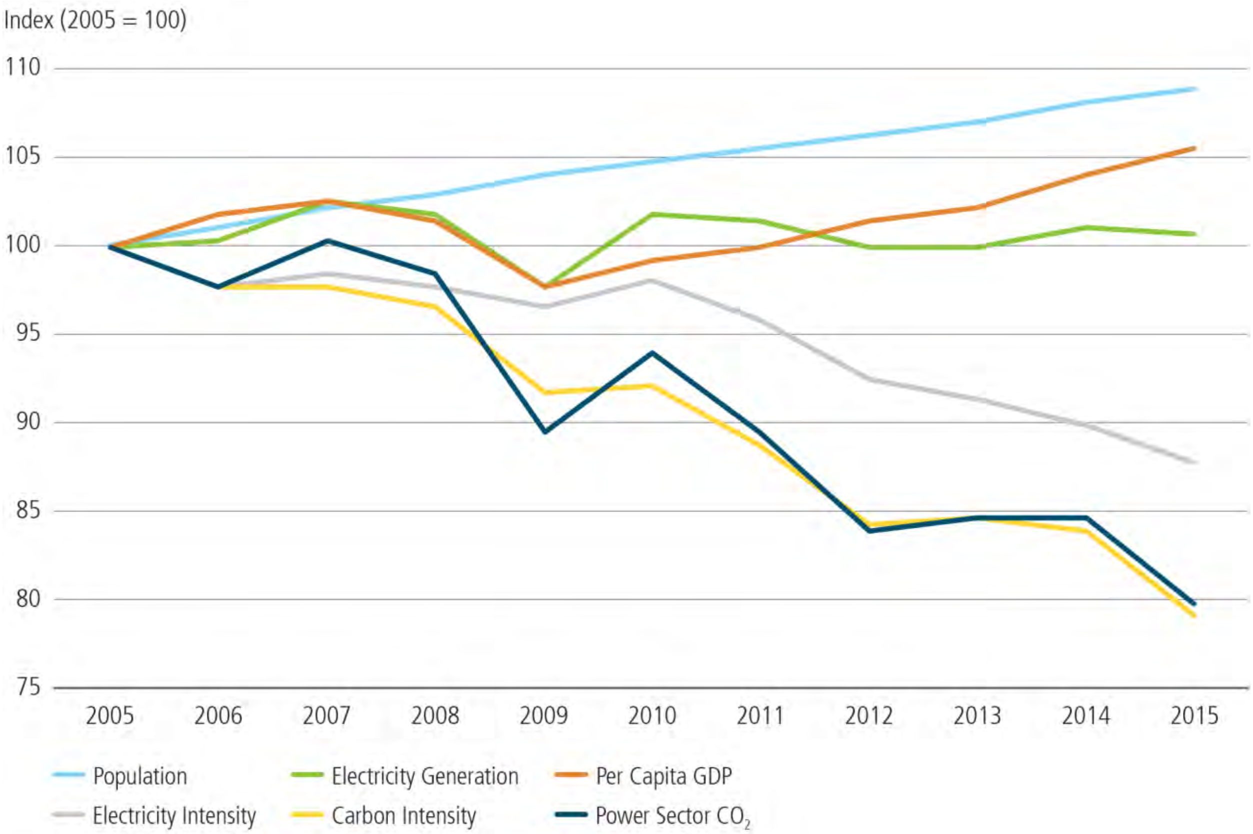
[illegible]

[illegible]

3.2.1 Decarbonization of the Electricity System

[illegible]

Figure 3-1. Trend Lines in Emissions Drivers, 2005–2015[17, 18, 19]

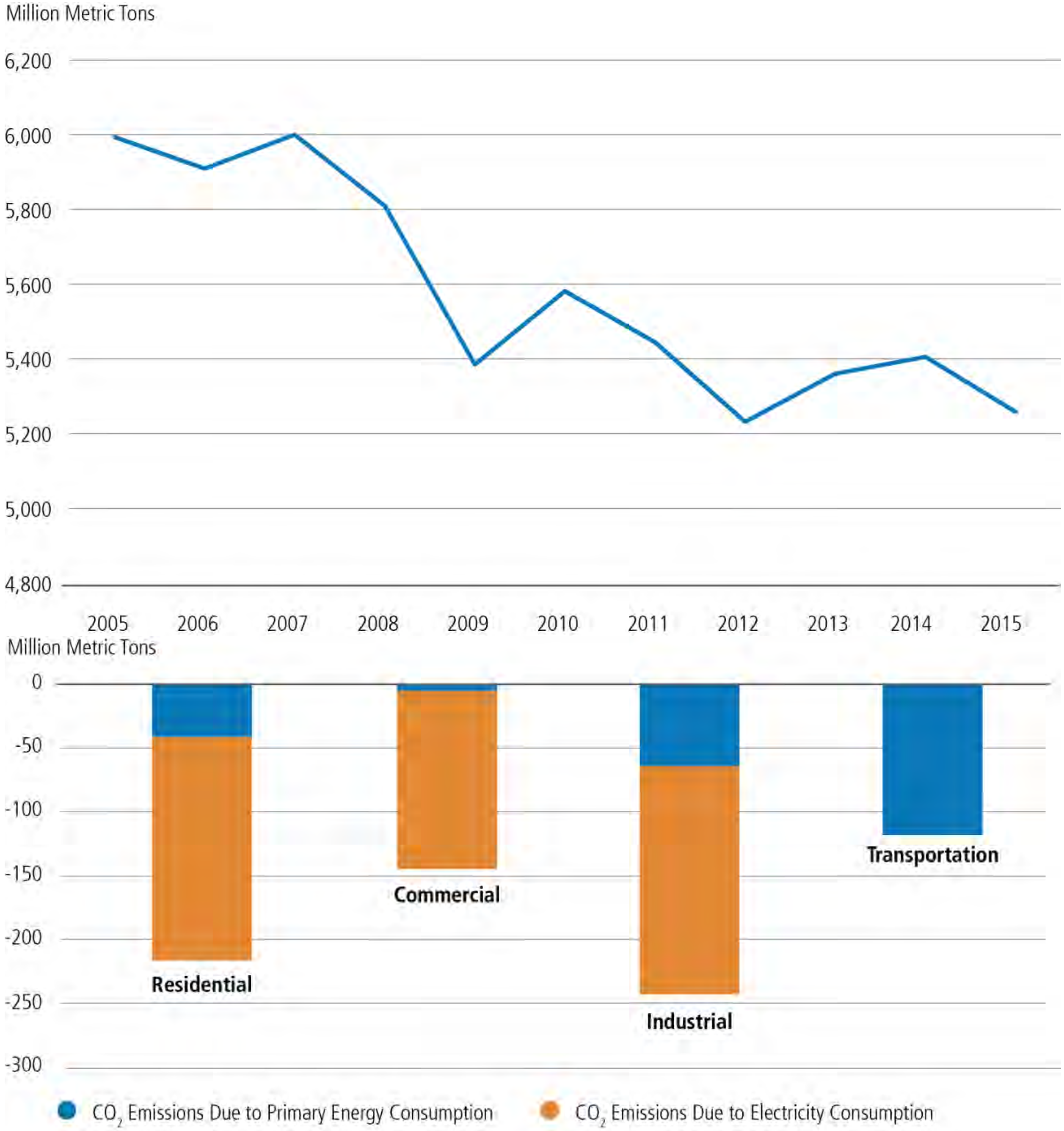


The population growth, per capita gross domestic product (GDP), and electricity intensity of the economy all factor into total U.S. electricity demand. While growth in population and per capita GDP has placed upward pressure on power-sector demand, this growth has been partially offset by a decline in the electricity intensity of the economy.

[illegible]

[illegible]

Figure 3-2. U.S. Energy-Related CO_2 Emissions, 2005–2015 (*top*), and Change in U.S. Energy-Related CO_2 Emissions by Sector, 2005–2015 (*bottom*) [21, 22]



After increasing in 2013 and in 2014, energy-related CO_2 emissions fell in 2015. In 2015, U.S. energy-related CO_2 emissions were 12 percent below the 2005 levels, mostly because of changes in the electric power sector.

[illegible]

[illegible]

[illegible]

[illegible] —particularly the definition of “beneficiary”— [illegible]

3.2.2 Low and Zero-Carbon Power Generation

[illegible]

[illegible]

[illegible]

Table 3-1. Change in Generation from Major Fuel Type, 2009–2014[27]

	Coal		Natural Gas		Nuclear		Non-Hydro Renewable		Total	
	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change	Absolute Change (TWh)	Percent Change
U.S.	-171.3	-10	204.6	22	-1.7	0	130.8	85	132.0	3
WECC	-13.8	-6	-4.3	-2	-10.3	-15	43.4	92	11.9	2
SERC	-53.9	-11	94.8	51	3.8	1	12.7	52	49.8	5
RFC	-83.0	-15	65.1	85	12.1	5	17.5	102	13.5	1
NPCC	-17.4	-62	11.8	12	0.2	0	14.5	148	-6.4	-2
SPP	-0.8	-1	-5.7	-10	-0.2	-2	4.0	29	3.4	2
MRO	-9.6	-6	2.7	31	-3.9	-11	19.2	105	12.2	6
FRCC	-4.1	-7	30.6	29	-1.2	-4	0.0	-1	9.7	4
TRE	11.4	10	9.7	6	-2.2	-5	19.4	105	37.8	12
Alaska	-0.1	-11	-0.3	-8	0.0	0	0.2	1,484	-0.7	-10
Hawaii	0.0	1	0.0	0	0.0	0	0.5	74	-1.3	-12

In recent years, the electricity generation mix in the western United States has shifted from fossil fuels and nuclear power to non-hydro renewables. In the eastern part of the United States, generation has shifted primarily from coal to natural gas. Texas has seen a growth in generation from both coal and non-hydro renewables. Acronyms: terawatt-hours (TWh), Western Electricity Coordinating Council (WECC), SERC Reliability Corporation (SERC), Reliability First Corporation (RFC), Northeast Power Coordinating Council (NPCC), Southwest Power Pool (SPP), Midwest Reliability Organization (MRO), Florida Reliability Coordinating Council (FRCC), Texas Reliability Entity (TRE).

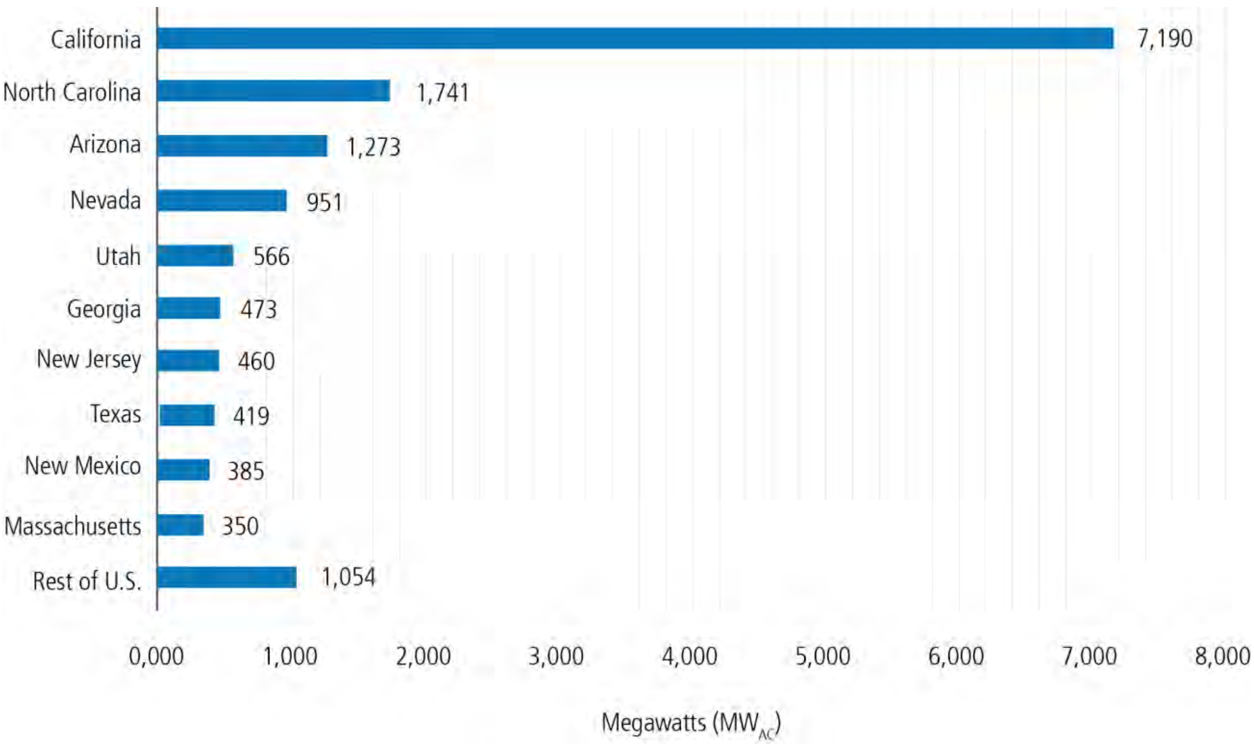
[illegible]

[illegible] *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016* [illegible]

3.2.2.1 Wind and Solar: Zero-Carbon Variable Energy Resources

[illegible]

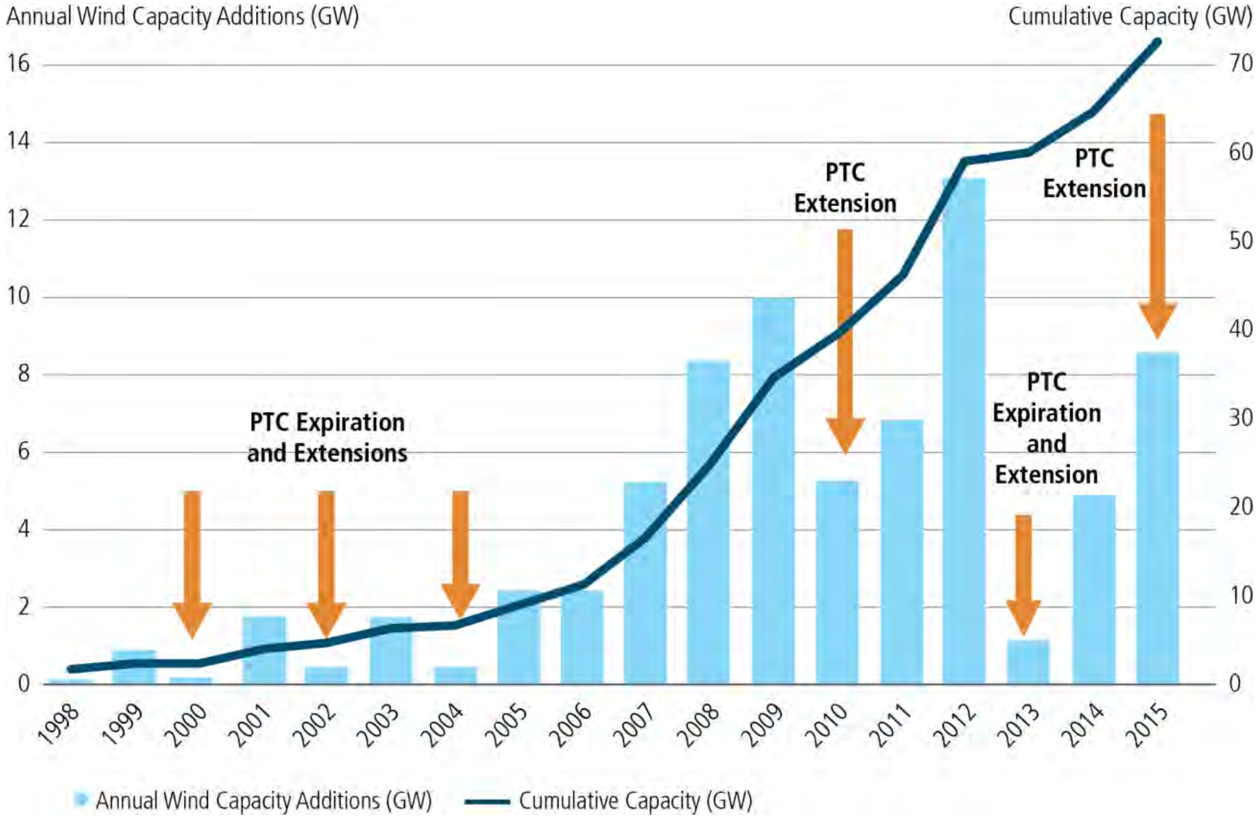
Figure 3-3. Utility-Scale PV Installed Capacity, Top 10 States, as of August 2016 (in MW_{AC})[38]



Utility-scale PV installed capacity is distributed unevenly across the United States. California comprises almost half of the installed utility-scale PV capacity in the country, followed by North Carolina, and the Southwest of the United States with Arizona, Nevada, and Utah. MW_{AC} denotes alternating-current megawatts.

[illegible] The Department of Energy's (DOE's [illegible] bation's installed capacity [illegible] the state's [illegible]

Figure 3-4. Relationship between the Production Tax Credit (PTC) and Annual Wind Capacity Additions[43]



The Production Tax Credit (PTC) has accelerated wind project deployment significantly—between 2000 and 2013, cumulative wind capacity grew from under 5 GW to over 60 GW—though capacity additions noticeably track the PTC expiration and extension schedule.

[illegible] expansion of the geographic distribution of wind power's technical potential to new regions of the United [illegible]

[illegible]

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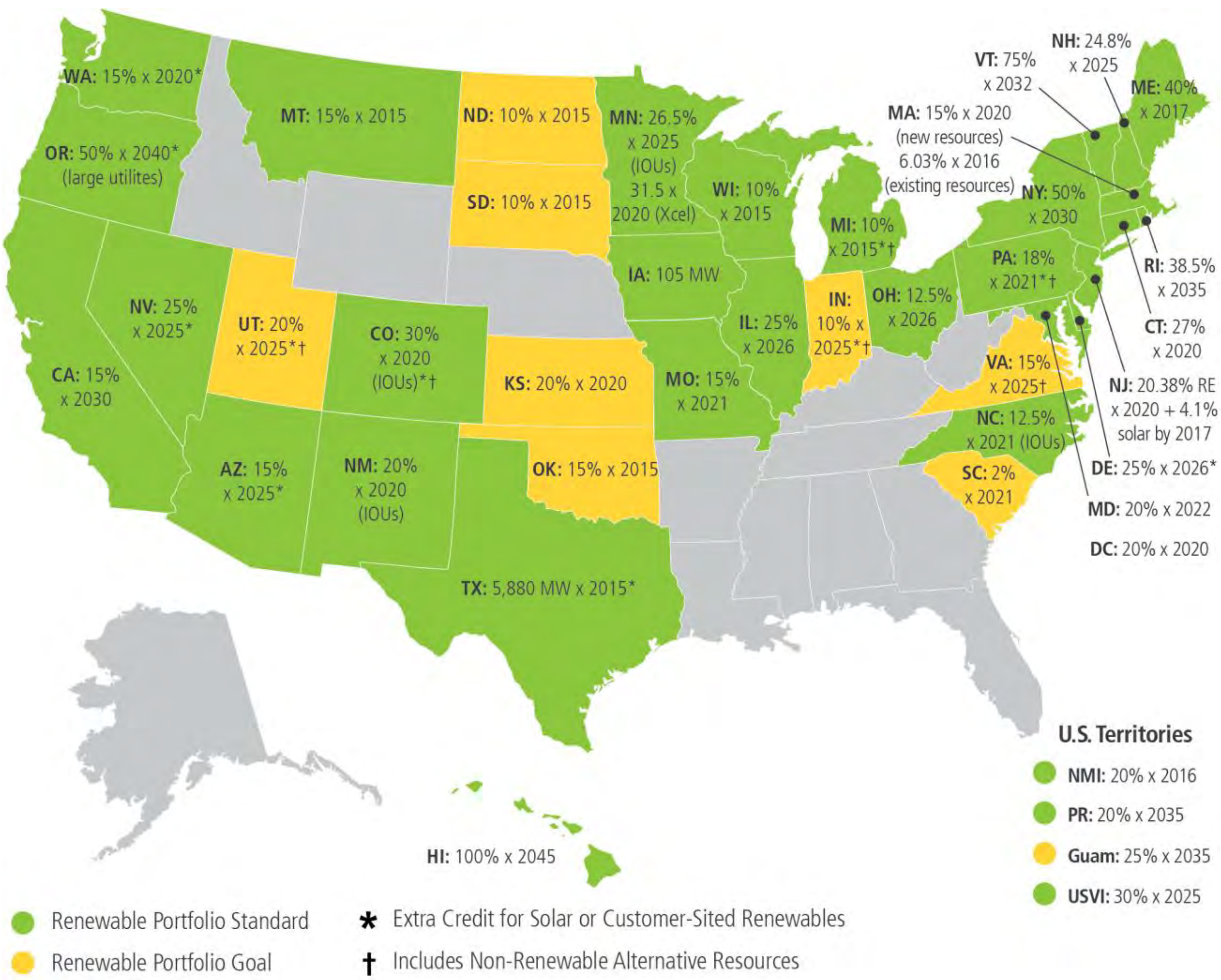
Figure 3-5. State RPS Policies, August 2016[49]



Twenty-nine states and the District of Columbia have an RPS, and an additional eight states have a renewable portfolio goal; some include extra credit for solar or customer-sited renewables or include nonrenewable alternative resources. The RPSs or renewable portfolio goals are key drivers of renewable energy growth.

[illegible] located in California, "reflecting the rapid and recent build[illegible] scale PV projects."[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

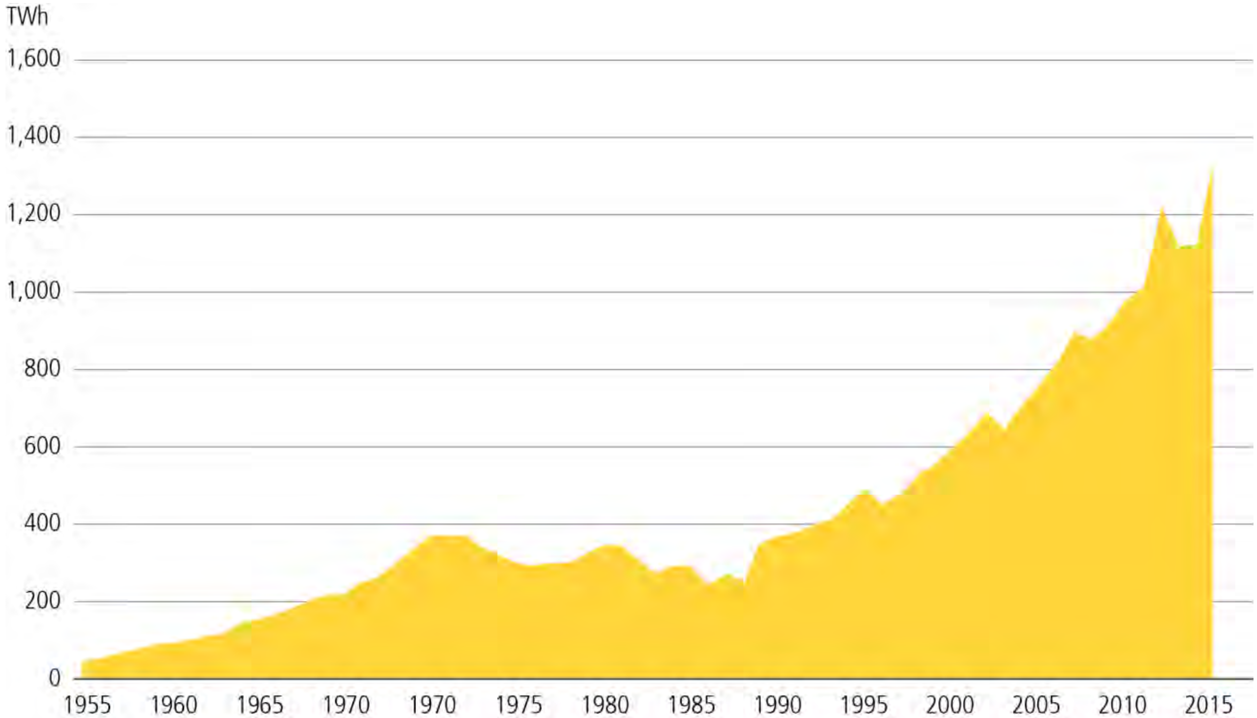
3.2.2.2 Natural Gas Generation: Lower-Carbon Flexible Baseload

[illegible]

[illegible] *Essential Reliability Services Task Force Measures Framework Report* [illegible]

[illegible] *Docket No. RM16-6-000, Essential Reliability Services and the Evolving Bulk-Power System-Primary Frequency Response* [illegible]

Figure 3-6. U.S. Natural Gas Generation, 1950–2015 (in TWh)[69]

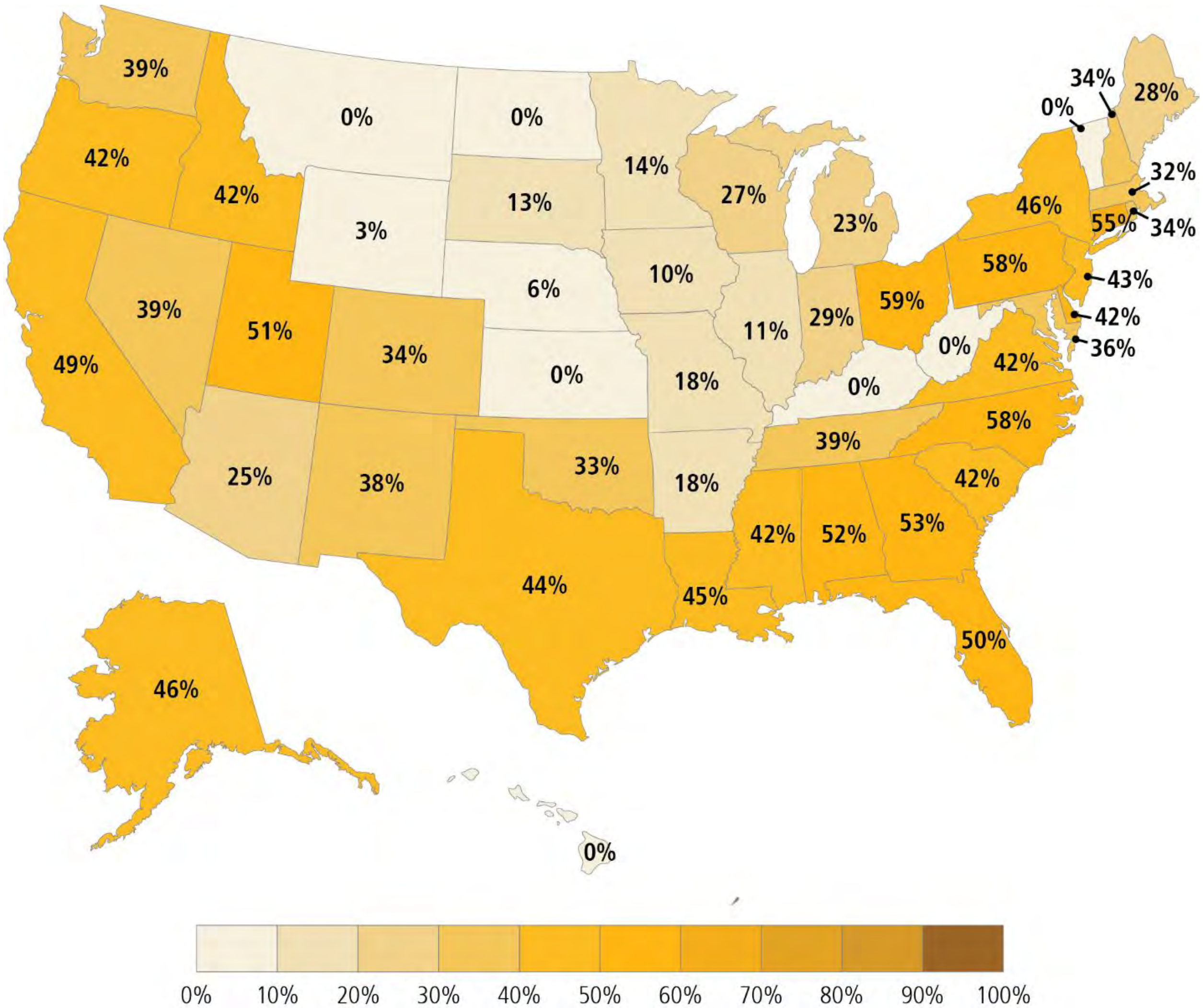


Natural gas–fired generation has grown nearly continuously since the late 1980s.

Addressing Environmental Aspects of TS&D Infrastructure … the EPA's voluntary Methane Challenge Program, and several new programs at …

[illegible]

Figure 3-7. NGCC Capacity Factors by State, 2014[74, 75]



Capacity factors of NGCC plants all generally increased across the United States between 2010 and 2014, and many states have constructed or are planning to construct new NGCC plants after 2014. Significant potential exists to further increase generation from NGCCs in most states. In the figure, “0%” represents states with no NGCC capacity.

A recent study of the value of fast ramping gas for supporting variable renewables noted that, “…to date [illegible] fossil technologies appear as highly complementary and…should be jointly installed to meet the goals of [illegible] emissions and ensuring a stable supply.”[76]

[illegible]

[illegible] *Ensuring Electricity System Reliability, Security, and Resilience).*

3.2.2.3 Coal, Natural Gas and Biomass Generation with Carbon Capture, Utilization, and Storage: Low-Carbon Baseload

[illegible]

3.2.2.4 Hydropower: Zero-Carbon Baseload and Flexibility Resource[k]

[illegible]

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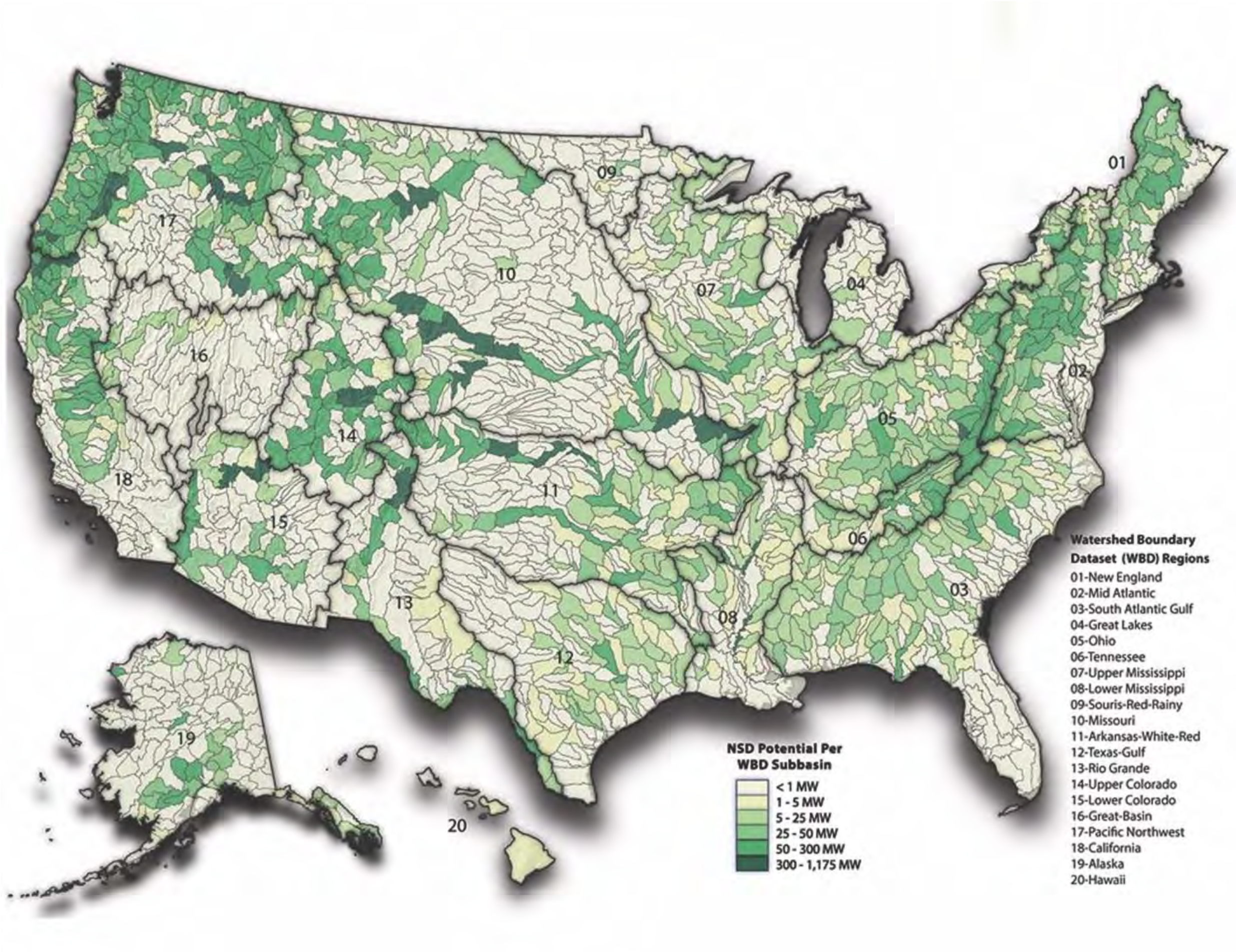
[k] [illegible] *Hydropower Vision: A New Chapter for America's First Renewable Electricity Source* [illegible]

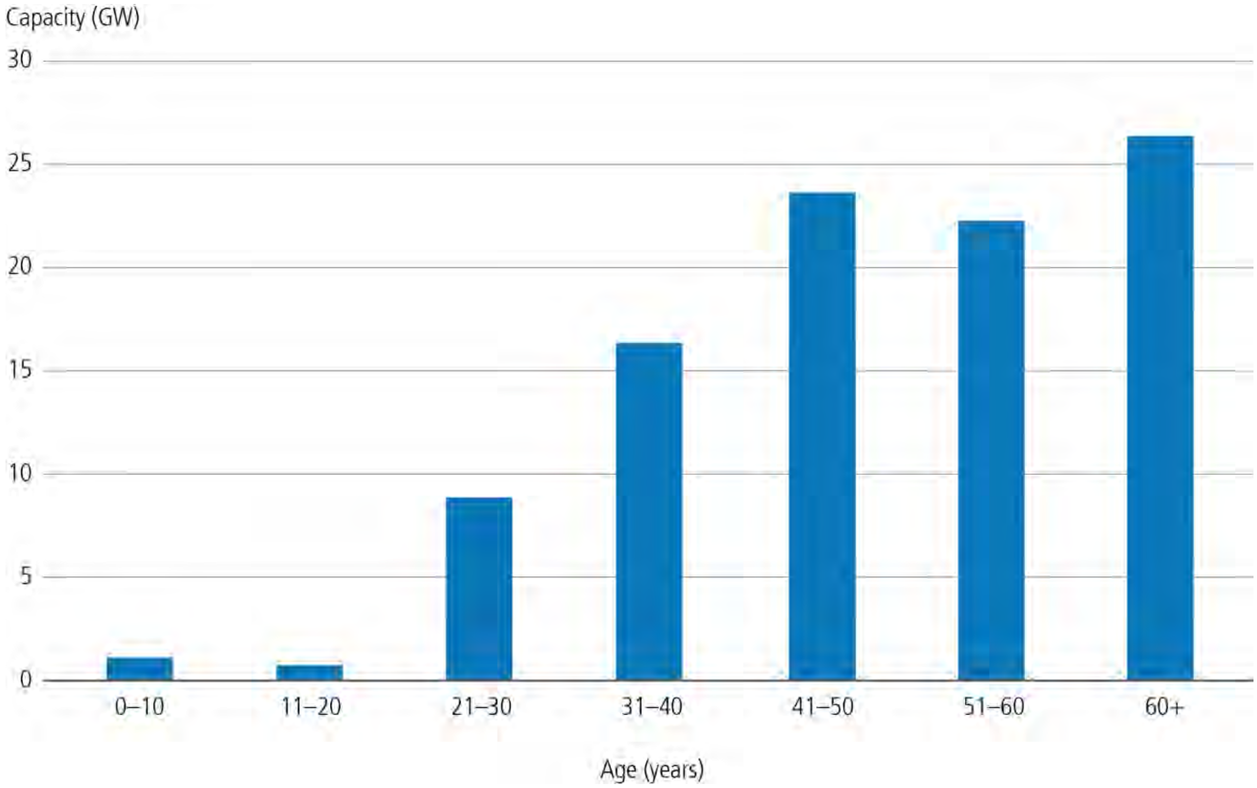
Figure 3-8. U.S. New Stream-Reach Development Potential by Subbasin for the United States[85]



The technical resource potential for new hydropower developments is 65.5 GW, focused largely in the Pacific Northwest and Rocky Mountain West.

[illegible]

Figure 3-9. Age Profile of U.S. Hydropower Generation Fleet, 2014[87]



About half the U.S. hydroelectric fleet is over 50 years old. Many large dams were built between the 1940s and 1960s.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] bation's total dams. (Other uses for dams include navigation, flood [illegible]

3.2.2.5 Biomass: Net-Zero Carbon Renewable Baseload and Flexibility Resource

[illegible]

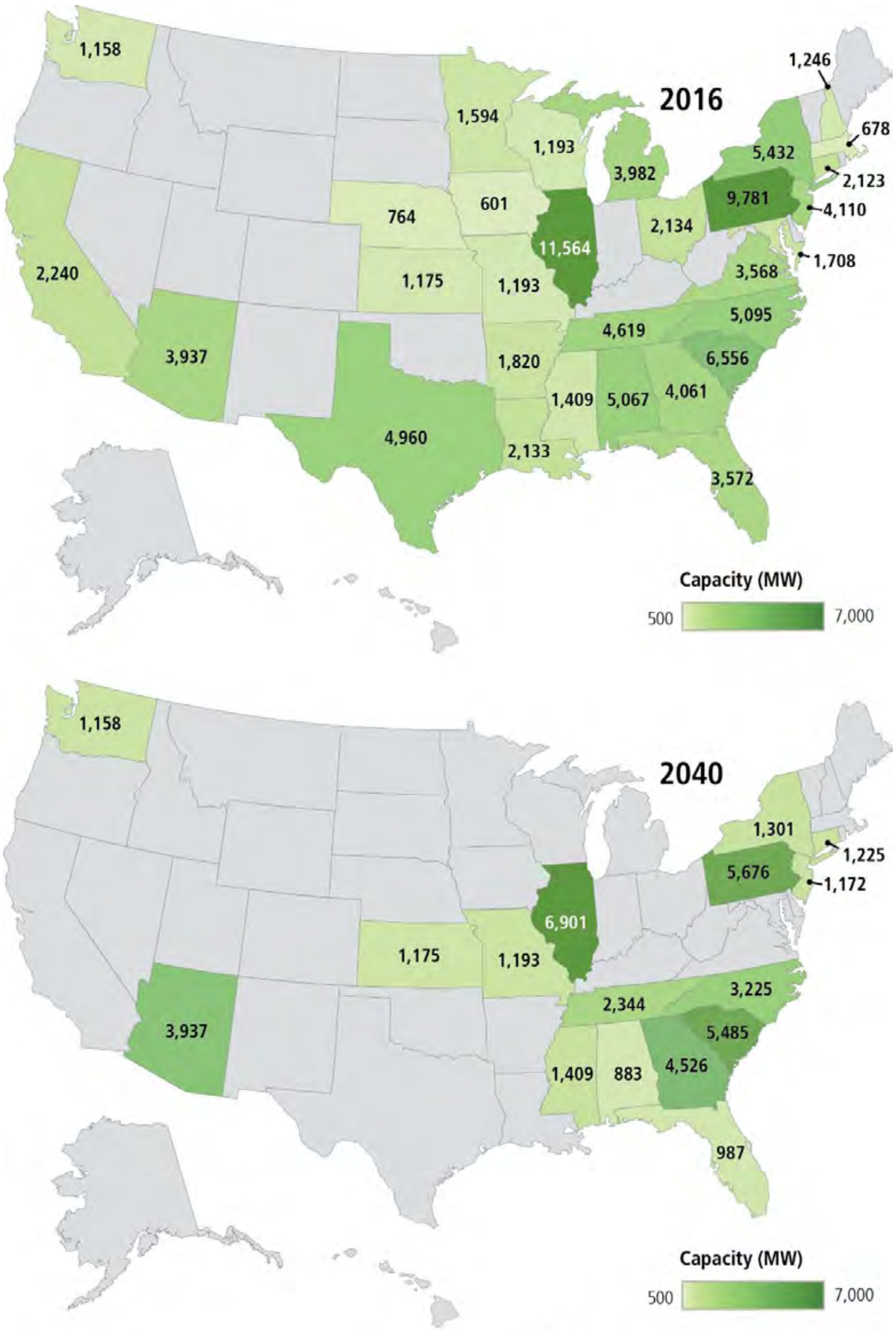
3.2.2.6 Geothermal Generation: Zero-Carbon Baseload and Flexibility Resource

[illegible]

3.2.2.7 Nuclear Generation: Zero-Carbon Baseload

[illegible] Nation's [illegible]

Figure 3-10. Current and Projected Nuclear Capacity Assuming No Subsequent License Renewals[101, 102]



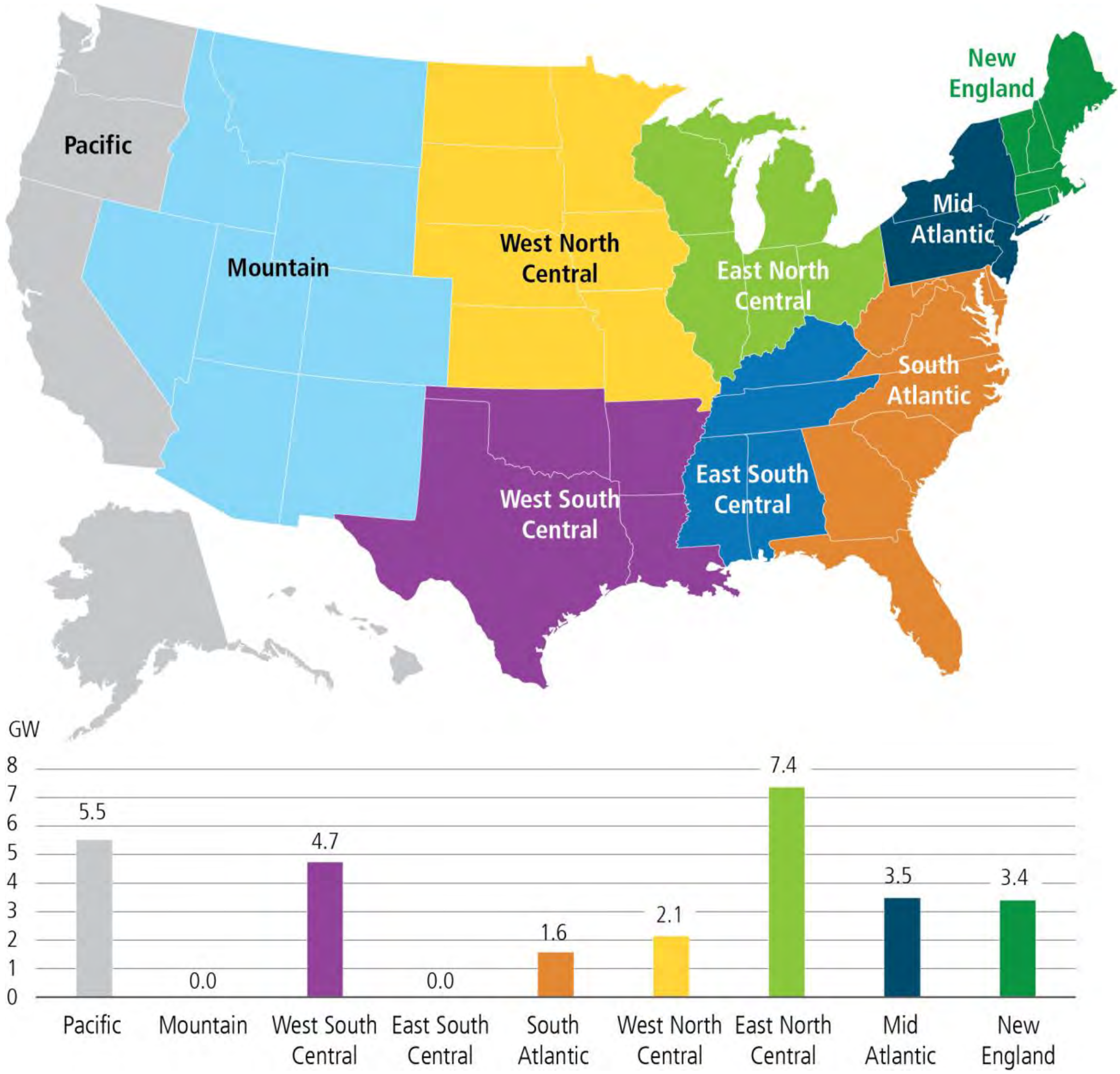
The top map in the figure shows U.S. nuclear power capacity (in MW) by state in 2016 (as of December 15, 2016). The bottom map shows what the U.S. nuclear power capacity by state would be in 2040 (December 31, 2040), assuming that all reactors, except those that have already specified closure dates, shut down at the expiration of their currently approved licenses.

[illegible] would occur prior to the expiration of the unit's existing licenses. [illegible]

[illegible] rs have found it to be increasingly difficult to compete under today's market conditions [illegible]

[illegible]

Figure 3-11. Nuclear Units at Risk or Recently Retired by Census Region[106]



Across the country, over 28 GW of nuclear generating capacity is at risk or recently retired, most of which is in the East North Central region.

[illegible]

[illegible]

[illegible]

[illegible]

3.2.3 Decarbonization via Distributed Energy Resources

[illegible] utility's distribution system or on the premises of an end[illegible] (*Ensuring Electricity System Reliability, Security, and Resilience).* [illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity)*[illegible]

[illegible]

[illegible]

[illegible] *not* [illegible] e grid as "dispersed generation" rather than "distributed generation." See Energy Information Administration (EIA), *Modeling Distributed Generation in the Buildings Sectors* [illegible]

[illegible]

[illegible]

Table 3-2. Potential Reductions in Electricity-Sector Energy and CO_2 Emissions in 2030 Attributable to Smart Grid Technologies[111]

	Reductions in Electricity-Sector Energy and CO_2 Emissions[a]	
Mechanism	**Direct (%)**	**Indirect (%)**
Conservation effect of consumer information and feedback systems	3	-
Joint marketing of energy efficiency and DR programs	-	0
Deployment of diagnostics in residential and small/medium commercial buildings	3	-
Measurement and verification for energy efficiency programs	1	0.5
Shifting load to more efficient generation	<0.1	-
Support additional electric vehicles and plug-in hybrid electric vehicles	3	-
Conservation voltage reduction and advanced voltage control	2	-
Support penetration of renewable wind and solar generation (25 percent RPS)	<0.1	5
Total reduction	**12**	**6**

The combined impact of nine smart grid mechanisms, assuming 100 percent penetration of smart grid technologies by 2030, is a 12 percent reduction in annual U.S. electricity-related CO2 emissions from direct

[illegible]

effects, and a 6 percent reduction from indirect effects.[q] Assumes 100 percent penetration of the smart grid technologies.

[illegible]

3.2.3.1 Energy Efficiency: Environmental Benefits and Consumer Savings

[illegible] (*The Electricity Sector: Maximizing Economic Value and Consumer Equity*).

DOE's Appliance and [illegible] bation's most effective [illegible]

[illegible]

[illegible]

[illegible] significant energy savings and GHG reductions beyond today's building codes have been demonstrated [illegible]

[illegible]

3.2.3.2 Distributed Generation, Distributed Storage, and Demand Response

[illegible]

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[a] EPA's ENERGY STAR Certified Homes are typically 15 percent to 30 percent more efficient than the average new home, yet [illegible]–$93 to consumers. DOE's Zero Energy Ready Homes are at least 40 [illegible]

[illegible]

[illegible]

[illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity).*

[illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity).*

[illegible]

3.2.4 Increased Electrification Is Essential for Decarbonization

[illegible]

3.2.4.1 Electrification of Buildings

[illegible]

[illegible]

[illegible]

3.2.4.2 Electrification of Industry

[illegible]

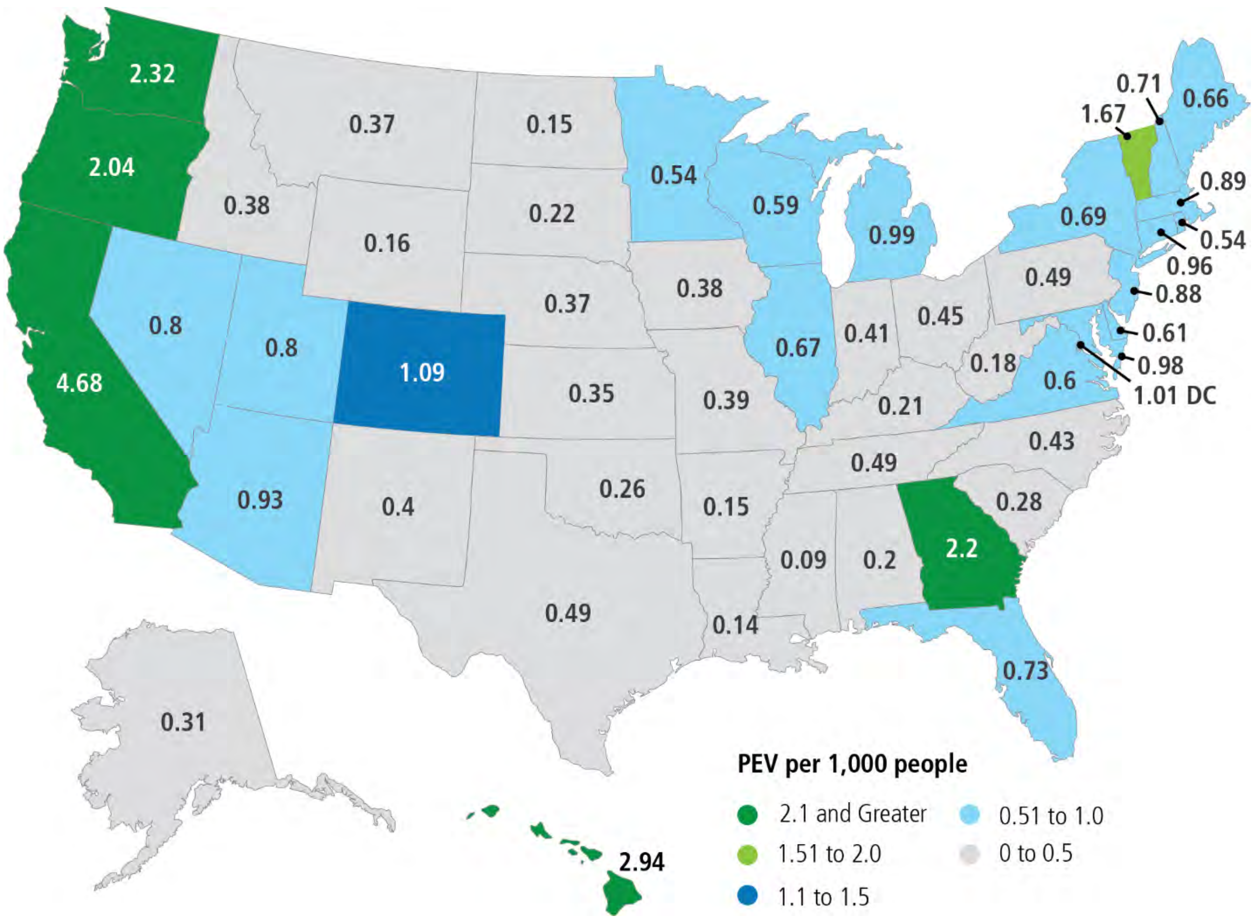
3.2.4.3 Electrification of Transportation

[illegible]

[illegible]

[illegible]

Figure 3-12. PEV Registrations per 1,000 People by State in 2015[160]



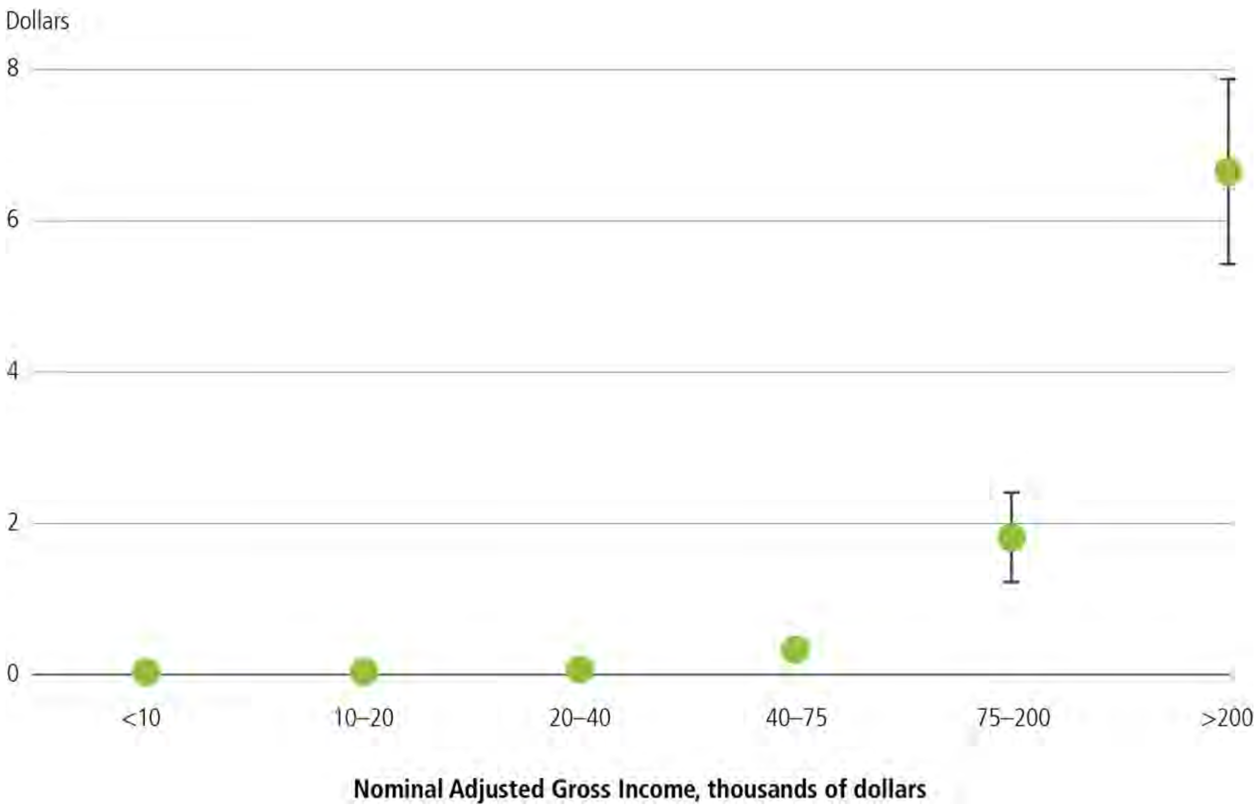
The concentration of PEV registrations varies by state, with the highest concentrations in California, Washington, Georgia, and Oregon.

[illegible]

[illegible] The state of California recently decided to increase the amount of the state's clean vehicle

[illegible]

Figure 3-13. Qualified Plug-In Electric Drive Motor Vehicle Credit, 2009–2012[173]



The relationship between average credit per tax return per adjusted gross income category demonstrates that, historically, high earners are the group that derives the most financial benefits from the Qualified Plug-In Electric Drive Motor Vehicle Credit.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] Those corridors are designated as "sign-ready," meaning [illegible]

[illegible] California's standards in their entirety. The California Air Resources Board adopted a zero-[illegible] (ZEV) rule as part of the state's 1990 Low Emission Vehicle Program. Nine additional states have chos[illegible] to adopt California's ZEV rule to date: Connecticut, Maine, Maryland, Massachusetts, New Jersey, New [illegible]

[illegible] Administration's Voluntary Airport Low Emissions and Zero Emission Vehicle Programs provide [illegible]

3.2.5 Analytical Tools: Converting Data to Information Is Key to a Cleaner Electricity System

[illegible]

[illegible]

[illegible]

“[illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity)* [illegible]

[illegible]

[illegible]

[illegible]

[illegible] *Electricity End Use, Energy Efficiency, and Distributed Energy Resources Baseline* [illegible]

[illegible]

[illegible]

[illegible]

3.2.6 Electricity-Sector Assets, Operations, and Planning

[illegible]

Electricity infrastructure owners' choices on resilience, expansion, and modernization will have implications for achieving the nation's environmental goals, and vice versa. [illegible] *Ensuring Electricity System Reliability, Security, and Resilience* [illegible] in the electricity system's clean, resilient, and flexible characteristics. The same chapter adds that [illegible]

Integrating Energy and Capacity Markets with Clean Policies

In the summer of 2016, the New England Power Pool (NEPOOL) began a stakeholder process designed to explore whether the various environmental policies across member states could be integrated into the regional energy and capacity markets operated by Independent System Operator New England. Known as the Integrating Markets and Public Policy initiative, it has the potential to set an important precedent for how clean policies can be integrated into existing regional markets.

"Our goal at NEPOOL and for the region is to create a competitive market signal to get the states what they need so they don't have to act on their own. If we're successful, the markets on their own will find the most cost-effective means in meeting those state objectives." – NEPOOL Chairman Joel S. Gordon[191]

Following the release of an initial problem statement and guidelines in May 2016, stakeholders were invited to propose ideas at the group's first meeting in August. Proposals offered a wide range of solutions: from a carbon price adder, to a separate "clean-only" auction process called a "Forward Clean Energy Market," to strengthening the Regional Greenhouse Gas Initiative. Some proposals recommended price adjustments in the energy markets, while others offered modifications to the capacity markets.

[illegible] *Ensuring Electricity System Reliability, Security, and Resilience* [illegible]

[illegible] *Ensuring Electricity Reliability, Security, and Resilience*[illegible]

[illegible]

[illegible]

[illegible]

[illegible] *The Electricity Sector: Maximizing Economic Value and Consumer Equity* [illegible] "will need to [illegible] they have in the past." [illegible] states' different policy objectives and generation portfolios. Many states have [illegible] of energy a utility sells and the revenue that it collects, increasing the utility's acceptance of energy [illegible] ±alue of solar tariffs, for example, intend to "associate a quantifiable benefit with each kWh of distributed solar exported to the grid" [illegible]

3.3 Multiple Paths Forward for CO_2 Emissions Reductions from the Electricity Sector

[illegible]

[illegible]

[illegible]

The President's “[illegible]” [illegible] when implemented, will further the goals of the President's “Climate Action Plan” by cont[illegible]

[illegible]

3.3.1 A Record of Environmental Policy Successes

[illegible]

[illegible]

[illegible]

On February 9, 2016, the Supreme Court stayed implementation of the CPP pending judicial review. The Court's decision was [illegible] to work to cut carbon pollution from power plants and seek the Agency's guidance and assistance.

[illegible] In addition, the United States is the world's largest producer and consumer of [illegible]

3.3.2 A Record of Clean Energy Technology Successes

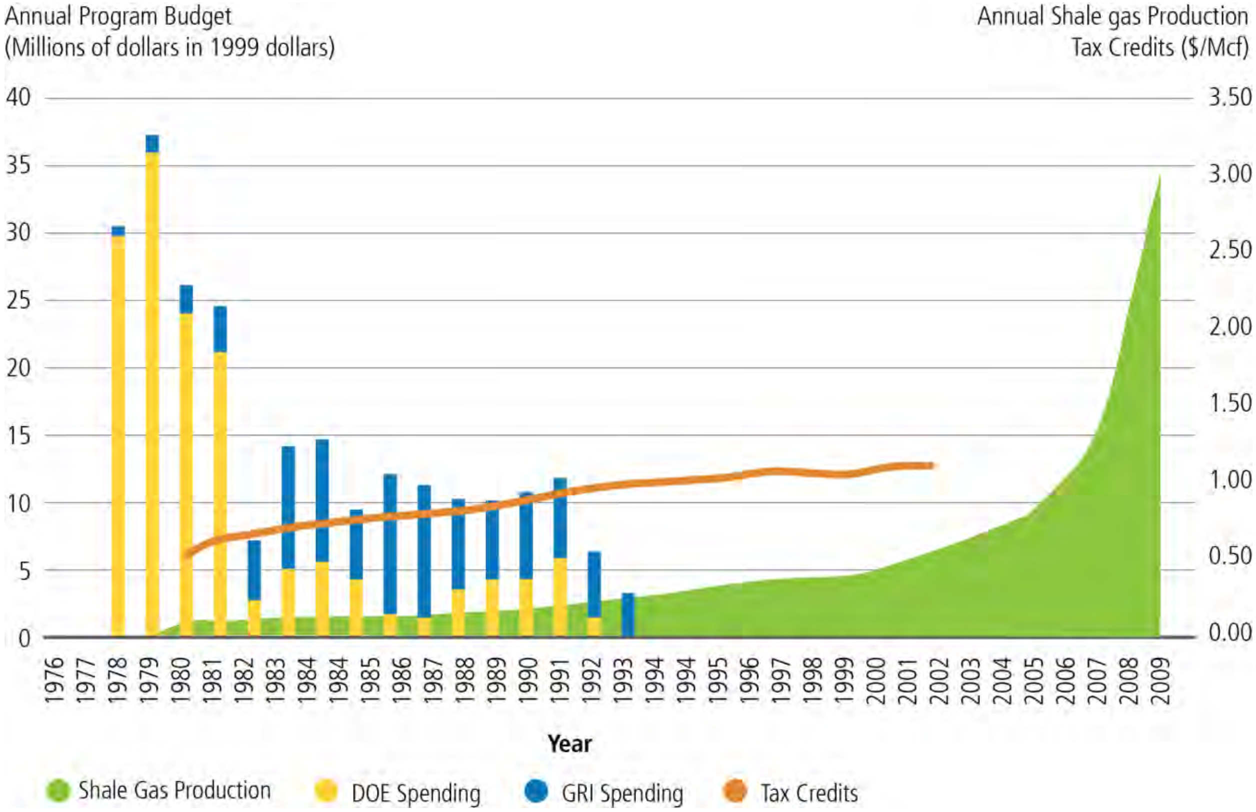
[illegible] RD&D in the world. The Federal Government's long standing [illegible] on the Nation's electric infrastructure for decades through the present day.

Shale Gas Research, Development, and Demonstration (RD&D) and Time-Limited Tax Credit

Early Federal shale gas RD&D funding, primarily for basin characterization and key drilling technologies, combined with a public-private partnership and a time-limited Federal Production Tax Credit, resulted in a sharp increase of shale gas in the mid-2000s (Figure 3-14). Today, shale gas is around 60 percent of total U.S. natural gas production. The interplay of early Department of Energy funding, industry-matched Gas Research Institute applied RD&D, and synergistic policy incentives enabled production from shales previously considered uneconomic. The switch from coal and petroleum power generation to less-carbon-intensive and more efficient combined-cycle natural gas generation resulted in over 1.2 billion metric tons of CO_2 emissions reductions from 2005 to 2014.[218]

[illegible]

Figure 3-14. Steady RD&D Funding and Time-Limited Tax Credit Led to Increase in U.S. Shale Gas Production (1976–2009).[219]

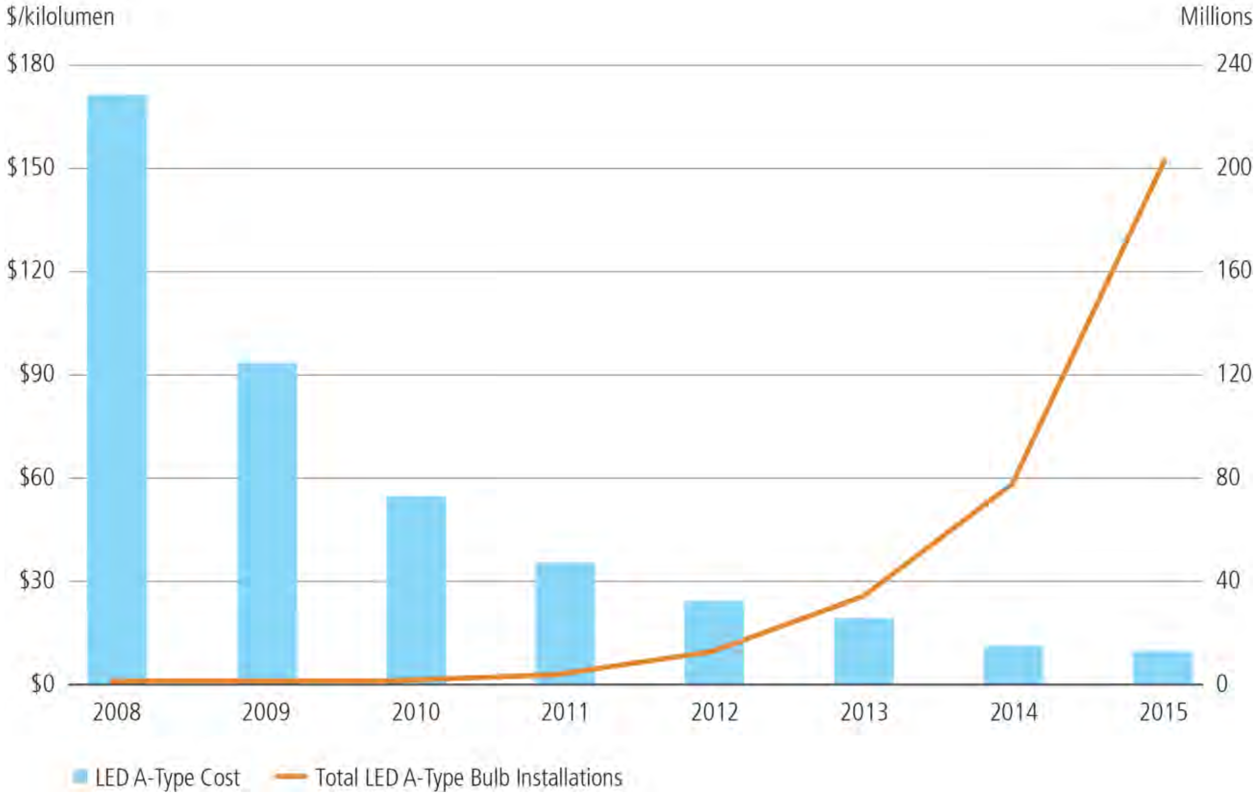


Federal funding, time-limited tax credits, and Gas Research Institute (GRI) funding led to a significant increase in gas production, starting in the mid-2000s.

Light-Emitting Diodes (LEDs) Research, Development, and Demonstration (RD&D) and Lighting Efficiency Standards

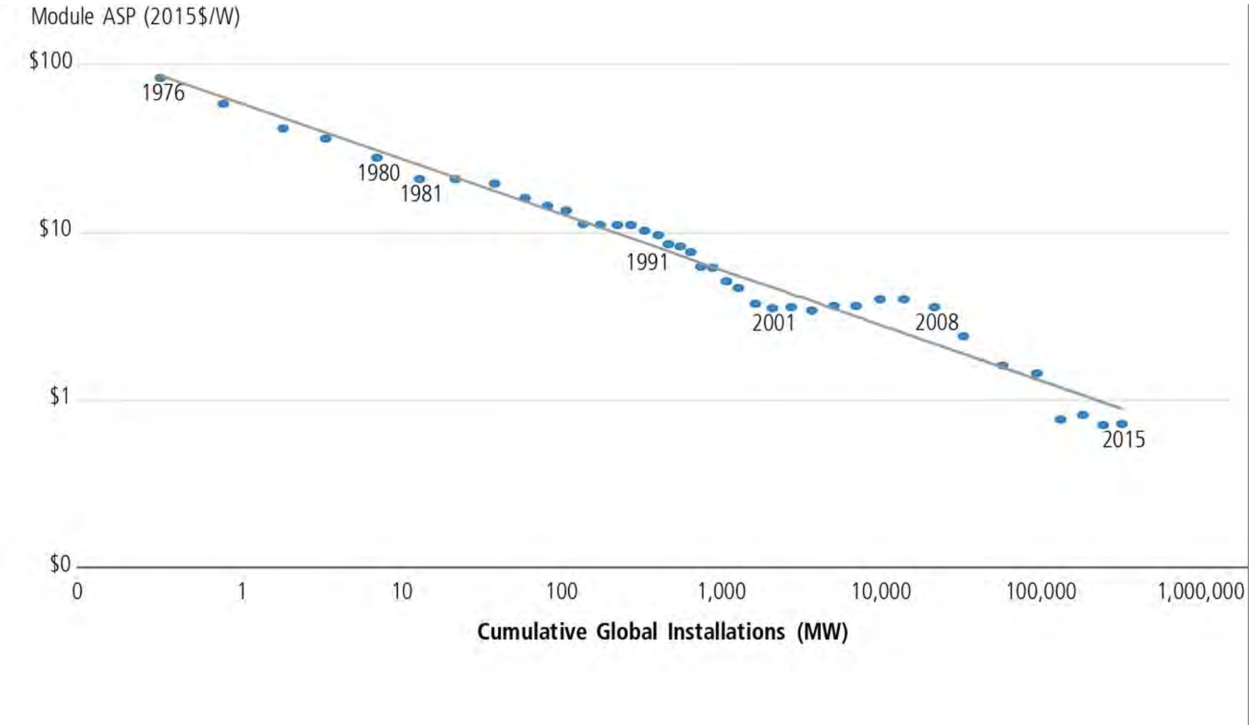
Federal and private-sector RD&D investments directly brought down LED costs, improved efficiency and performance, and fostered domestic manufacturing of LED lighting components and products.[220] Since the Department of Energy (DOE) began funding solid-state lighting research projects in 2000, large and small businesses, universities, and National Laboratories that received DOE funds have applied for more than 260 patents and developed more than 220 commercially available products in this technology area, including lighting products, power supplies, materials, and manufacturing tools.[221, 222] In 2007, Federal legislation set minimum operating life and energy efficiency standards for a majority of light sources used by the public, and relied heavily on technology innovation for manufacturers to meet those standards. The same legislation also mandated an efficient lighting competition, the “L Prize,” that provided cash prizes and Federal Government purchase contracts for winning products. The combination of national lighting standards and lighting technology innovation investments and incentives has contributed to a rapid decline in LED product costs and a corresponding increase in LED sales (Figure 3-15).

Figure 3-15. LED Costs and Installations, 2008–2015[223]



LED bulbs now account for 6 percent of all installed A-type bulbs, which are common in household applications. This growth has been enabled by a 94 percent reduction in cost since 2008. In 1 year, total installations of common home LED bulbs more than doubled from 77 million to 202 million—a particularly rapid growth considering there used to be fewer than 400,000 installations as recently as 2009. Across all LED product types, LED installations prevented 13.8 million metric tons of CO_2 emissions and saved $2.8 billion in energy costs in 2015 alone.

Figure 3-16. Long-Term Solar PV Cost Decline and Global Deployment Growth, 1976–2015[224, 225, 226, 227, 228]



This experience curve displays the relationship, in logarithmic form, between the average selling price (ASP) of a PV module and the cumulative global shipments of PV modules. Average module prices have dropped by about a factor of 100 since 1976 to under $1/watt (W), while cumulative module shipments have increased from less than 1 MW to over 200 GW. For every doubling of cumulative PV shipments, there is, on average, a corresponding reduction of about 20 percent in PV module price. Acronyms: watt-peak (Wp); megawatt-peak (MWp).

3.3.3 Market-Based Carbon Policies

[illegible]

[illegible] are estimated "to save 76.1 million Btu of fossil fuels and 20.6 million MWh of electricity" [illegible] GHG emissions to 1990 levels by 2020. One component of California's program is a statewide GHG cap-[illegible] California's program is linked to Quebec's program [illegible]

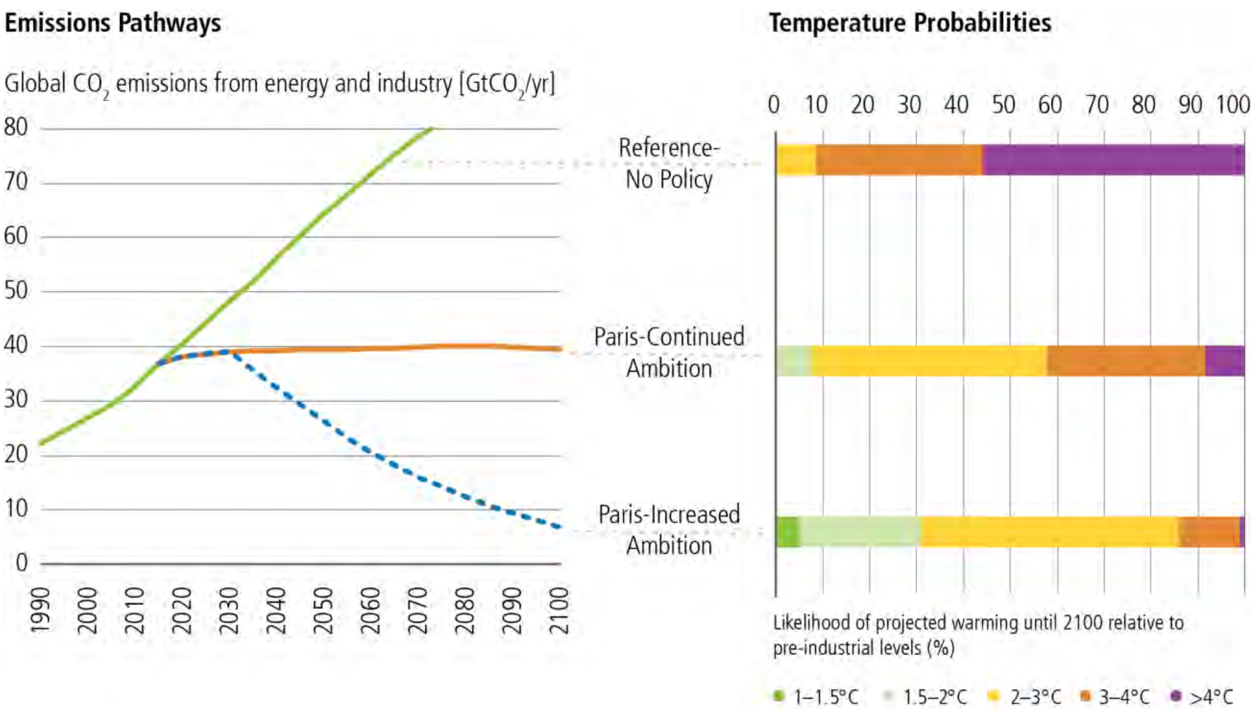
[illegible]

3.3.4 Addressing Climate Change, Growing the Economy through Innovation

Climate change is one of the world's major challenges. The 17 warmest years on record have [illegible]

[illegible]

Figure 3-17. Global CO_2 Emissions (*left*) and Probabilistic Temperature Outcomes (*right*) of United Nations Framework Convention on Climate Change's 21st Session of the Conference of the Parties in Paris in December 2015 (COP 21), 1990–2100[239]



Implementing the 21st Conference of Parties pledges could significantly reduce the chances of a level of warming greater than 4 degrees Celsius by 2100 (as seen under the Paris-Continued Ambition scenario). However, to decrease the likelihood of projected warming above 2 degrees Celsius, additional actions are required (as seen under the Paris-Increased Ambition scenario).

[illegible]

[illegible]

[illegible] years that “represent a progression” beyond their current NDC [illegible]

[illegible] beyond the previously announced “economy [illegible]

[illegible]

3.3.5 Realizing Future GHG Reductions: DOE Integrated Modeling Assessment

[illegible]

[illegible]

[illegible]

[illegible] DOE’s EPSA. This analysis was commissioned by EPSA and uses a version of NEMS that differs from the one used by the Energy [illegible]

Table 3-3. Summary of DOE QER Analysis Cases using EPSA-NEMS[249, 250]

Case	Description
Base Case	Based on the "Annual Energy Outlook 2015" High Oil and Gas Resource Case, with (1) updated cost and performance estimates for CCUS, solar, and wind, and (2) adjustments to incorporate all existing U.S. policies that were final at the time of this analysis, the most recent of which were the CPP and the December 2015 extension of the Federal Renewable PTC and ITC.[jj]
CCUS Incentives Analysis	A variation of the Base Case where the DOE RDD&D program goals for CCUS technologies are achieved. Two potential CCUS incentives are considered: • CCUS incentives in the Administration's fiscal year 2017 budget proposal, including a refundable sequestration tax credit of $10/metric ton CO_2 for EOR storage and $50/metric ton CO_2 for saline storage, and a refundable 30 percent ITC for carbon capture and storage equipment and infrastructure • A hypothetical revision of the Section 45Q sequestration tax credits[kk] to provide a credit of $35/metric ton CO_2 for EOR storage and $50/metric ton CO_2 for saline storage.
Advanced Technology	Current DOE energy program goals (including cost, performance, and deployment goals) overlaid on top of the Base Case.
Stretch Technology	More ambitious RDD&D program goals (including cost and performance goals) overlaid on top of the Advanced Technology Case, based on an assumption of additional RDD&D, such as what could be enabled by Mission Innovation (which will be discussed in Section 3.3.7).
Carbon Price (CP 10)	As a proxy for additional policy action, an initial carbon price of $10/metric ton of CO_2, starting in 2017 and rising at 5 percent per year in real dollars, was overlaid on top of the Base Case, Advanced Technology Case, and Stretch Technology Case.
Side Cases	The Base, Advanced Technology, and Carbon Price (CP 10) Cases were also modeled using the "Annual Energy Outlook 2015" Reference case assumptions instead of the High Oil and Gas Resource assumptions—the "Annual Energy Outlook" Reference case has lower resources (higher natural gas and oil prices). All other inputs explained above stayed the same.

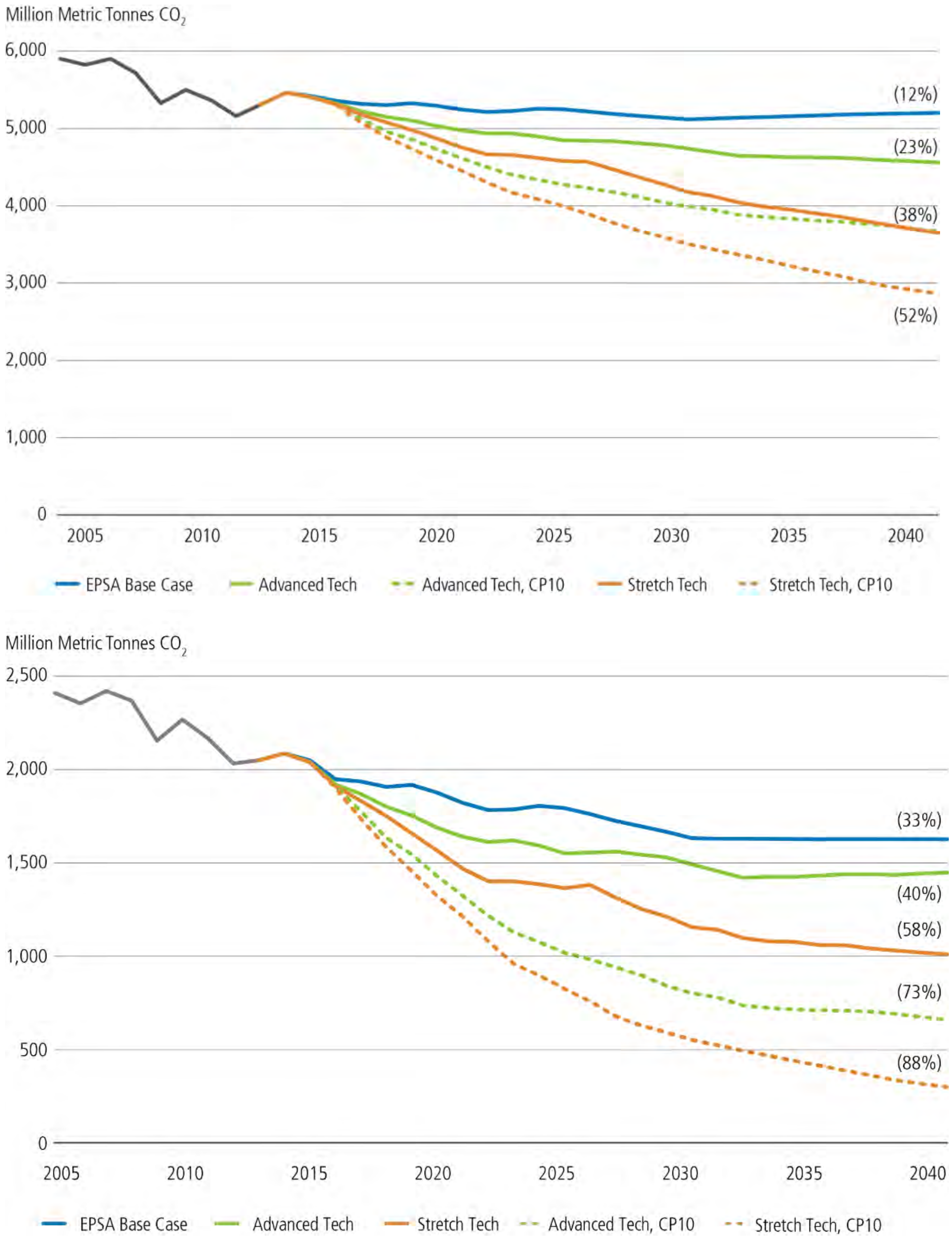
Table 3-3 summarizes the technology and policy assumptions underlying several illustrative analysis cases that DOE constructed to explore how the electric power sector can contribute to U.S. mitigation efforts for climate change.

[illegible]

jj [illegible]

kk [illegible]

Figure 3-18. U.S. Energy CO_2 Emissions, 2005–2040 (*top*), and U.S. Electricity-Sector CO_2 Emissions, 2005–2040 (*bottom*)[251]



Top: Projections of energy CO_2 emissions are shown for several cases along with the corresponding percent decrease in CO_2 emissions relative to a 2005 baseline. These results indicate that successful clean energy RDD&D can drive significant emissions reductions beyond those projected under the EPSA Base Case (which incorporates all existing policies but assumes no new policies). Current levels of RDD&D investment in clean energy technologies (Advanced Technology) can double the projected emissions reductions by 2040, while more ambitious advancements in clean energy technologies (Stretch Technology) could triple the emissions reductions by 2040. These results also indicate that a combination of policy "pull" and technology "push" can achieve much greater reductions than policy or technology alone. Additional technology and/or policies beyond what was modeled are needed to obtain energy CO_2 emissions reductions that are consistent with goals of deep decarbonization.

Bottom: Projections of CO_2 emissions associated with electricity generation are shown for several cases. The sharp reductions projected in the near future can be largely attributed to a cleaner electricity generation mix as more high-carbon generation is offset by a variety of low- and zero-carbon generation sources. Reductions in electricity demand, primarily from more efficient building shells and equipment, and faster adoption at lower cost of more efficient building technologies, also play a major role in driving down electricity-sector CO_2 emissions throughout the analysis. Altogether, these analysis cases show that successful, clean energy RDD&D can drive emissions reductions beyond what is achieved with current policies, measures, and projections for technology advances. In addition, there are multiple pathways to achieving even greater reductions in CO_2 emissions associated with electricity generation through additional technology and/or policies.

[illegible] The analysis considered tax incentives proposed in the Administration's [illegible] ("CCUS Incentives Analysis") [illegible]

Table 3-4. Percent of Utility-Scale Generation by Fuel Source, 2015, and Projected to 2040 for Selected Cases[253, 254]

	2015	2040			
Fuel Type	**Base Case**	**Base Case**	**Advanced Technology**	**Carbon Price (CP 10)**	**CCUS Incentives Analysis**
Coal without CCUS	39%	18%–28%	23%–31%	4%–14%	19%
Coal with CCUS	0%	<1%	<1%	<1%	3%–4%[a]
Natural Gas without CCUS	27%	21%–42%	11%–28%	13%–31%	37%–38%
Natural Gas with CCUS	0%	0%	0%	1%–2%	2%–3%[a]
Conventional Hydropower	7%	6%–7%	7%	7%–8%	6%
Non-Hydro Renewables	7%	17%–25%	26%–30%	36%–38%	14%
Nuclear Power	20%	17%–19%	15%–20%	21%–28%	17%

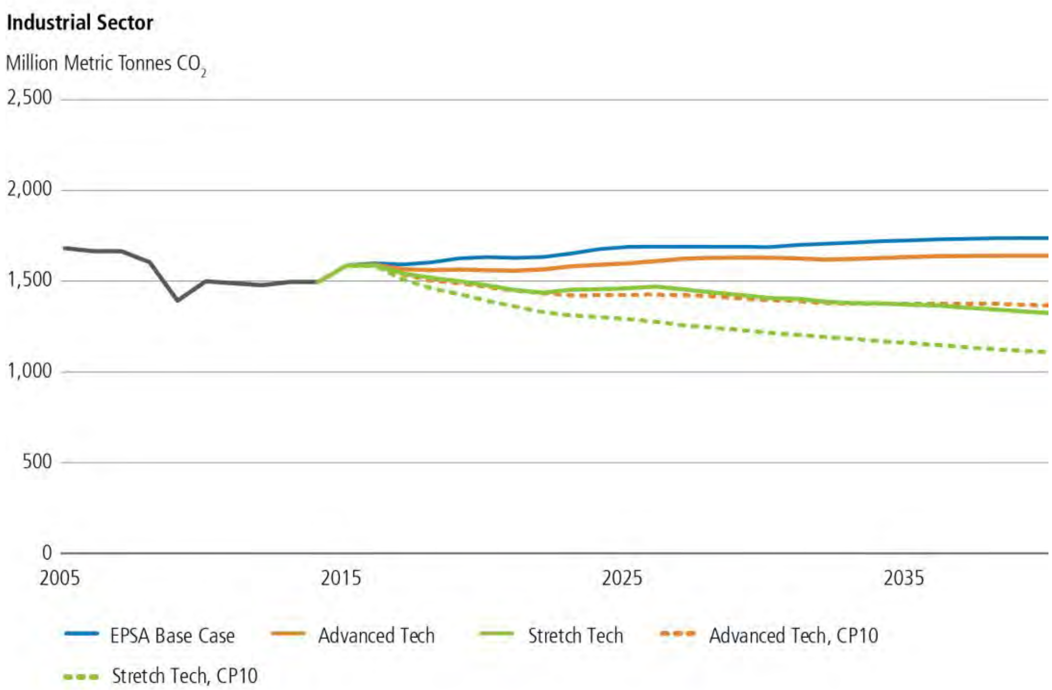
[a] Incremental to generation without CCUS.

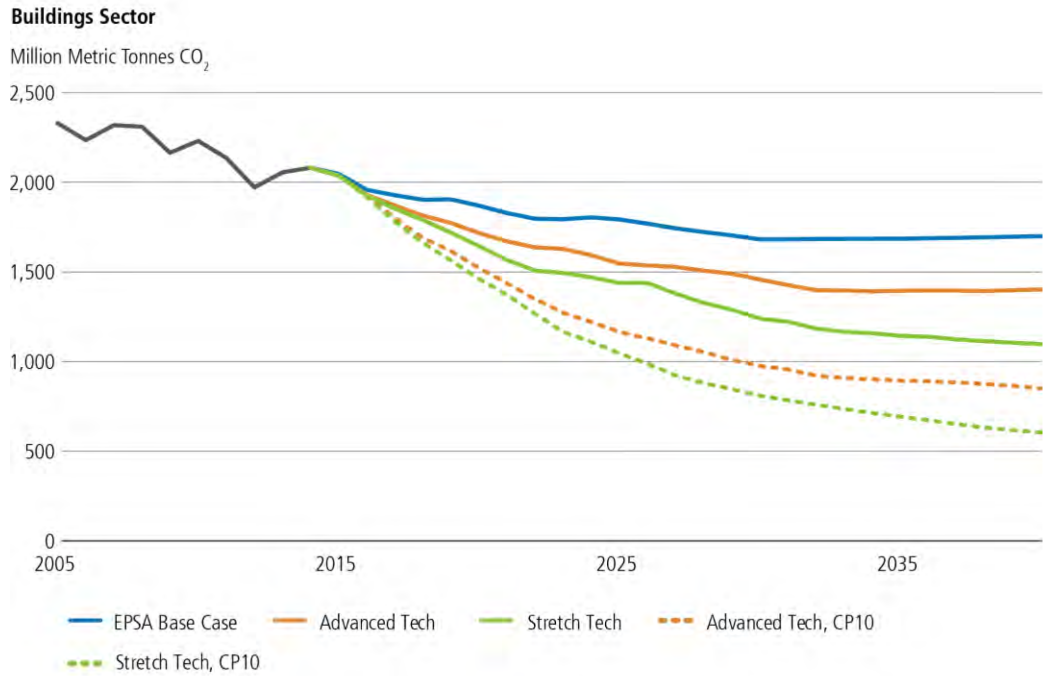
The range in percentages shown in 2040 in the Base Case and Advanced Technology Case highlights the significant impact that future natural gas prices will have on the modeled U.S. electric power generation mix. Similarly, the incentives included in the CCUS Incentives Analysis illustrate the potential to increase penetration of CCUS technologies with additional incentives.

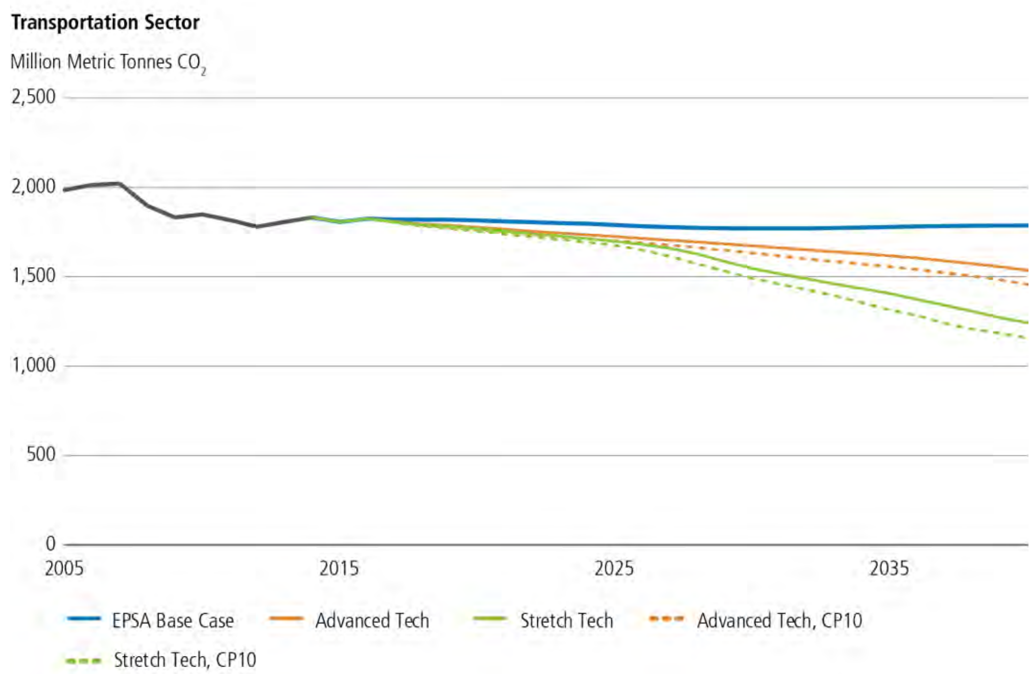
[illegible]

[illegible]

Figure 3-19. Total Direct and Indirect CO_2 Emissions by End-Use Sector, 2005–2040[256]



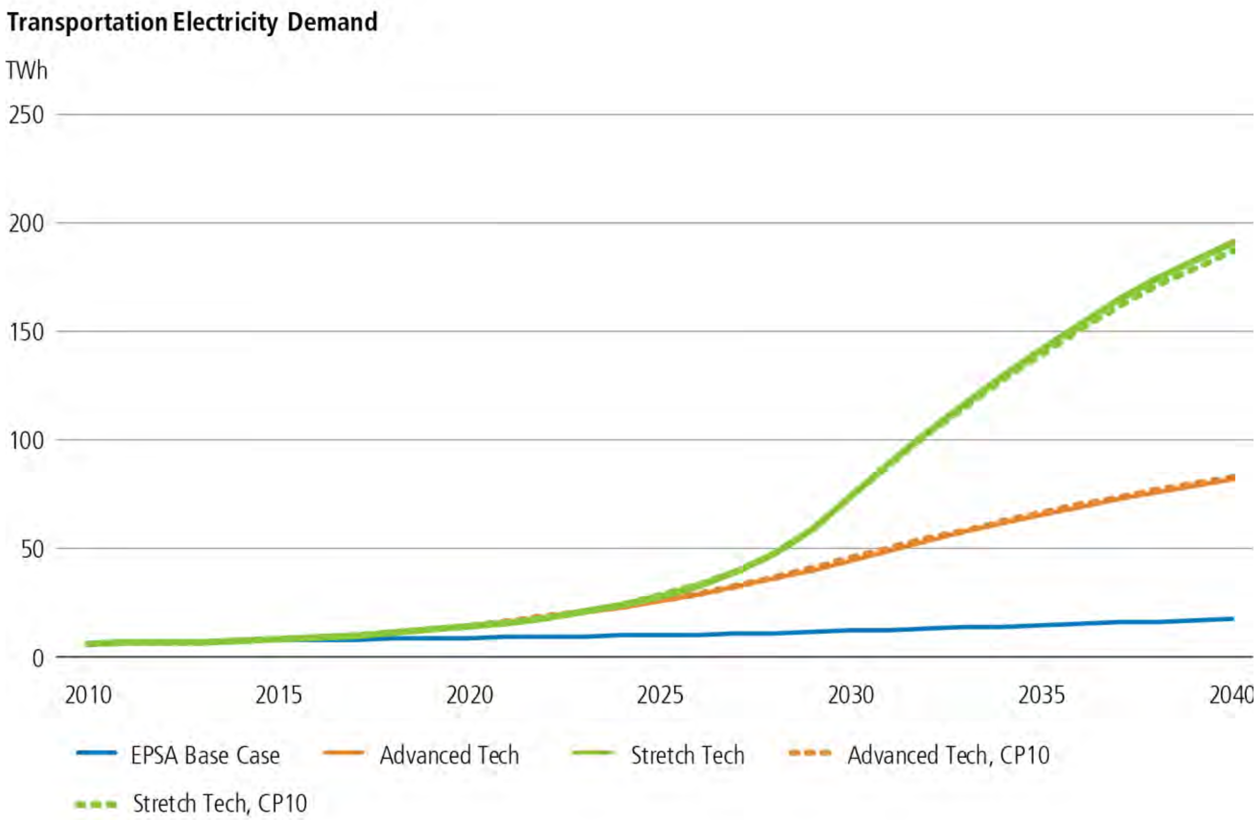




This figure shows the projected impact of technology and policy assumptions on total CO_2 emissions from the industrial (*top*), buildings (*middle*), and transportation (*bottom*) sectors, including emissions associated with both (1) direct fuel use (direct emissions) and (2) electricity generation allocated to end-use sectors based on their electricity use (indirect emissions). Successful clean energy RDD&D is projected to reduce end-use CO2 emissions by accelerating the transition towards a cleaner electricity generation mix and the adoption of cleaner and more efficient technologies. Both efficiency improvements (especially in energy-intensive industries) and additional policy can drive significant emissions reductions in industry and buildings. Technology advances can have a significant impact in the transportation sector, but the modest carbon price proxy does not dramatically reduce transportation emissions.

[illegible] *decrease* [illegible]

Figure 3-20. Electricity Demand by the Transportation Sector, 2005–2040[257]



The DOE scenarios all project a small but growing shift towards electrification in the transportation sector. In the Advanced Technology and Stretch Technology Cases, advances in RDD&D lead to increased market penetration of alternative vehicles, including battery electric and fuel cell light-duty vehicles. In 2040, battery electric vehicles and hydrogen fuel cell vehicles comprise 18 percent of new light-duty vehicle sales in the Advanced Technology Case and 40 percent of new light-duty vehicle sales in the Stretch Technology Case.

[illegible] each sector's [illegible]

3.3.6 Need for Accelerated Innovation in the Electricity-Sector

[illegible]

The Advanced Research Projects Agency–Energy (ARPA-E) Program and Electricity Innovation

The Department of Energy's ARPA-E funds technically innovative, high-risk, high-potential energy projects that are too early for private-sector investment but could significantly advance how the Nation generates, stores, distributes, and uses energy.[285] ARPA-E competitively supports innovative ideas with the specific purpose of advancing them from early-stage concept to application prototype. One of the Mission Innovation goals that ARPA-E supports is to deliver more investment-ready, innovative energy technologies for private-sector investors and industry to commercialize. To date, 45 ARPA-E projects have attracted more than $1.25 billion in private-sector follow-on funding to support commercial development.

There is significant opportunity for accelerating the development of more innovative project concepts based on the number of applications for ARPA-E projects. On average, ARPA-E is only able to fund 10 percent of the proposals for its focused solicitations, and only 1.4 percent of the proposals that it receives in its open solicitations.[286]

Many of ARPA-E's programs are directly or indirectly focused on breakthroughs for the electricity sector. For example, the Green Electricity Network Integration program has supported the development and demonstration of new grid optimization technologies such as power flow controllers.[287] By redirecting power away from congested lines, power flow controllers can increase transmission capacity without construction of new assets.[288]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] President's [illegible]

3.3.7 Mission Innovation: Accelerating Clean Electricity Technology RDD&D

[illegible]

[illegible]

[illegible]

- *"Drive down energy costs:* [illegible]
- *Enhance system reliability:* [illegible]
- *Improve energy security:* [illegible]

[illegible]

- *Curb adverse environmental and public health effects:* [illegible]
- *Build economic opportunities:* [illegible]
- *Improve energy access and equity:* [illegible]

[illegible]

- *East Asia and the Pacific:* [illegible]
- *Latin America and the Caribbean:* [illegible]
- *South Asia:* [illegible]
- *Sub-Saharan Africa:* [illegible] d'Ivoire, Kenya, Nigeria, and South Africa.
- *Eastern Europe:* [illegible]
- *Middle East and North Africa:* [illegible]

3.4 Environmental Impacts of Electricity on Air, Water, Land Use, and Local Communities

[illegible]

[illegible]

3.4.1 Air and Water Pollution

[illegible]

[illegible]

[illegible]

Table 3-5. Summary of Physical Impacts of the Most Common Air Pollutants[317, 318, 319, 320]

	Human Health	Crops and Timber	Materials	Visibility	Recreation
NO_x	Chronic obstructive pulmonary disease		Material deterioration		Eutrophication
	Ischemic heart diseaseIHD				
SO_2	Asthma	Damages to forests	Material depreciation		Damages to forests
	Cardiac				
O_3 (ozone)	Chronic asthma	Crop loss Timber loss	Rubber deterioration		Damages to forests and wilderness areas
	Acute-exposure mortality				
	Respiratory problems				
	Acute asthma attacks				
$PM_{2.5}$	Premature death			Loss of visibility	
	Nonfatal heart attacks				
	Hospital admissions				
	Emergency Room visits for asthma, acute bronchitis, upper and lower respiratory symptoms				
$PM_{10-2.5}$	Chronic bronchitis				

Major impacts of air pollution are delineated by sector and pollutant. PM2.5 is particulate matter with a diameter of 2.5 micrometers or less. $PM_{10-2.5}$ is coarse particulate matter with diameter between 10 and 2.5 micrometers.

[illegible]

[illegible]

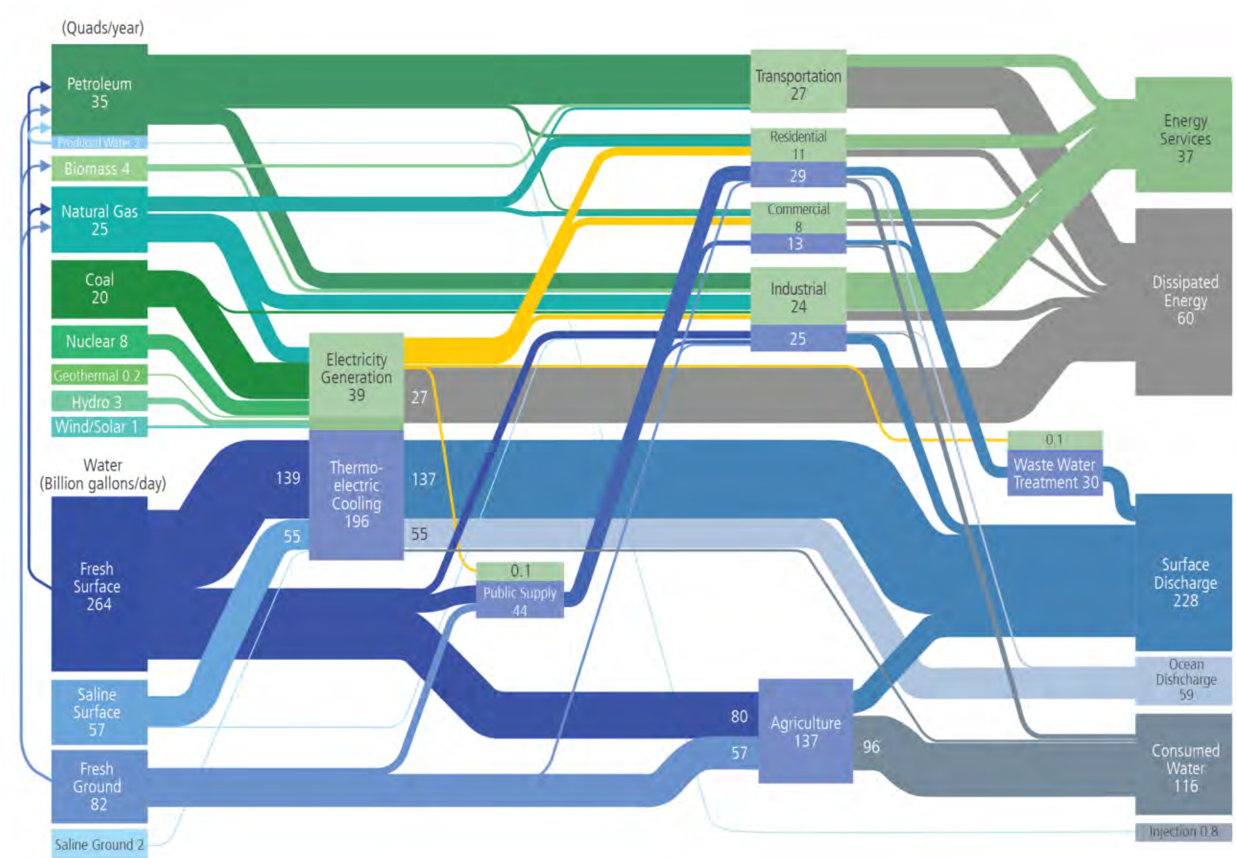
[illegible]

3.4.2 Role of Water in Thermoelectric Power Generation

[illegible]

[22] [illegible]

Figure 3-21. Hybrid Sankey Diagram of 2011 U.S. Interconnected Water and Energy Flows[331]



Significant fractions of surface freshwater withdrawals are for thermoelectric cooling and for agriculture, but agriculture consumes more water than thermoelectric cooling consumes. Most electricity is generated for residential, commercial, and industrial use, but significant fractions are used for public water supply and wastewater treatment. The Sankey diagram aids in visualizing these complex data streams and interconnections as a first step toward further analysis.

[illegible] *withdrawn* [illegible] *consumption* [illegible]

[illegible]

---

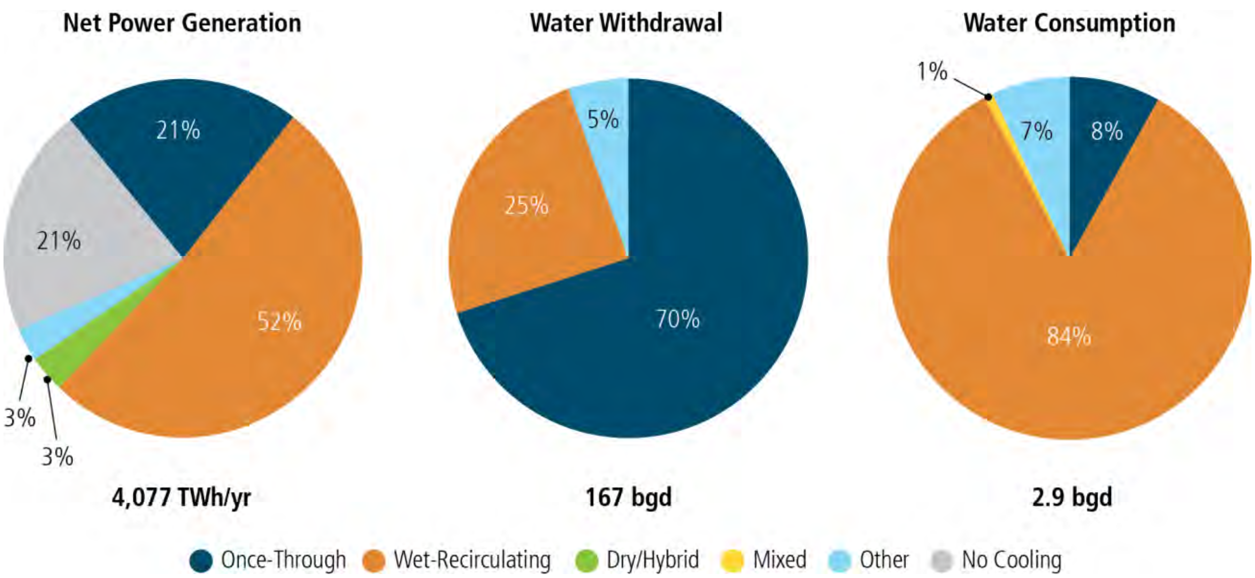
[330] "Withdrawal" designates any water diverted from a surface or groundwater source. "Consumed water" designates [illegible]

[331] [illegible]

[illegible]

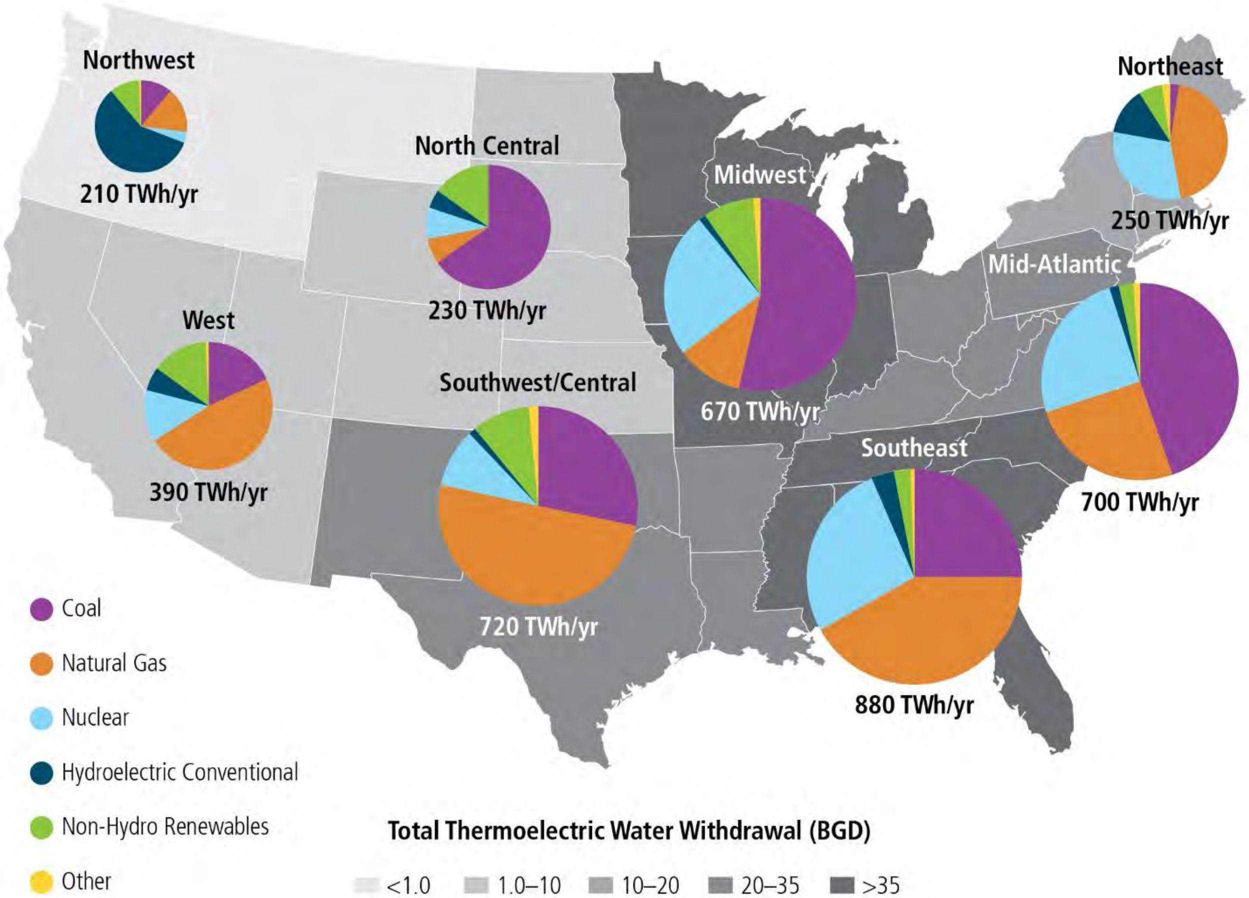
[illegible]

Figure 3-22. U.S. Power Generation, Water Withdrawal, and Water Consumption by Cooling Type, 2015[335, 336, 337, 338]



In 2015, nearly 21 percent of generation used once-through cooling, and 52 percent of generation used wet-recirculating cooling. About 21 percent of the electricity generated—including hydropower, natural gas turbines, and wind turbines—did not require cooling. Water withdrawals for electricity generation totaled 167 billion gallons daily (BGD), the majority of which was withdrawn by once-through cooling. Water consumption totaled 2.9 BGD, with 84 percent of this amount consumed by wet-recirculating cooling.

Figure 3-23. Water Withdrawal and Generation by Region, 2015[339, 340]



The largest water withdrawal regions are dominated by coal and/or nuclear power generation. The area of each pie chart corresponds to total power generation in that region. “Other” includes petroleum, other fossil fuels, pumped storage, non-biogenic municipal solid waste, batteries, and hydrogen. The eight regions shown in the figure are notional, based upon contiguous groupings of states and their generation mixes, resources, and market structures.

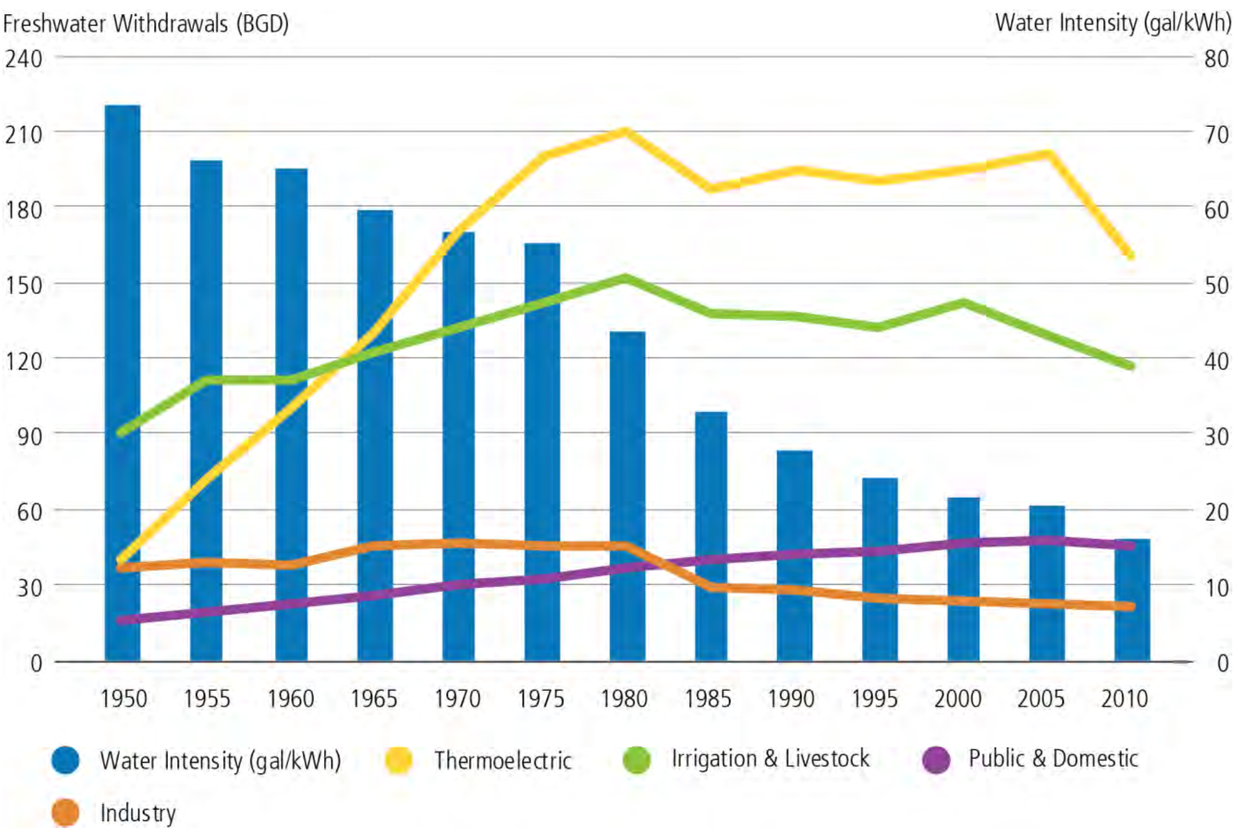
[illegible]

[illegible]

[illegible]

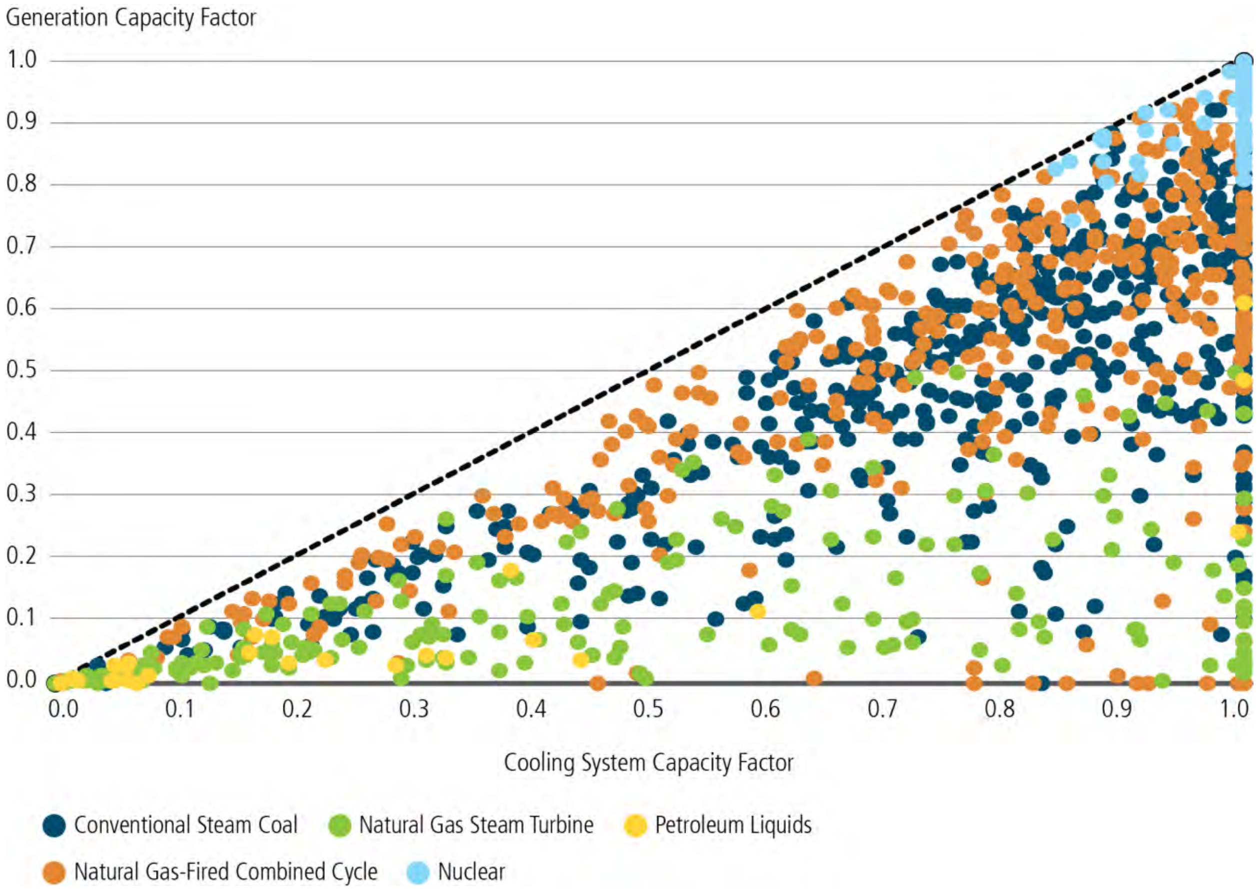
[illegible]

Figure 3-24. Water Withdrawals for Thermoelectric Generation and Other Sectors[343, 344]



The water intensity of thermoelectric generation (represented by bars) has decreased over time. The total amount of water withdrawn by thermoelectric generation (represented by colored lines) has increased significantly relative to other sectors, but it is now declining.

Figure 3-25. 2015 Cooling System Capacity Factors vs. Generation Capacity Factors[345]



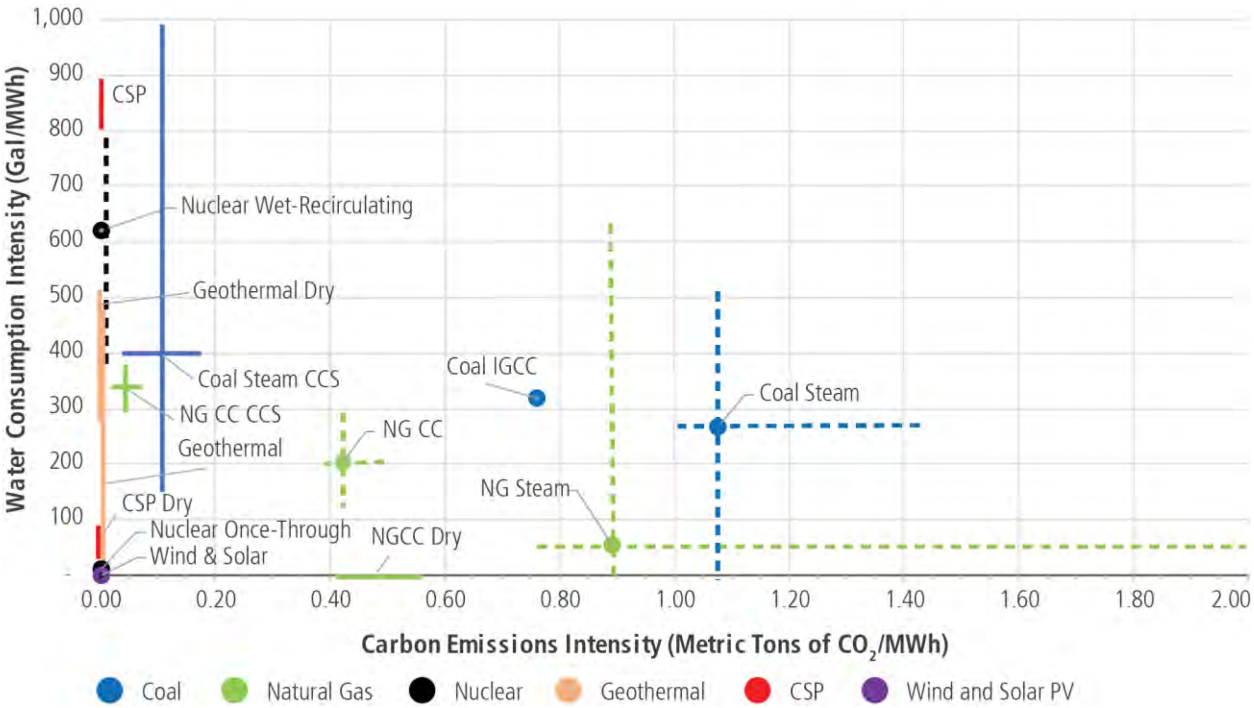
Electricity generators run their cooling systems with varying capacity factors relative to their generating capacity factors. Natural gas steam turbines (Rankine cycle plants)—many likely acting as peakers—run their cooling systems for a substantial amount of time when they are not generating, as do a number of NGCC plants. Plants on the dotted line run their cooling systems with the same capacity factor as their power generation capacity factor (i.e., only when they are generating). Plants that are dispatched primarily during times of peak electricity demand are considered peaking plants and will generally have lower power generation capacity factors. Plants used for baseload electricity will generally have higher power generation capacity factors.

3.4.3 Low-Carbon Generation and Water

[illegible]

[illegible]

Figure 3-26. Carbon Emissions and Water Consumption Intensity Tradeoffs[348, 349, 350, 351, 352, 353]



Some generation technologies (e.g., solar PV and wind) can have both low water and carbon intensities while other generation technologies present tradeoffs between water and carbon emissions. For example, low-carbon technologies, such as nuclear, geothermal, and CSP generation, along with carbon capture and storage (CCS), require large amounts of water. Conversely, dry cooling, which greatly reduces water requirements for thermoelectric cooling, often induces an efficiency penalty, which increases the carbon intensity of generation. Dotted lines represent ranges calculated from data, and solid lines represent ranges from literature values.

[illegible]

3.4.4 Land-Use and Ecological Impacts of the Electricity System

[illegible]

3.4.4.1 Land-Use Impacts

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] leakage occur, "[t]he risks to local water resources will [illegible] how quickly and effectively cleanup operations occur." [illegible]

[illegible]

[illegible]

[illegible]

[illegible] bation's projected 2050 electricity needs. [illegible]

3.4.4.2 Wildlife Impacts

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] issued a "Generic Environmental Impact Statement [illegible]

[illegible]

[illegible] California’s Ivanpah solar thermal facility last year [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] *A Review of Avian Monitoring and Mitigation Information at Existing Utility-Scale Solar Facilities* [illegible]

[illegible] *Indiana Bat: Section 7 and Section 10 Guidance for Wind Energy Projects* [illegible] populations. Changes to the rule “include revisions to permit issuance criteria, compensatory [illegible] “Service Announces Final Rule to [illegible],” Fish and Wildlife Service, [illegible]

[illegible]

3.4.4.3 Waste Impacts

[illegible]

[illegible]

3.4.4.4 Other Ecological Impacts

[illegible]

[illegible] hydroelectric power plants depend on a river's size and flow rate [illegible]

[illegible]

[illegible] of Water Resources," *Fisheries* [illegible]

[illegible]

3.4.4.5 Land-Use and Ecological Impacts of Electricity T&D

[illegible] against transmission lines' benefits. [illegible]

[illegible]

[illegible]

[illegible]

3.4.4.6 Mitigation of Environmental Impacts

[illegible] depending on the implications of the proposed facility's proximity to [illegible]

[illegible]

Mitigating Environmental Impacts[402]

- Mitigation is an important mechanism for agencies to use to avoid, minimize, rectify, reduce, or compensate the adverse environmental impacts associated with their activities.[403, 404] Federal agencies typically rely upon mitigation to reduce environmental impacts through modification of proposed actions and consideration and development of mitigation alternatives during the National Environmental Policy Act process.[xx]
- Mitigation is important to Federal agencies managing public lands, which impose a responsibility to sustain an array of resources, values, and functions. For example, public lands contain important wildlife habitat and vegetative communities—in addition to recreational opportunities and ecosystem services, cultural resources, and special status species. These lands are managed for the use and enjoyment of present and future generations. The location, construction, and maintenance of energy infrastructure should avoid, minimize, and, in some cases, compensate for impacts to these public resources, values, and functions. Mitigation is of critical importance to agencies responsible for protecting the Nation's waters.[405] Applying this mitigation hierarchy early in transmission and distribution infrastructure planning provides better outcomes for the impacted resources, values, and functions.[406]
- Resource-specific mitigation measures can be applied to avoid or minimize impacts from a pipeline or an electric transmission project. In order to identify and implement appropriate mitigation measures, first the potential impacts of a project on a specific resource must be assessed. Then, project-specific and site-specific factors must be evaluated to determine whether the impact can be avoided or mitigated, what action can be taken, how effective the mitigation measure will be, and the cost effectiveness of the measure.

3.4.4.7 Mitigating Impacts through Siting and Permitting of Electricity Infrastructure

[illegible]

[illegible]

[xx] The Council on Environmental Quality's NEPA regulations [illegible]

[illegible]

[illegible]

3.4.5 Federal and State Initiatives to Modernize Permitting and Review Processes

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]

Table 3-6. Federal and Sub-National Initiatives to Modernize Electric Infrastructure Permitting and Review Processes[413]

Initiative Title	Description (Scope and Specific Focus Areas)
Facilitate Better Coordination between Permitting Authorities, Increase Transparency	
Establishing an Implementation Plan to Modernize Permitting	National; Federal plan includes four strategies, 15 reforms, and nearly 100 near-term and long-term milestones, established by Presidential Memorandum
Improving Performance of Federal Permitting and Review of Infrastructure Projects	National; Executive Order 13604 to improve the efficiency and transparency of permitting and review processes for infrastructure projects while producing measurably better outcomes for communities and the environment
Transforming the Nation's Electric Grid through Improved Siting, Permitting, and Review	National; developing an integrated interagency pre-application process for significant onshore electric transmission projects requiring Federal approval, identifying and designating energy corridor
Creating a Permitting Dashboard	National; online database to track the status of Federal environmental reviews and authorizations for projects covered under Title 41 of the Fixing America's Surface Transportation Act
Establishing an Interagency Rapid Response Team for Transmission	National; improve Federal interagency coordination, tribal consultation, and conflict resolution for challenging transmission projects
The Western Governors Association Regulatory and Permitting Information Desktop Toolkit	Western United States; includes wiki platform for stakeholder and agency collaboration
Integrated Interagency Pre-application Process	National; DOE final rulemaking to improve project planning process

Initiative Title	Description (Scope and Specific Focus Areas)
Fixing America's Surface Transportation Act	National; Title 41 establishes the Federal Infrastructure Permitting Improvement Steering Council to inventory major infrastructure projects that are subject to NEPA and improve the review process
Publish Information, Data, and Tools	
EPA's NEPAssist	National; web-based mapping tool
Fish and Wildlife Service's Information, Planning, and Conservation Tool	National; help identify endangered and threatened species before beginning project design
Army Corps' Federal Support Toolbox	National; "one-stop shop" online water resources data portal
Eastern Interconnection States Planning Council's Energy Zones Mapping Tool	Eastern United States; includes 273 geographic information system data layers and links to key resources
Energy Zones Mapping Tool for the Eastern Interconnection Planning Collaborative	Eastern United States; mapping clean energy resources and transmission
Western Electricity Coordinating Council Environmental Data Viewer	Western United States; interactive transmission planning tool
Support Infrastructure Planning	
Undertaking landscape- and watershed-level mitigation and conservation planning	National; environmental mitigation and resource protection at the landscape and watershed levels
Speeding infrastructure development through more efficient and effective permitting and environmental review	National; Presidential Memorandum calling for expedited review of priority projects and improved accountability, transparency, and efficiency
Memorandum of Understanding regarding transmission siting on Federal lands	National; aims at reducing approval time and reducing barriers to siting new transmission lines
Designating corridors for pipelines, electric transmission lines, and related infrastructure	Western United States; Energy Policy Act of 2005 Section 386 establishes rights-of-way on Federal land to promote energy development, resolve resource disputes, and reduce congestion
Desert Renewable Energy Conservation Plan	California; Federal and state collaboration on landscape-level plan streamlining renewable development while conserving unique and valuable desert ecosystems
Technology R&D	
Promoting grid modernization, DOE	National; Enhance security capabilities and stakeholder support

A number of federal and regional initiatives are designed to improve the electric infrastructure permitting and review process. Improved coordination not only reduces permitting and review time, but also improves environmental and community outcomes. These initiatives include the facilitation of coordination between authorities and increased transparency, new tools to disseminate information effectively, the support of infrastructure planning, and technology R&D.

3.4.6 Addressing Impacts of Increased Deployment and New Clean Energy Technologies

[illegible]

and ecological impacts in the R&D process for new technologies could avoid most impacts and decrease the need for mitigation.

Improving environmental outcomes from infrastructure siting requires the joint efforts of agencies at all levels of government and the private sector.

Recent Transmission Line Approvals

- **Clean Line Plains & Eastern Project**:[414] In March 2016, Secretary Moniz announced that the Department of Energy (DOE) would participate in the development of the Plains & Eastern Clean Line Project (Clean Line), a major clean energy infrastructure project. The Clean Line project taps abundant, low-cost wind generation resources in the Oklahoma and Texas panhandle regions to deliver up to 4,000 megawatts (MW) of wind power via a 705-mile direct current transmission line—enough energy to power more than 1.5 million homes in the mid-South and Southeast United States.

  The Clean Line project will include a 500-MW converter station in Arkansas that will allow the state to access the low-cost renewable energy supplied from the project. Currently, Arkansas has no utility-scale wind generation facilities and none under construction. Furthermore, as a condition of its participation, DOE required that Clean Line make payments to localities for any otherwise-taxable land and assets that are owned by the Federal Government.

- **Great Northern Transmission Line**:[415] In November 2016, DOE announced the issuance of a Record of Decision and Presidential Permit for the Great Northern Transmission Line. The 224-mile, overhead alternating current transmission line will bring up to 883 MW of hydropower from Manitoba Power in Canada to Grand Rapids, Minnesota, and will deliver wind power generated in North Dakota to Manitoba Power in Canada. The project has the potential to provide enough reliable, affordable, and carbon-free electricity to serve approximately 600,000 residential customers in the Upper Midwest.

- **New England Clean Power Link**:[416] In December 2016, DOE announced the issuance of a Record of Decision and Presidential Permit for the New England Clean Power Link Transmission Line. The 154-mile underground and underwater direct current transmission line will bring up to 1,000 MW of hydropower from Quebec, Canada, to southern Vermont. The project has the potential to provide enough reliable, affordable, and carbon-free electricity to serve approximately 1 million residential customers in New England.

3.4.6.1 Data and Analytical Needs

In general, it is important to have authoritative, unbiased data in order to make informed Federal policy decisions, but this is also important to empower other public- and private-sector entities at all levels to identify cost savings, provide better services, effectively plan for the future, make research and scientific discoveries, etc. DOE has done well to provide relevant electricity data for many years, most notably via the Energy Information Administration. However, attempts to address a host of emerging issues and pursue key policy objectives in the electricity sector have uncovered data issues that are inhibiting such efforts by actors at all levels of government.

Ecological and other environmental impacts, specifically, can be reduced by improving availability, quality, harmonization, standardization, and accessibility of relevant data to inform decision making. Some data sets exist already, including Tethys,[417] a growing compendium of information and data exchanges on the environmental effects of wind and marine renewable energy technologies,[418] and the Wind-Wildlife Impacts Literature Database, a searchable document collection focusing on the impacts to wildlife from a variety of technologies.[419] However, relevant data, if available, can be plagued with quality issues, and there are often spatial and temporal disparities between related data sets that make analysis difficult.

There is a need for additional data and analytical tools on updated life-cycle analysis using consistent methodologies, as well as studies that attempt to monetize external costs[420] associated with land-use requirements and ecological impacts. More research and increased availability of data would improve the transparency of environmental impacts to developers, regulators, and the public, and help inform more effective strategies for mitigating ecological impacts of electricity infrastructure and operations.

Including analysis of land and ecosystems in the R&D process could decrease the need for mitigation. New technologies with no adverse effects on ecosystems would unlock further areas where that technology could be deployed. As the United States and other countries accelerate clean energy innovation through Mission Innovation, including land-use and ecosystem impacts in Mission Innovation could provide a more holistic assessment of the environmental and ecological effects of new clean energy technologies.

3.4.6.2 Multiple Uses for Rights of Way: Repowering and Repurposing Degraded Lands or Brownfields

Electricity infrastructure can be sited at less environmentally sensitive locations, such as Superfund sites, brownfields, landfills, abandoned mining land, or existing transportation and transmission corridors. Through its cataloging of Federal and state tracked contaminated lands, landfills, and mine sites, EPA has identified thousands of potential sites that could potentially ameliorate incremental environmental impacts.[421] Comprehensive land-use planning exercises have also identified areas appropriate for development, such as the California Desert Renewable Energy Conservation Plan and the DOE-BLM Solar Programmatic Environmental Impact Statement. States and Federal agencies could assess the amount of land suitable for multiple simultaneous uses, including the installment of clean energy technologies. Zoning laws could allow multiple land uses as a factor in permitting decisions for clean energy technologies.

3.4.6.3 Programmatic Environmental Planning and Land-Scale Impact Assessments

The trend has been to consider mitigation through programmatic environmental impact statements (PEIS) and landscape scale impact assessment, replacing a more project-orientated focus. A November 2013 Presidential Memorandum outlined further mitigation principles for Federal agencies, including requiring agencies to set a “no net loss” or “net benefit” goal. Subsequent Department of the Interior guidance on landscape-scale mitigation supported examining project impacts by considering the range of the resource in the context of the larger landscape where the project would be built. Landscape-scale strategies consider impacts across ecosystems and administrative boundaries, and give a more comprehensive picture than studies focused narrowly on impacts on a project-by-project basis. This approach is being applied to a variety of major infrastructure development projects, including transmission and other electricity projects. The Fish and Wildlife Service uses landscape-scale analysis to protect the golden eagle, among other species, defining its “no net loss” policy to require every golden eagle killed at a wind plant to be offset by reducing eagle mortality from another source or by increasing eagle productivity.[422]

BLM also conducts PEIS for geothermal explorations or solar energy development in six southwestern states. PEIS evaluate environmental impacts of a variety of individual projects over a long time frame and a large geographic area.[423] Land-use and ecological impacts of energy technologies should be assessed on a larger scale, and the necessary cooperation across jurisdictions should be expanded, especially as impacts on wildlife could be felt far away from the original site of the deployed technology.

3.4.7 Electricity and Environmental Justice

Populations of concern—including low-income communities and some minority and tribal communities—are more vulnerable to the air- and water-quality impacts of the electricity system. These communities are also disproportionately vulnerable and less resilient to the impacts of climate change. These communities may have greater exposures due to their proximity to sources of pollution; may be inherently more sensitive to environmental impacts of pollution due to higher baseline risks, such as poor overall health; and typically have lower capacity to adapt to the impacts of pollution and extreme weather.[424] For example, a greater percentage of minorities and people living below the poverty level live within a 3-mile radius of coal- and oil-fired power plants, compared to the U.S. population overall.[425] Additionally, existing health disparities and other inequities in these communities increase their vulnerability to the health effects of degraded air quality and climate change.[426]

Populations with the greatest sensitivity to the impacts of air pollution from power generation include children, the elderly, African Americans, and women.[427] Several factors make children more sensitive to air quality impacts, including lung development that continues through adolescence, the size of children's airways, their level of physical activity, and body weight. Ground-level ozone and PM are associated with increased asthma episodes and other adverse respiratory effects in children.[428] Minority adults and children bear a disproportionate burden associated with asthma, as measured by emergency hospital visits, lost work and school days, and overall poorer health status.[429]

Environmental justice concerns have been addressed in recent regulatory actions affecting power plant emissions, wastewater discharges, and onsite solid waste impoundment.[430, 431, 432] In many cases, these rulemakings have provided the opportunity to reduce existing disparities in health impacts. For example, the Mercury and Air Toxics Standard requires power plants to limit their emissions of toxic air pollutants like mercury, arsenic, and metals, which disproportionately impact certain communities. In addition, Executive Order 12898 requires Federal agencies to consider environmental justice in regulatory, permitting, and enforcement activities. Also, in developing the CPP, EPA took steps to ensure that vulnerable communities were not disproportionately impacted by the rule and that the rule's benefits, including climate benefits and air quality improvements, were distributed fairly.

The Federal Interagency Working Group on Environmental Justice's "Promising Practices for EJ Methodologies in NEPA Reviews"[433] contains successful ideas across nine areas, from which all Federal agencies can draw to develop their approaches to address environmental justice in the NEPA process:

- Meaningful engagement
- Scoping process
- Defining the affected environment
- Developing and selecting alternatives
- Identifying minority populations
- Identifying low-income populations
- Impacts
- Disproportionately high and adverse impacts
- Mitigation and monitoring.

3.4.8 Decommissioning of Generation Assets

Infrastructure expansion can improve environmental performance by replacing higher-polluting with lower-polluting technologies.[434] Because of their unique environmental concerns, nuclear power plants have strict, mandatory guidelines, payment processes, and monitoring for decommissioning activities, while in general, other generation assets do not. There are multiple ways to improve and expedite end-of-life-cycle processes while also improving environmental and societal outcomes.

Currently, the changing electricity sector is causing the closure of many coal and nuclear plants in a shift from recent trends. From 2000 through 2009, power plant retirements were dominated by natural gas steam turbines. Over the past 6 years (2010–2015), power plant retirements were dominated by coal plants (37 GW), which accounted for over 52 percent of recently retired power plant capacity.[435] Over the next 5 years (between 2016 and 2020), 34.4 GW of summer capacity is planned to be retired, and 79 percent of this planned retirement capacity are coal and natural gas plants (49 percent and 30 percent, respectively). The next largest set of planned retirements are nuclear plants (15 percent).[436yy] A much smaller percentage of planned retirements are diesel combustion and oil steam turbines. These are less prominent in planned retirements, in part because they now represent a much smaller percentage of the Nation's electricity capacity than has historically been the case.

During decommissioning, all plants have waste streams that need to be managed. Coal and nuclear power plants produce the largest amount of solid waste during generation. For coal plants, the most expensive part of decommissioning in many cases will be environmental remediation of the CCR disposal sites.[437] Nuclear waste is stored at the reactor site where it is generated. The lack of a centralized permanent waste disposal facility for nuclear waste means that spent fuel storage facilities require continued management after a plant has been decommissioned. Decommissioning needs will continue to evolve as new generators, especially non-hydro renewables, reach the end of their operating lives in the next 20–30 years. These plants have some unique waste streams, including large volumes of glass and aluminum, large fiberglass blades, and in some cases, rare earth metals; however, there is a high potential for recycling some of these materials, and wind plants often have the opportunity for repowering by upgrading the turbine.

3.4.8.1 Coal

Increases in coal retirements imply a greater need for decommissioning these plants. The coal ash byproduct of conventional coal-fired power plants is the largest quantity of solid waste produced from the generation of electricity.[438] The composition and quantity of this solid waste depends on the type of coal burned, the power conversion technology used, and the addition of environmental controls. Decommissioning needs include (1) data on waste and decommissioning costs; (2) development of coal plant decommissioning procedures; and (3) identification of barriers to waste recycling and options for overcoming these barriers.

3.4.8.2 Nuclear Power

NRC operating licenses for approximately 60 percent of the existing nuclear-power generating units in the United States will expire by 2040. Without further license extensions, these expirations could result in retirements and decommissioning wastes in the coming decades.[439] Nuclear plant owners must provide NRC with detailed decommissioning plans and periodic updates on the status of their decommissioning fund for the nuclear reactors they own.[440] Three of the paramount considerations when developing a decommissioning plan are the radiological contamination, condition, and configuration of the plant. Two decommissioning methods have been used in United States: Safe Enclosure ("SAFSTOR") and Immediate Dismantling ("DECON").[441] In DECON, the plant is immediately dismantled, and the site is prepped for reuse by removing nuclear waste in casks for storage. In SAFSTOR decommissioning, plant dismantling is deferred for about 50 years. There is currently no centralized permanent disposal facility for commercial used nuclear fuel in the United States, so this radioactive material is stored at reactor sites in 35 states awaiting construction of a permanent handling facility.[442]

3.4.8.3 Oil and Gas

Unlike coal plants and nuclear reactors, gas- and oil-fired plants do not generate combustion ash or nuclear waste. The unique solid waste concerns for gas- and oil-fired plants are the byproducts from

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[yy] These totals are based on announced retirements as of October 2016. Pending state action may prevent six nuclear reactors from retiring, and another reactor has since announced it will retire during this timeframe.

emission controls. However, the solid waste from electricity generation is small because of the low adoption rate of these emission controls for gas- and oil-fired plants. These solid wastes are similar to the waste generated by environmental controls placed on the stacks of coal plants, especially for most post-combustion removal technology.

There are three methods for decommissioning an oil or gas plant, considering the conditions of the plants and the total budget: cold closure, selective demolition, or total demolition.[443] The decommissioning of gas and oil power plants creates construction and demolition waste, general refuse, and chemical waste.[444]

Chemical waste that is particular to oil and gas plants includes naturally occurring radioactive materials (NORM). During the oil and gas combustion process, because NORM are not volatile, burning away the carbon leads to higher levels of radioactive waste in scale, sludge, and scrapings of the generator, tanks, and pipelines.[445] Radioactive material can also form a thin film on the interior surfaces of gas processing equipment and vessels. Currently, no Federal regulations exist that specifically address the handling and disposal of NORM wastes. However, several oil-producing states (Texas, Louisiana, New Mexico, North Dakota, and Mississippi) have enacted specific NORM regulations.[446]

3.4.8.4 Hydropower

There are two options for decommissioning a hydropower plant. A partial retirement involves retirement of only the hydroelectric facilities and retains portions of the dam and other structures. Some rehabilitation of the structure for safety or maintenance may be required and can include reduction in height or breach of the dam. In this case, the dam is either reduced or eliminated, while some of the ancillary facilities may remain intact. A full retirement includes the removal of the project and all appurtenant structures, including rehabilitation or restoration of the affected project area. Decommissioning (whether partial or full) generally requires completion of an environmental impact statement, and every dam removal process will have site-specific engineering, environmental, and community issues.

3.4.8.5 Wind

To date, there have not been many wind decommissioning projects. As a result, details of decommissioning wind projects are very limited. In some states, developers are required to have decommissioning process and cost estimates ready with the decommissioning plan. In general, the decommissioning process of a wind plant consists of removing the turbine, destroying the concrete pads, restoring the surface, and replanting and rebuilding the soil of disturbed land. Communication towers are taken apart, removed, and then either disposed of, recycled or reused.[447]

3.4.8.6 Solar PV

Like wind, there have not been many decommissioning projects for solar to date. During decommissioning, PV modules must be removed from racks, and the racks must be dismantled. These are stored temporarily onsite until they are transferred by trucks to appropriate facilities, like recycling sites, or back to the manufacturer. Similarly, inverters and associated components must be transported to an appropriate site per local, state, and Federal waste disposal regulations. Finally, re-vegetation of the site is done to minimize erosion and disruption of vegetation. In the case of one solar farm decommissioning, the recycling value of the raw material for the solar array is expected to exceed the removal costs and provide a net economic benefit.[448]

While there is no industry-wide requirement for solar and wind developers to develop and fund decommissioning plans, BLM does impose decommissioning requirements on Federal lands. BLM requires developers seeking to site renewable generation projects on Federal lands to file a decommissioning plan and post a performance bond to help fund site remediation. The performance bond is intended to cover costs associated with (1) removing hazardous materials, including "herbicide use, petroleum-based fluids, and dust control or soil stabilization materials"; (2) decommissioning, removing, and properly disposing of all "surface facilities," such as panels; and (3) "addressing reclamation, revegetation, restoration, and soil stabilization," such as regrading or vegetation, as required under the Clean Water Act.[449] Thus, solar and wind facilities sited on Federal lands must have a decommissioning plan before they are granted right of way and must post a bond to fund decommissioning.

3.5 Endnotes

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IV Ensuring Electricity System Reliability, Security, and Resilience

This chapter addresses a range of possible risks to the electricity system and the broader economy, and it suggests options to mitigate and prepare for these risks. The first section explores the changing nature of reliability—the ability of the system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components—in the future electricity system. The next section examines existing and growing vulnerabilities for the electricity system and opportunities to address these vulnerabilities, including cybersecurity risks, interdependency of electricity with other critical infrastructures, and increased risk due to worsening global climate change. The final section focuses on enhancing the resilience of the system to minimize disruptions of service and return rapidly to normal operations following adverse events.

Ensuring Reliability, Security, and Resilience: Summary of 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 have 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, which 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, social-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 these events 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 because the two industries are organized and regulated differently.
- As distributed energy resources 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 and flexibility technologies – such as hydropower and storage – offer particularly flexible grid resources that are 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. These resources can be used for load reduction, load shaping, and consumption management 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, as well as 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 they 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."[1]

4.1 Reliability, Resilience, and Security: Grid Management and Transformation

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 flow 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.

The concepts of reliability, security, and resilience are interrelated and considered from different perspectives. Meeting consumer expectations of reliability is a fundamental delivery requirement for electric utilities, where reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent. The utility industry typically manages system reliability through redundancy and risk-management strategies to prevent disruptions from reasonably expected hazards.

Grid Reliability, Security, and Resilience

For purposes of this discussion, *reliability* is the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components. *Resilience* is the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions. *Security* refers specifically to the ability of a system or its components to withstand attacks (including physical and cyber incidents) on its integrity and operations.

Delivery of electricity service has been consistently and highly reliable for most of the century-long development, expansion, and continuous operation of grids across all regions of the Nation. The traditional definition of reliability—based on the frequency, duration, and extent of power outages—may be insufficient to ensure system integrity and available electric power in the face of climate change, natural hazards, physical attacks, cyber threats, and other intentional or accidental damage; the security of the system, particularly cybersecurity, is a growing concern.

Resilience is the ability to prepare for and adapt to changing conditions, as well as the ability to withstand and recover rapidly from disruptions, whether deliberate, accidental, or naturally occurring.[2] While resilience is related to aspects of both reliability and security, it incorporates a dynamic response capability to reduce the magnitude and duration of energy service disruptions under stressful conditions.[3] Infrastructure planning and investment strategies that account for resilience typically broaden the range of risk-reduction options and improve national flexibility through activities both pre- and post-disruption, while also focusing on the electricity-delivery outcomes for the consumer.

U.S. policies, markets, and institutional arrangements must evolve to reflect new electricity system realities and trends—continuing to enable and enhance the reliability, security, and resilience of the electric grid. The Department of Energy (DOE), the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), regional planning authorities, utilities, power system operators, states, and other organizations work together to ensure the reliability of the U.S. power system through the implementation of reliability standards, timely planning and investment, and effective system operations and coordination.

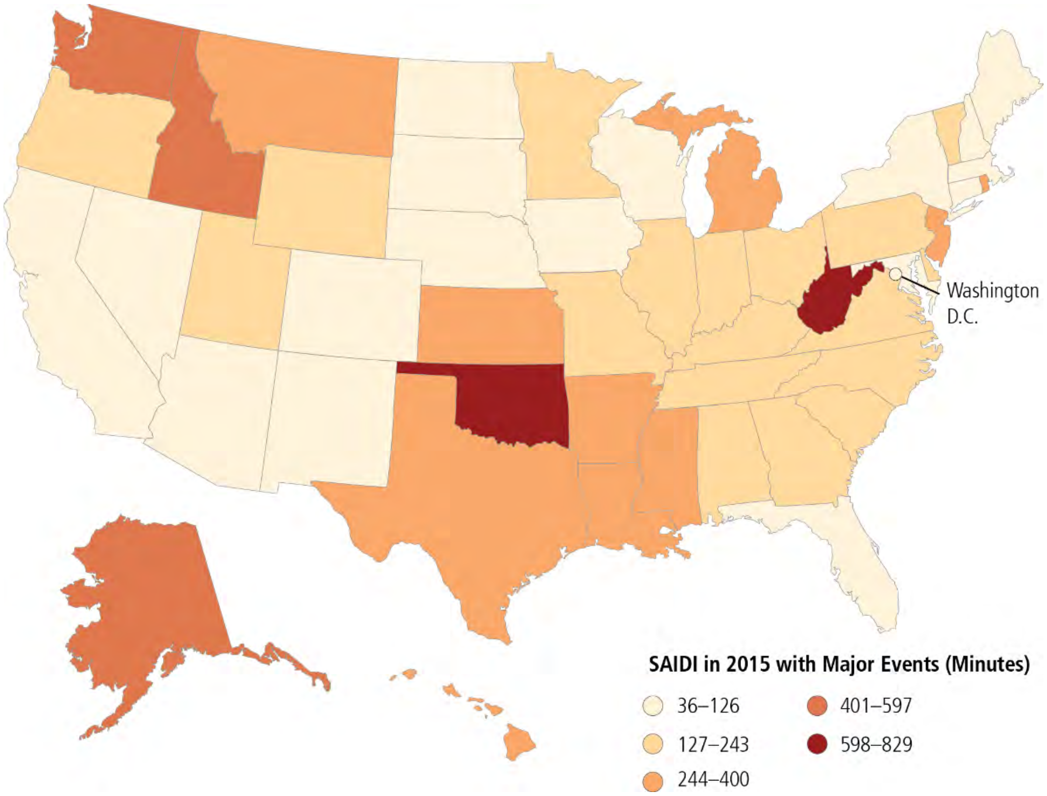
4.2 The Changing Nature of Reliability

Electricity customers have high expectations of electricity reliability from their utility providers. Virtually every sector of the modern U.S. economy depends on electricity—from food production, to banking, to health care. Critical infrastructures like oil, gas, transportation, and water all depend on electricity, and the electric system depends on them. This places a high premium on reliability.

4.2.1 Standard Measures of Reliability

A brief review of how reliability is measured today will help define the playing field and the associated value at stake. From the utility industry perspective, reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent. Reliability within the utility industry is managed to ensure the system operates within limits and avoids instabilities or the growth of disturbances. These practices are not static, and utilities continue to improve their reliability practices and implementation methods to reflect increased consumer expectations. Typical approaches to reliability include hardening, investment, and redundancy to prevent disruptions from reasonably expected hazards.

Figure 4-1. System Average Interruption Duration Index (SAIDI) in 2015 by State[4]



States experienced varying levels of reliability in 2015. A reliable bulk power system does not necessarily mean reliable end-user electricity service because outages often originate on local distribution systems, as reflected in the SAIDI measurements in the above map.

Most state and Federal regulators have significant experience addressing system reliability and currently consider the issues of resilience and security through the lens of existing reliability tools, approaches, and metrics. One metric applied with the goal of improving system performance with respect to reliability indicators is the System Average Interruption Duration Index (SAIDI). SAIDI measures the total duration of an interruption for the average customer given a defined time period. Typically, it is calculated on a monthly or yearly basis. Another metric, the Customer Average Interruption Duration Index (CAIDI), measures how long it takes to restore the system once an outage occurs. And, the System Average Interruption Frequency Index (SAIFI) measures the average number of times that a customer experiences an outage during the year. SAIFI is calculated by dividing SAIDI by CAIDI. As most outages occur on the distribution system rather than the bulk system, these reliability indices are commonly used to measure distribution level reliability. NERC uses a number of bulk power system reliability indices.[5]

Based on these reliability measures, the average customer experiences 198 minutes of electric power unavailability per year,[a, 6] although there is significant variability among states and utility providers. The best-performing state had a SAIDI level of 85 minutes a year. In contrast, as shown in Figure 4-1, one state had a SAIDI statistic in 2015 of nearly 14 hours of outage for the year, with an availability level of 99.84 percent. Even this state level of aggregation masks some outliers in the data. There were several utilities with a SAIDI index below 1 minute of outage for the year.

[a] Analysis is based on 2016 Energy Information Administration (EIA) data. Information reported to EIA is estimated to cover approximately 90 percent of electricity customers.

There are, however, caveats to these findings. First, the variability of reliability performance is a function of a myriad of factors, including regional differences, varying regulatory standards, costs, system configuration, customer density, hazard exposure, and other. Also, utilities have historically reported SAIDI, SAIFI, and CAIDI statistics in inconsistent ways; for example, some utilities include data associated with "major events" in their public reporting to public utilities commissions, while others do not.[7] Utilities also take inconsistent approaches to defining "major events."[8] The lack of uniform national data inhibits more sophisticated analysis of macro trends in distribution reliability—something that is important to remedy in an electricity sector that is increasingly data intensive.

Also, although the predecessor to today's NERC was first formed in 1968 to address system reliability, the Institute of Electrical and Electronics Engineers (IEEE) Standard 1366 only formally defined industry reliability metrics in 1998.[9] The Energy Information Administration (EIA) began collecting distribution-level reliability data, including SAIDI and SAIFI information, in 2013—marking increased attention and effort on the reliability front. Yet, even today, only 33% of utilities report these statistics, covering 91% of the electricity sales in the nation, which indicates that there is room for improving reliability reporting practices.[10]

There are other reliability measures and associated government reporting requirements as well. NERC, for example, collects the additional data it needs to promulgate reliability and security standards, but it does not make all of these data available to government agencies. Beyond reliability, a number of resilience metrics and measures have been proposed; however, there has not been a coordinated industry or government initiative to develop consensus or implement standardized resilience metrics, though the Grid Modernization Laboratory Consortium is launching the Foundational Metrics Analysis project to develop some resilience metrics.[11]

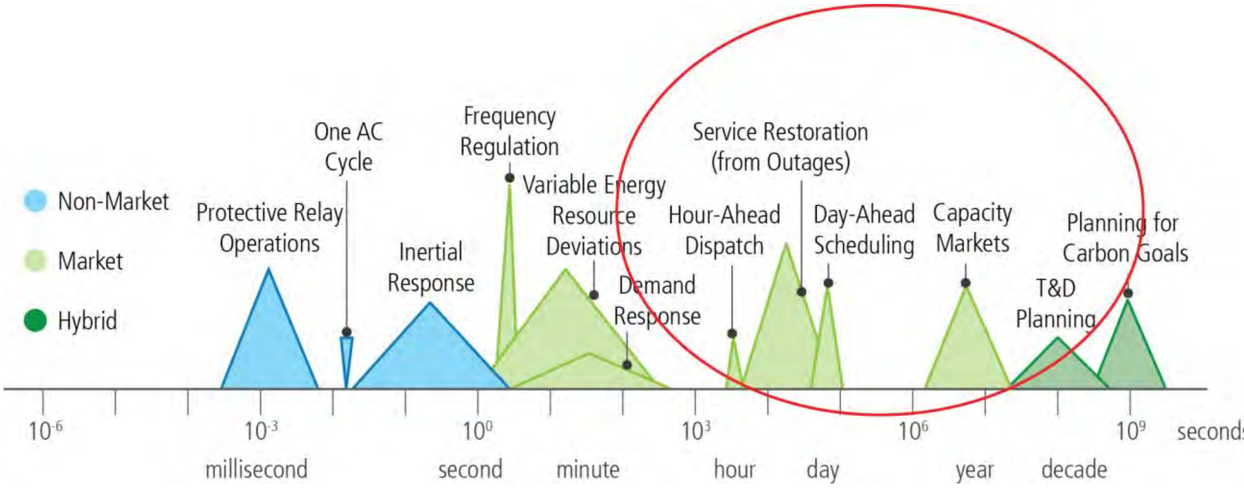
4.2.2 Time Scales and Grid Reliability

Throughout the 20th century, the design of power systems and early metrics (such as the loss of load expectation) focused on periods of maximum consumer electricity use. With more controllable loads, more variable generation, new technologies (such as storage), and the increasing importance of power system reliability, reliability is becoming a more complex concept, and reliability metrics and criteria must evolve accordingly.

Adequacy of generation resources is measured by a utility's reserve margin and has traditionally meant the extent to which utilities have adequate infrastructure to generate electricity to meet customers' needs. Generation reliability criteria is focused on installed generation to meet customer demand; the role of the customer as a system resource was not a consideration.

For vertically integrated systems, grid operators manage the entire electricity supply chain from end (generation) to end (delivery service). When new market structures were created across many U.S. regions in the form of independent system operators (ISOs) or regional transmission organizations (RTOs), end-to-end management was replaced with competing power generators. In these markets, variable generation may be the lowest cost generation; , generation from certain power stations may not be accepted to run because they are not cost competitive for a specific day's operations. However, if a generator is deemed critical to system integrity, power stations can get "reliability must run" payments. These out-of-market payments, in turn, lower power market prices, which has been especially problematic for certain types of generation such as nuclear, which already faces challenges from low power prices due to the relatively low capital, operations, and fuel costs of natural gas-fired generators.

Figure 4-2. System Reliability Depends on Managing Multiple Event Speeds[12]



Markets are used for traditional grid operations, including hour-ahead, day-ahead, and capacity markets. Long-term planning reaches byond typical market and financial signals.

Supply variability[b] is an important part of system operations, where ISOs/RTOs must ensure that risks of unexpected loss or variability of supplies are hedged by having some power plants immediately available (spinning reserves) and other plants able to supply power with short-term notifications of need (non-spinning reserves).

These adjustments to power flow management occur within the general framework of grid operations. This framework has historically been well understood by grid operators because the time dimensions of operations have not changed significantly, even when ISOs/RTOs were given responsibility for transmission system management. These dimensions, which operators have historically understood well, are seen in

[b] As used here, variability refers to the difference between the expected and actual load or generation.

Figure 4-2 on the right side of the continuum, where the time scales of capacity markets, day-ahead, and hour-ahead products are depicted. For out-years beyond capacity contracts, traditional transmission and distribution system planning methods work to map and price investment requirements to ensure long-term grid reliability. Planning for decarbonization and climate resilience reaches beyond typical planning horizons for grid operators.

4.2.2.1 Changing Time Dimensions, Grid Topology, and Emerging Grid Management Challenges

Variable energy resources (VERs) provide a range of benefits to utilities and their customers, including avoided fuel costs, greenhouse gas emissions, and costs associated with environmental compliance.[13, 14] In some cases, distributed VERs are also credited with providing electric reliability and resilience benefits, particularly in the context of microgrids.[15]

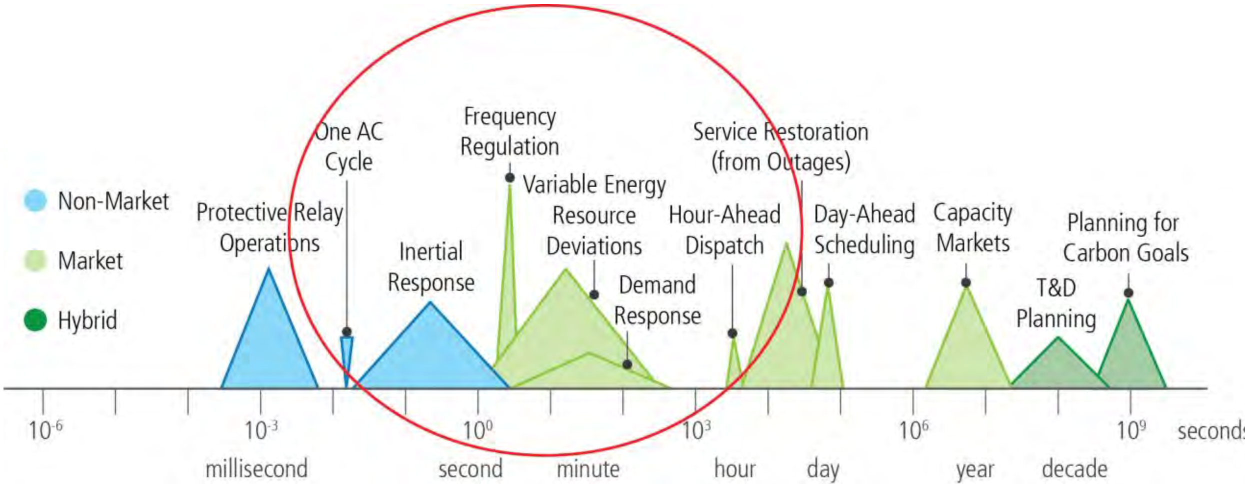
However, the widespread integration of VERs at both utility scale and distributed across all consumer segments significantly expands the time dimensions in which grid operators must function, and it complicates operations. It underscores the need “to coordinate time and space within the electric grid at greater resolution or with a higher degree of refinement than in the past.”[16] A recent White House report noted, “The distinctive characteristics of [VERs] will likely require a reimagining of electricity grid management.”[17]

Impacts on transmission and distribution systems and integration options vary by scale. For instance, utility-scale solar power flowing onto high-voltage transmission lines can be smoothed and firmed up at the point of production by using smart inverters and storage. When onshore wind plants are integrated at a large geographic scale, lower correlation factors can smooth out variability. Assuming these aggregations are visible to grid operators to adequately assess both their costs and benefits, many aggregated distributed solar installations can smooth out the random variations from individual installations.

The time dimensions in which grid operators must function to accommodate the unique characteristics of VERs and distributed energy resources (DERs) are identified in the hourly, to minute, to second intervals (see

Figure 4-3). While grid operations are successfully managed today in some markets with relatively high levels of VER penetration,[18] this can complicate grid management. Consider a generic example of utility-scale generation portfolio management in a high VER supply system. Power supplied from solar stations has two types of variability to manage: minute-to-minute fluctuations and the dramatic drop in power supplied from solar as the sun goes down. This drop can be precipitous and occur within an hour or less.

Figure 4-3. System Reliability Depends on Managing Multiple Event Speeds[19]



Markets are used for grid operations on the order of seconds to minutes, such as frequency regulation and demand response. Some essential reliability capabilities, such as inertial response, occur faster than typical market signals.

Grid dispatch (actions that operators take to engage power suppliers to provide power to the grid) occurs around load changes, traditionally referred to as load-following activities. In grids with wholesale markets, economic dispatch occurs based on which generators win daily auctions and produce power for the grid. ISOs/RTOs also load follow for grid management, and in regions with high VER production, load following and load shaping may provide linked challenges.

By calling or not calling on generators to produce electricity, grid dispatch determines the value that power producers obtain from their assets. Grid dispatch ensures system reliability through management of operating generators, as well as those waiting to be called if needed. In a world of sub-second decision making, dispatch effectiveness will require the integration of automated grid management, with continuing human oversight. The pace of change may dictate faster adaptation times for grid operators, but grid reliability may dictate a more methodical consideration of operating protocol changes, which are driven by changes in the types, scale, scope, and location of power supplies. Continuous engagement of grid dispatchers in planning for the 21st-century grid is essential.

VER fluctuations on the bulk power side of the equation can be mitigated by regulating power flows onto the grid—both up and down and from minute to minute. Mitigating power flows can occur with resources and services such as regulation that respond in one to several seconds; through process-flow techniques involving ramping up and throttling down generation plants; via transmission system blending with flexible resources such as hydro; and through demand response (DR) (including advanced water infrastructure),[20] which can be used to align demand with supply variations for grid services, including frequency regulation.

Variability is managed through geographic diversity and aggregation. FERC (through NERC) requires balancing authorities to constantly match supply and demand within their respective balancing areas.[c, 21] Larger balancing areas could help manage variability by sharing generation resources to smooth out

[c] A balancing authority "integrates resource plans ahead of time, maintains Demand and resource balance within a Balancing Authority Area, and supports Interconnection frequency in real time." The Balancing Authority Area (shortened here to Balancing Area) is the "collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority." From North American Energy Regulatory Commission (NERC), "Glossary of Terms Used in NERC Reliability Standards," NERC, last updated November 28, 2016, http://www.nerc.com/files/glossary_of_terms.pdf.

supply. A recent National Renewable Energy Laboratory analysis concluded that, "consolidated operations of two or more balancing authorities fully captures the benefits of geographic diversity and provides more accurate response."[22] For example, the integration of PacifiCorp into the California ISO Energy Imbalance Market reduced the amount of required flexibility reserves by about 280 megawatts (MW), or 36 percent.[23]

While there is ramping associated with all generation technologies, because of their variability, baseload generators must ramp more frequently to accommodate VERs. Ramping to match supply and demand can reduce the efficiency of baseload generators, possibly decrease their ability to recover capital costs, and increase fossil unit emission rates. Innovation to improve baseload generators' ramping capability is an important need that will become more important at high levels of VERs. Recent analysis suggests that "…High renewable energy penetrations could significantly change dispatch requirements and use of conventional generators."[24] Also, price suppression is occurring in RTO/ISO wholesale markets, with noticeable amounts of wind and solar generation (and low-cost gas generation). While passing on savings to consumers is desirable, in some regions, these low prices have put pressure on baseload units, particularly zero-carbon emissions nuclear generation.

Better forecasting has also reduced VER integration costs. Most North American power markets dispatch wind plants along with conventional power plants based on current grid conditions and economics.[25] Setting wind generator schedules as close as possible to the dispatch time minimizes forecast errors, and using wind forecasting can greatly facilitate wind integration and reduce costs from carrying reserve capacity.[26]

Another complication, as noted earlier, is that system operators dispatch the least-cost mix of generation needed to meet load, and the least-cost sources are often VER sources, which are fueled by the sun or the wind and therefore have low or zero marginal cost of production. In New England, as additional variable resources have come online, there has been "more frequent localized [transmission] congestion."[27] In the past, congestion was reduced by the system operator "through manual curtailment instructions that [were] not reflected in Real-Time Prices," causing a "mismatch" of signals, when generators who would normally respond to high prices by increasing output were instead told to decrease output in order to maintain reliability.[28] The system operator has undertaken several steps to address these challenges, and in April 2016, wind and hydro resources were designated as automated dispatch.[29] Going forward, the system operator will require a series of actions to further integrate VER sources.[30] Specifically, on October 12, 2016, ISO New England filed proposed revisions to its Transmission, Markets, and Services Tariff with FERC, which in part were made to "more directly incorporate non-dispatchable, intermittent power resources into [market pricing]", and on December 12, 2016, FERC issued an order accepting the proposal.[31] [32]

Another example of the changes to grid management made in response to increasing penetrations of VERs is seen in the California market. Under existing operations, the California ISO found that "the fleet of resources committed…to provide energy often does not provide sufficient flexible ramping capability…to meet the actual changes in net load."[33] As a result, the operator must "dispatch units out of economic sequence, or dispatch units that are not in the market," imposing "additional costs on the system" and creating "prices [that] do not reflect such marginal costs."[34] In California, the ISO addressed this issue by amending its tariff to "enhance the CAISO ability to manage the ramping capacity necessary to meet changes in net load—both forecasted and unexpected."[35]

Real-time wind penetration in the Southwest Power Pool (SPP) has, at times, approached 40% of generation.[36] Between March 2016 and May 2016, wind accounted for 21.5% of all energy generated in SPP.[37] In examining scenarios with significantly more VER, SPP found that new procedures "would enable the SPP transmission system to reliably handle up to…60% wind penetration" [38] while lowering overall costs and reducing price volatility. [39] These new procedures include increasing the dispatchability of renewable resources, additional transmission capacity, enhancements to ancillary services, and new tools to manage inter-hour ramps.[40]

In the Pacific Northwest, an increase in wind generation has meant that the operator must "dispatch units out of economic sequence, or dispatch units that are not in the market," imposing "additional costs on the system" and creating "prices [that] do not reflect such marginal costs."[41] Additionally, an increase in wind generation has meant that "utilities must hold more resources in reserve to help balance demand minute-to-minute," increasing "the need for system flexibility."[42] The Northwest Power and Conservation Council anticipates, however, "that the region will have sufficient generation and demand side capability on its existing system to meet balancing and flexibility reserve requirements over the next six years if [the region's] energy efficiency and demand response development goals are achieved."[43]

Hydropower provides a variety of essential reliability services that are beneficial to the electricity system. One example is regulation and frequency response (including inertia), in which hydropower generators can quickly respond to sudden changes in system frequency, making hydro a very suitable complement to wind generation. Other essential reliability services include spinning and supplemental reserves enabled by high ramping capability, reactive power and voltage support, and black start capability.

Despite the technical ability of hydropower to provide essential reliability services, these services provided by hydropower are not always explicitly compensated by existing market structures. For example, hydropower is one of the main providers of inertia and primary frequency response in the Western Electricity Coordinating Council, but it is not explicitly compensated for either service.[44] Some recent market advances have been made that allow greater ancillary service participation. For example, FERC now requires ISOs to better compensate generators for frequency regulation services based on their response speed and flexibility to respond to a range of situations.[45] In addition, in June 2016, FERC issued Order No. 825, requiring all regional transmission organizations (RTOs) and ISOs to implement sub-hourly settlements, allowing more accurate alignment of the services provided with the prices paid for them. Market rules governing participation of flexible resources, such as hydropower and pumped storage, could be reviewed to determine if additional changes could allow these resources to participate more effectively and ensure just and reasonable compensation.

Part of the challenge facing hydropower lies in the difficulty of optimizing the limited generating ability of hydro resources due to non-market environmental and competing use constraints. Determining the best use of hydro resources through manual dispatch or market-based bidding process can be difficult because the value of essential reliability services can change quickly due to a number of factors, including location, day, time, regulatory constraints, and interaction with other generators. Moreover, in the long term, the best use of hydro resources may evolve as the generation mix changes.[46] Essential reliability services are, however, undervalued in some existing market structures.

On the consumer side of the utility meter, consistent growth in DERs (of which distributed VERs are a subset) has also changed how grid operators sustain high system reliability at both the distribution and transmission levels of electricity delivery. DERs represent a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid, and they include distributed generation (DG) and storage technologies, as well as DR.[47] Consumers with rooftop solar may influence their demand frequently and in diverse ways. This can impact total load (tending to reduce it) but may not be directly controlled by grid operators. Other DERs, such as truly dispatchable DR, can be directly managed and called by grid operators when needed.

Deployment of distributed VERs places additional design and operational requirements on distribution grid operators. Currently, distribution systems are predominantly radial networks (feeders) delivering grid-supplied power to customer premises. With significant penetration of distributed generation, some distribution utilities are facing new demands to interconnect multiple feeders together to accept customer-generated power and to be able to balance generation and demand. The new structure and roles of distribution systems will require development of advanced distribution circuits and substations to enable significant two-way power flows, new protection schemes,[d] and new control paradigms.

Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii

Hawaii leads the United States in the portion of its electricity that is produced from variable renewable sources, and as an island state, it cannot rely on neighbors to help balance generation and load. Hence, the Hawaiian Electric Companies are currently experiencing the bulk system frequency stability impacts that mainland U.S. power systems will experience in the coming years and decades.[48] The Grid Modernization Laboratory Consortium will develop, simulate, validate, and deploy practical solutions that enable distributed energy resources (DERs) to help mitigate bulk system frequency contingency events on the fastest time scale (milliseconds to seconds).[49] The project will examine the ability to leverage the fast response capability of power electronics to enable photovoltaic inverters and storage inverters to support grid frequency starting a few fractions of a second after the appearance of a frequency event. The capabilities of currently available products to provide rapid frequency response will be characterized, and new capabilities will be developed with a goal of maximizing DERs' ability to support grid frequency stability.

California's recent experience with its requirements for 20,000 MW of small renewable generation (under 20 MW) by 2020 is instructive for both valuation and grid management. To make these volumes both visible to the ISO and valuable to consumers, aggregators, and grid operators, market designers at the California ISO allowed bids of at least 0.5 MW into day-ahead, energy and ancillary markets. Similar efforts are underway in Texas and New York.[50]

The electricity system is also experiencing an increasing array of "sub-second" events that require response times that are far too short for humans to react. One of the driving forces making smart grids necessary is the proliferation of smart devices; each one is capable of microscopic frequency disruptions, which cumulatively present an unprecedented new challenge for system operators. Many consumer electronic devices (such as mobile phones, Wi-Fi-based home automation solutions, and smart entertainment devices) represent "endpoints" that can impact system operations. In addition, Internet of things (IoT) devices function at microsecond "clock speeds." In the aggregate, these devices represent a new source of variability at speeds far faster than what grids have traditionally managed. The solution must take the form of protective relays and synchrophasors operating more-or-less autonomously in real time. The upside implications going forward include the need for integrating machine learning into grid operations (i.e., as positive solutions for mitigating unprecedented grid disruptive forces); on the downside, digitizing grid operations deep into sub-second operations raises new cyber vulnerabilities.

The kinds of anomalies affecting wholesale markets and grid operators noted above suggest the need for frequent adjustments to market designs to accommodate new technologies, changing consumer preferences, and security needs. The Nation's ISOs/RTOs, FERC, and NERC are continuously engaged in analysis, evaluation, and design modification processes—working to ensure that the present scoping and pace of regulatory change is aligned with the scale and speed of change occurring as a result of continued VER deployment. In September 2016, FERC approved new requirements for the quality of real-time monitoring and analysis capabilities for system operators,[51] and NERC has made a number of improvements that have significantly reduced the time it takes to develop a standard. This is an ongoing process: both state and Federal regulators face complicated and evolving challenges that grid operators

[d] Protection schemes identify coordinated corrective actions to detect and address abnormal system conditions (e.g., faults).

must address in a timely fashion while simultaneously operating under existing performance standards and system requirements.

4.2.2.2 Grid Operation Impacts of the Internet of Things

Grid control systems now handle, sense, and control endpoints numbered in the thousands. Widespread DER/DR penetration implies that future grid control systems may have to coordinate millions of end point control devices to support grid functions. These devices vary in type, from digital sensors and smart boards built into transformers, to mobile devices used by field operators and grid control managers.

Current grid control systems are not structured for large-scale optimization of millions of devices and they are not equipped to handle increasingly large volumes and types of data. End-users (consumers, as well as aggregators controlling multiple demand profiles) may wish to perform optimal local controls to meet their desired requirements that may be in conflict with optimal *system-wide* control.

Grid control systems must evolve from being centralized to a hybrid of central and distributed control platforms. The need for flexible grid operations is challenging basic assumptions about grid control, which will require changes in standards and operating protocols. Bulk power systems operations are the purview of both FERC and NERC, but grid security and reliability assurance concerns mean that Federal authorities must be included in designing 21st-century grid control systems.

Overview of DHS Strategic Principles for Security of the Internet of Things (IoT)

The Department of Homeland Security (DHS) developed strategic principles, published on November 15, 2016,[52] to mitigate vulnerabilities introduced by the IoT through recognized security best practices. These principles are intended to offer guidance to stakeholders as they seek to manage IoT security challenges.

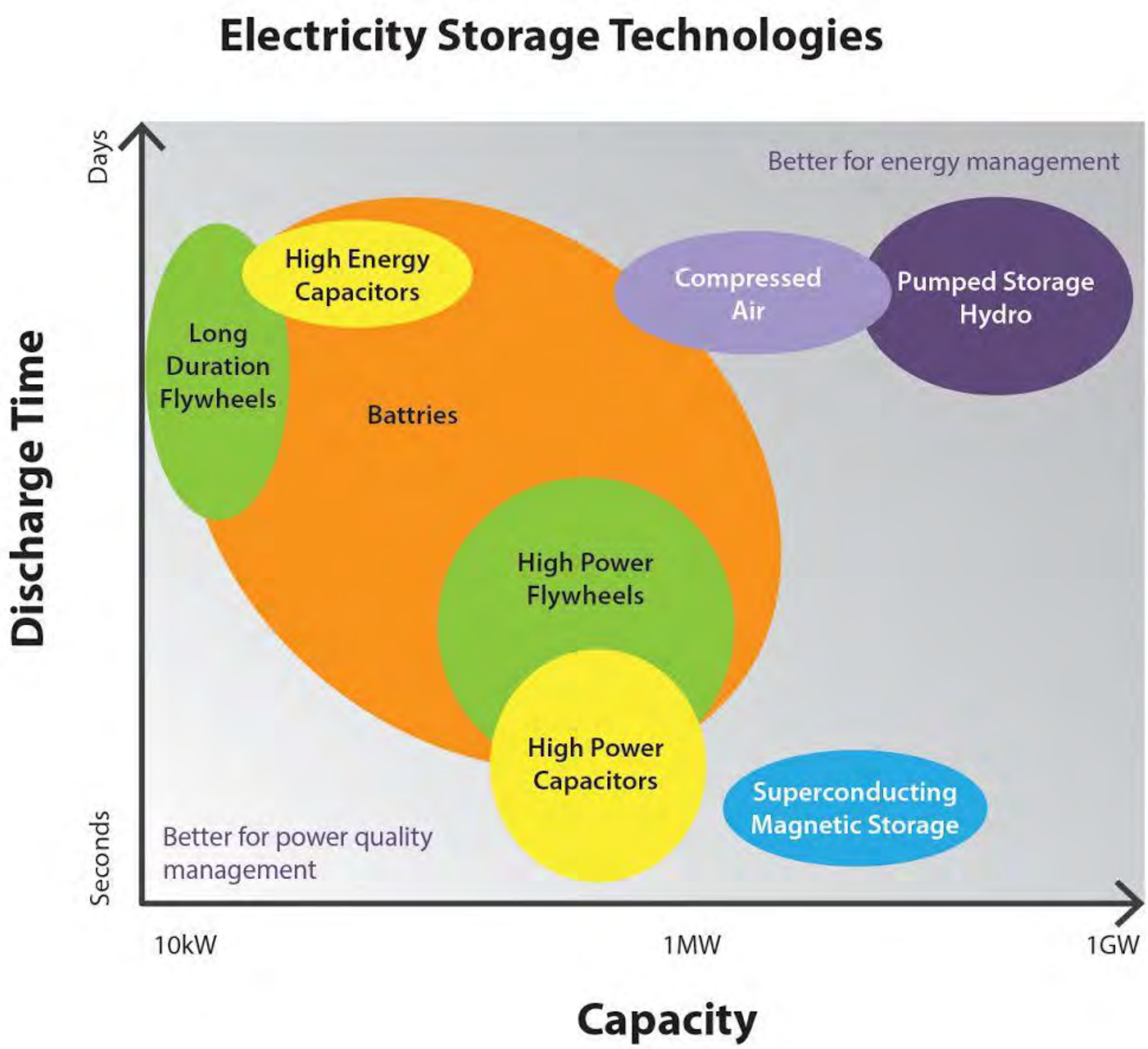
Strategic Principles for Securing IoT:

1. Incorporate security at the design phase—building in security at the design phase reduces potential disruptions and avoids the much more difficult and expensive endeavor of attempting to add security to products after they have been developed and deployed.
2. Advance security updates and vulnerability management—vulnerabilities may be discovered in products after they have been deployed. These flaws can be mitigated through patching, security updates, and vulnerability management strategies.
3. Build on proven security practices—many tested practices used in traditional information technology and network security can be applied to the IoT, helping to identify vulnerabilities, detect irregularities, respond to potential incidents, and recover from damage or disruption to IoT devices.
4. Prioritize security measures according to potential impact—risk models differ substantially across the IoT ecosystem, and the consequences of a security failure across different customers will also vary significantly. Focusing on the potential consequences of disruption, breach, or malicious activity across the consumer spectrum is therefore critical in determining where particular security efforts should be directed and who is best able to mitigate significant consequences.
5. Promote transparency across the IoT—increased awareness could help manufacturers and industrial consumers identify where and how to apply security measures, build in redundancies, and be better equipped to appropriately mitigate threats and vulnerabilities as expeditiously as possible.
6. Connect carefully and deliberately—IoT consumers can also help contain the potential threats posed by network connectivity, connecting carefully and deliberately, and by weighing the risks of a potential breach or failure of an IoT device against the costs of limiting connectivity to the Internet.

4.2.2.3 Utility-Scale and Distributed Storage

Electricity remains unique among commodities in its limited capability available for storage. There are few viable ways to store electrical energy (e.g., batteries, or pumped storage solutions), and there are other more exotic possibilities like superconducting magnet rings. Inventory options tend to narrow the amount and duration of ready access electricity. The graphic depiction in Figure 4-4 summarizes the power and duration capabilities of various storage technologies.

Figure 4-4. The Storage Technology Development Map[53]



Most electricity storage is water that fuels turbines that produce electricity. Currently, the largest storage capacity is pumped hydro. Electrochemical batteries have been the fastest growing new storage technology. Batteries in the form of fuel cells can be used for continuous power production and the scaling capabilities of fuel cells make them attractive for fitting load shapes to specifically sized power supplies. Other technologies for energy storage include compressed air, flywheels, and capacitors.

Utility-scale battery storage and distributed battery storage vary by scale and duration, but perform consistently at any scale from a grid management perspective. When distributed storage is aggregated, it can offer to local grid operators greater flexibility for managing system reliability and power quality than utility-scale resources. Aggregation can be scaled to fit specific local needs in distribution systems

An example of grid reliability applications of energy storage is seen in California, where the building of about 60 MW in new battery storage capacity is underway. [e, 54, 55, 56] These installations are being built to

[e] Upon commissioning, the 20 MW/80 MW-hour SCE Mira Loma project will be the largest battery in operation. The 37.5 MW/120 MW-hour San Diego Gas & Electric Escondido project will then overtake Mira Loma as the largest battery when it is

resolve reliability issues caused by the Aliso Canyon leak[57] (for more information on Aliso Canyon, see "Underground Storage Leak in California Driving Natural Gas Storage Safety and Reliability Improvements" text box in section 4.3.3) and the San Onofre Nuclear Generating Station outage,[58] and they will help level out electricity supply in California by moving energy from the afternoon production of solar to the evening peak.[59] While region-specific critical reliability requirements can drive storage deployment, additional incentives can help accelerate these benefits ahead of a major disruption.

Public investment and policy have been key to electricity storage technology development; the American Recovery and Reinvestment Act is the most commonly identified funding source for storage projects.[60] By 2015, through a combination of regulatory reforms, innovation, and cost reductions, lithium-ion batteries emerged as a dominant battery design for frequency regulation and renewables integration; lithium-ion batteries made up 95% of deployed capacity in 2015, with 80% of this capacity located in the PJM Interconnection territory, attracted by its pay-for-performance frequency regulation market.

The evolution of storage technology is likely to take the electricity sector into new realms. "Hybridizing" storage solutions with solar and wind power sources may redefine what is meant by "power plant," and alter how the grid is understood and used. If hybrids can "self-power" even a portion of a significant load, then tomorrow's future electricity sector will be able to achieve national objectives for clean, secure, and affordable electricity supplies in a system that is imminently flexible and considerably resilient.

4.2.2.4 Demand Response Can Aid Grid Management

DR empowers consumers to change their normal electricity consumption patterns; it is a particularly flexible grid resource, capable of improving system reliability, reducing the need for capital investments to meet peak demand, as well as electricity market prices. DR can also be used for load reduction and load shaping, as well as to help grids mitigate generation variability, including from VERs. A variety of DR programs exist, some of which are offered directly by utilities, while other programs are offered by the grid system operators, retail competitors, and aggregators. DR challenges the view that a utility's generation adequacy, measured by its reserve margin, is "steel in the ground". DR can offset "installed capacity" and currently provides nearly 30 gigawatts (GW) of peak reduction capability nationwide;[61] this accounted for 3.9 percent of U.S. peak demand in 2016[62] and exceeded 10 percent in some regions.[f, 63, 64] Future DR growth—FERC scenarios show 82 GW to 188 GW in possible DR capacity by 2019[65]—along with other DER could significantly shift customer demand from peak to off-peak periods.

A key driver of today's DR programs has been the growth of advanced metering infrastructure (AMI), now deployed for nearly 65 million customers in the United States (see Figure 4-5).[66] AMIs typically include two-way communications networks that utilities can leverage to improve electric system operations, enable new technological platforms and devices, and facilitate consumer engagement. More than half of deployed AMIs are in five states, with California, Florida, and Texas accounting for over 40 percent of the total.[67] AMI investments have been largely driven by state legislative and regulatory requirements and ARRA funding.[68]

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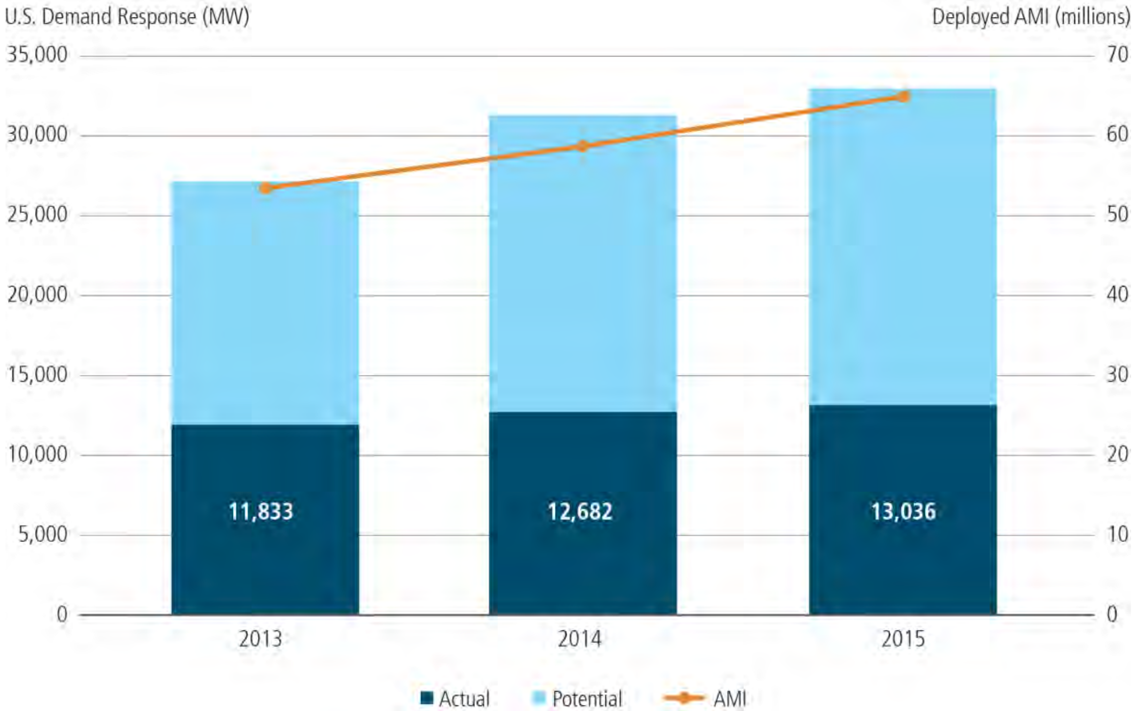
commissioned. In addition to their titles as largest yet in operation, both projects were built quickly: about six months from contract award to commissioning. These projects show how new technologies, many of which benefitted from early publicly supported demonstrations, can provide rapid solutions for reliability, resilience, and security.

[f] For example, in PJM Interconnection, demand resources account for over 10 GW out of the 167 GW from all capacity resources in the 2019/2020 delivery year. See references for more information.

Figure 4-5. Advanced Metering Infrastructure Growth Has Contributed to Expanded Role of DR Programs[69]



A key driver of today's demand response programs has been the growth of advanced metering infrastructure (in orange). In 2015, approximately 65 million customers in the United States had advanced metering infrastructure installations.

State Regulatory Actions That Have Impacted DR[70]

- The California Public Utilities Commission will require default time-of-use (TOU) rates for residential customers in 2019, and it is working with California Independent System Operator and the California Energy Commission to create a market for demand response (DR) and energy efficiency resources.[71]
- In 2014, Massachusetts ordered its electricity distribution companies to file TOU rates with critical peak pricing as the default rate design for residential customers once utility grid modernization investments are in place.[72]
- In 2015, the Michigan Public Service Commission directed DTE Electric to make TOU and dynamic peak pricing available on an opt-in basis to all customers with advanced metering infrastructure by January 1, 2016. Similarly, Consumers Energy must make TOU available on an opt-in basis by January 1, 2017.
- Also in 2015, the New York Public Service Commission released a regulatory framework and implementation plan (Reforming the Energy Vision) to align electric utility practices and the state's regulatory framework with technologies in information management, power generation, and distribution. A related measure in 2014 approved a $200 million Brooklyn-Queens demand management program, which includes 41 megawatts (MW) of customer-side measures, including DR, distributed generation, distributed energy storage, and energy efficiency, to cost-effectively defer approximately $1 billion in transmission and distribution investment.
- In June 2015, the Pennsylvania Public Utility Commission set a total peak demand reduction of 425 MW for electric distribution companies by 2021, against a 2010 baseline.
- In Rhode Island, DR is continuing to be tested in pilot programs by National Grid and will be incorporated in analysis for "non-wires alternatives" to traditional utility infrastructure planning.[73]

The legal and regulatory environment for DR is highly dynamic and evolving at both the national and state levels. On January 25, 2016, the U.S. Supreme Court upheld FERC's authority to regulate DR programs in wholesale electricity markets (FERC Order No. 745).[74] While this decision provides final policy clarity, it was made almost 2 years after the Appeals Court issued the opposite decision; in the intervening time, the markets were operating under the lower court's interpretation that FERC's DR order was encroaching on each state's exclusive right to regulate its utility markets. As affirmed by the Supreme Court, the FERC order ensures that DR providers are compensated at the same rates as generation owners. This ruling is also expected to provide a more favorable environment for DR market growth by facilitating the participation of third parties in the aggregation of DR resources.

As noted, total DR capacity varies widely by region, reflecting the diversity in utility, state, and regional policies toward DR and other forms of demand-side management. Regions where DR is installed directly in multiple electricity markets (e.g., capacity and essential reliability services) generally have greater total DR capacities and can reduce a larger proportion of their peak demand by using DR.[75]

Table 4-1. Potential Peak Reduction from Retail DR Programs, by Region and Customer Class[76]

NERC Region	Total DR Capacity (megawatts)	Residential	Commercial	Industrial	Transportation
Alaska	27	19.0%	48.0%	33.0%	0.0%
Florida Reliability Coordinating Council	1,924	42.0%	39.0%	19.0%	0.0%
Hawaii	35	57.0%	43.0%	0.0%	0.0%
Midwest Reliability Organization	4,264	44.0%	19.0%	37.0%	0.0%
Northeast Power Coordinating Council	467	8.0%	55.0%	34.0%	3.0%
Reliability First Corporation	5,362	29.0%	13.0%	58.0%	0.0%
SERC Reliability Corporation	8,254	16.0%	10.0%	74.0%	0.0%
Southwest Power Pool	1,594	13.0%	20.0%	66.0%	0.0%
Texas Reliability Entity	459	19.0%	74.0%	7.0%	0.0%
Western Electricity Coordinating Council	4,681	22.0%	24.0%	50.0%	3.0%
Unspecified	28	100.0%	0.0%	0.0%	0.0%
Totals	27,095	25.8%	18.9%	54.6%	0.6%

Demand response (DR) resources tend to be drawn principally from industrial and commercial customers of utilities, although three regions—Florida Reliability Coordinating Council, Hawaii, and Midwest Reliability Organization—exhibit high-residential DR capacity. Variability among segments within and between regions is a function of DR program characteristics and requirements—whether penalties for non- or under-performance apply, the frequency with which DR resources are called, and the purpose for which DR is used, such as peak mitigation or frequency regulation. Capacity estimates must be adjusted for value and reliability of delivery based on operational outcomes, as well. DR, when called, may not sustain for a complete event period; only a portion of what is called may show up; resource availability may vary over an event period; and sometimes the "snap back" at the end of an event can create "echo effects" of peak mitigation problems, as well.

It is important to note that the potential peak reduction in Table 4-1 may not all be reduction in "real capacity." There are significant challenges to making DR resources reliable, predictable, and sustainable so that they may function as "proxy generators." Also, the terms related to non-delivery or partial delivery of DR that is called into service by grid operators tend to have highly variable penalty clauses from region to region and from utility to utility' grid operators generally favor more reliable and predictable resources over DR. Until there are consistent standards across regions that ensure data accuracy and validity, data on DR capacity will tend to be discounted by grid operators—an estimated 100-MW DR resource that *can* be called does not mean that 100 MW will show up *when* called. Real-time visibility of these resources is important to grid operators and essential for maximizing the value of DR.[77]

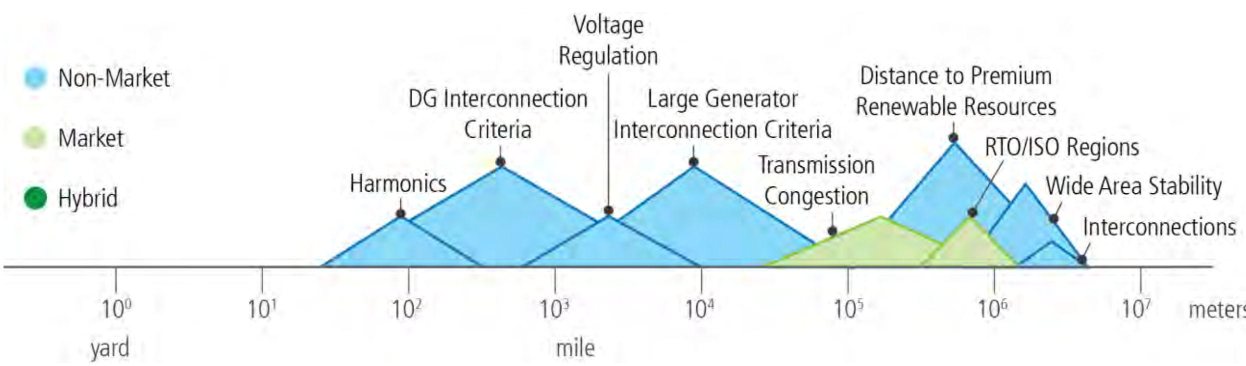
4.2.2.5 Topography and Geography are also Important to Grid Operators

Topography and geography are additional and important aspects of core grid management challenges (see Figure 4-6). Geography is the physical area covered by the grid; topography is the type of geography (e.g., flat, hilly, mountainous, etc.). Figure 4-6 illustrates how physical distances can influence system structure and operational challenges.

An example of why these features are important is that information and communications technology (ICT) infrastructure and reliability for smart meters and smart grid assets are less effective when mountainous terrain and urban infrastructure disrupt reliable wireless signal strength. Smart grid designers must and do build in redundancy to deal with certain topographic asymmetries by using multiple ICT channels.

As another example, the concentration of distributed VERs in a specific urban geography can lead to stresses on local infrastructure, including transformers and substations. This can present more disruptive problems for local grid operators than non-clustered dispersion of VERs. System operators must watch for grid impacts in more granular ways, and grid design changes to mitigate clustering effects will become important new paths for adapting to consumer-side influences on grid operations. Because consumer behavior can change quickly, new grid design processes must be made to function faster, from core architecture to actual deployment. In turn, regulators must become nimble in considering incremental system costs that are compelled by grid operators anticipating problems and acting to mitigate them before they lead to grid interruptions.

Figure 4-6. Network Geography and Topography Impact Real-Time Operations Management and Influence How System Planning Is Done for Grid Operations and Related Markets[78]



A variety of grid services are managed across different distance scales, and markets can be used to integrate some necessary services.

4.2.3 The Growing Role of the Consumer in Grid Reliability

Reliability is increasingly a two-way proposition between grid operators and consumers, and grid reliability, while remaining true to its longstanding commitment to ensure high system "uptime," now abuts an emerging "consumer reliability." Reliability has typically been synonymous with "grid reliability" or "system reliability." Consumer reliability derives from a series of initiatives over several decades; the continuous improvement in energy efficiency; the value of DR to both the grid and consumer; emerging new consumer value creation from IoT development; and the shifting priority of consumers (especially the commercial segment) for uninterruptible power services. The growing interdependence between grid operators and consumers—the two-way flow of information and power—means that grid reliability can be made more efficient and more robust if consumer integration into grid operations occurs.

4.2.3.1 Customer Engagement in Demand-Side Management

Today, many customer categories and segments are interacting with the grid in some way. Customers now have the tools to alter their consumption patterns in response to price signals or requests from grid operators. This significant change—from a customer that is a passive load to one that is more actively engaged in demand management—may trend toward greater customer participation in the future. Within 10 to 15 years, many of the new devices likely to become part of our electricity system—from power plants to rooftop solar systems, from batteries to street lights, from transformers to electric vehicles—will also be digitally communicating with the grid.[79] Most of these new devices will be able to "see" others on the grid, as well.

This kind of connectivity with customers may lead to more fully integrated customer participation in grid operations on either an active level—where customers respond to time-of-use or real-time price signals—or a passive level—with devices encoded to reflect customer preferences that are responsive to system prices and operating signals. Visibility of this connectivity is however, key to grid operations and management and essential for both customer and system reliability.

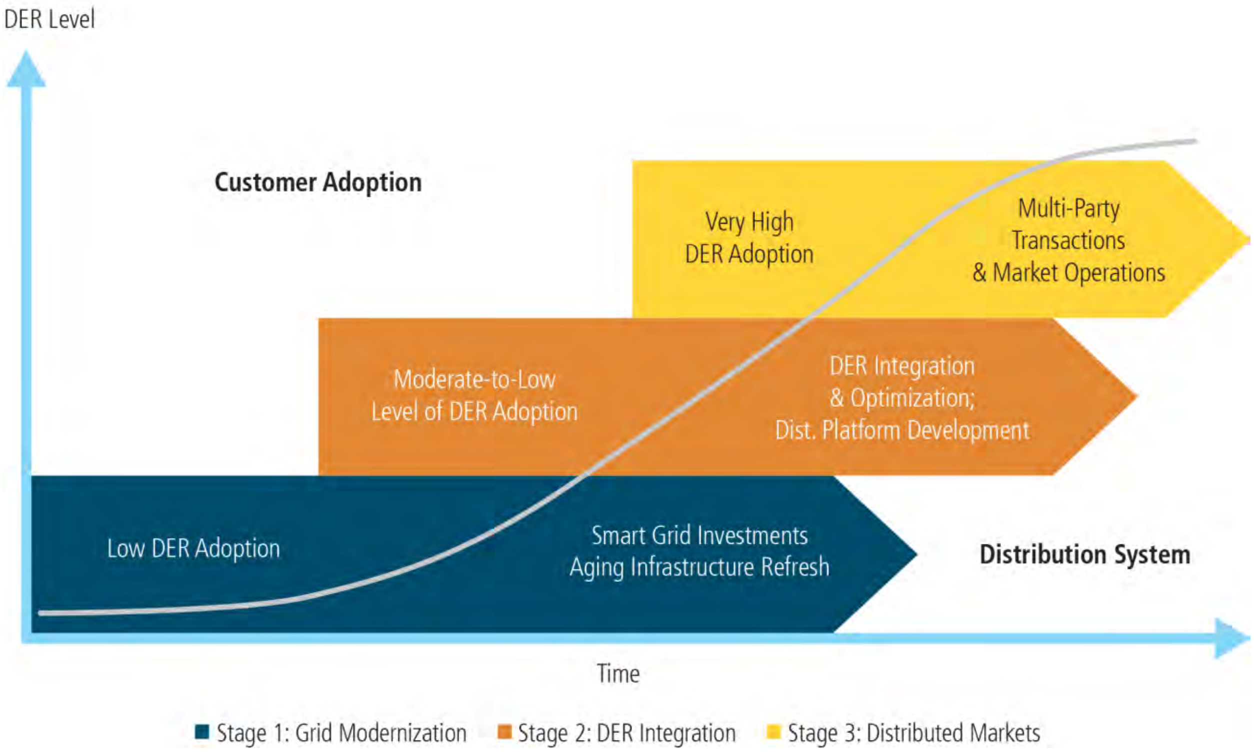
Consumption response to system signals can be more precise, timely, and predictable thanks to improved ICT enablers and better grid-side analytics focused on managing overall system reliability, not just peak mitigation. DOE, through its laboratories, for example, has developed a platform that "enables mobile and stationary software agents to perform information gathering, processing, and control actions and independently manage a wide range of applications, such as HVAC [heating, ventilation, and air conditioning] systems, electric vehicles, distributed energy or entire building loads, leading to improved operational efficiency." This platform provides the capabilities for real-time, scalable distributed control and diagnostics that we need for security and reliability and "…the integration of today's new energy system."[80]

4.2.3.2 Customer Engagement in Generation and System Reliability

In addition to the potential for increased customer participation in demand side management, there have been dramatic increases in distributed generation, such as rooftop solar, which enable customers to produce power that is sold back to the grid by the customer or aggregators acting on behalf of the customer. The result is that both electricity and information can now flow in two directions across the distribution grid, enabled by smart meters and/or Internet platforms. This two-way engagement has become more complex as distributed generation continues to penetrate industrial, commercial, and residential delivery service segments.

Most utilities are in the low distributed generation adoption phase, with some states approaching moderate levels.[81] The growth will be driven by regulatory characteristics within each state, for example, through rate design and utility regulation as set by a public utilities commission. Figure 4-7 shows the conceptual growth of DG/DER in three phases, from low to high adoption. Such conceptual forecasts are helpful in posing policy issues and assisting investors in seeing new opportunities. However, structural and systems outcomes depend as much on actual results of markets, regulators, and various jurisdictions co-evolving into the future.

Figure 4-7. Major Technology, Policy and Infrastructure Enablers of DER Adoption[82]



This figure shows a three-stage evolutionary framework based on an assumption that the distribution system will evolve in response to both top-down policy and bottom-up customer drivers. Each level includes additional functionality to support greater amounts of distributed generation/distributed energy resource (DG/DER) adoption and complexity building upon the earlier level. Most of the U.S. distribution system is at stage 1; the speed and nature of DG/DER adoption will vary by region based on top-down and bottom-up drivers.

Currently, around 4 percent of U.S. generation is from DG, although this varies widely by region.[83] Low levels of DG penetration generally require modest, though critical, levels of planning and operational considerations. Under high DG adoption rates, grid operations and market structures will most likely require significant modification. In a future grid where DG comprises a larger portion of the resource base, disruptions of system dispatch and control signals that could result from higher levels of DG penetration will increase the risk of disturbing grid stability and reliability. In its *2015 Long-Term Reliability Assessmen*t, NERC noted the complications DG/DERs create for grid operations and how these issues might be resolved:

> "Operators and planners face uncertainty with increased levels of distributed energy resources and new technologies. Distributed energy resources (DERs) are contributing to changing characteristics and control strategies in grid operations. DERs are not directly interconnected to the BPS [bulk power system], but to sub-transmission and distribution systems generally located behind customer metering facilities. Visibility, controllability, and new forecasting methods of these resources are of paramount importance to plan and operate the BPS—particularly because the majority of DERs are intermittent in nature and outside the control of the System Operator. As more DERs are integrated, the supply of control to System Operators can decrease. However, distribution-centric operations can reliably support the BPS with adequate planning, operating and forecasting analyses, coordination, and policies that are oriented to reliably interface with

> the BPS. Coordinated and reliable integration of DERs into the BPS can also present opportunities to create a more robust and resilient system."[84]

At high penetration levels, distribution system changes to enhance DG/DER value to grid reliability will require developing advanced distribution circuits and substations that allow for two-way power flows, new protection schemes, and new control paradigms. There are digital solid-state technologies combined with ICT, such as smart inverters, power electronics, and smart energy storage that can provide grid operators the flexibility needed to manage a mixed set of DERs and deal with inbound impacts from utility-scale VERs upstream as well. The introduction of new grid control and optimization algorithms taking advantage of distributed generation and load flexibility in the United States could also contribute to grid reliability and related benefits, such as reduction of renewables curtailment, peak load mitigation, and transmission and distribution (T&D) congestion management. Development of new technologies could enable DGs to provide voltage or reactive[g] control resources.

Currently, customer reliability investments and interests are not necessarily contributing to supporting and enhancing overall grid system reliability. In cases where DGs are part of the equation, particularly distributed VERs, customer actions can increase reliability risk. The electricity sector has a range of choices to adapt to these challenges and demands, many of them coming from new generators and consumers. The path that is chosen will shape future sector value-creation potential and the long-term relevance of utilities to electricity service delivery. Technology innovation, along with market forces, are redefining "grid reality," the management space where high system reliability is sustained under the aegis of critical national goals for a clean, secure, and competitive electricity sector.

Increased penetration of DGs and increased interconnectivity also bring increased vulnerabilities to malicious attacks on customer assets and on the grid. Public networks carry with them risks of being conduits through which cyber attacks can be executed—where impacts can spread through grids as well as through customer assets that are part of the IoT. There are policy gaps at the interface of electricity and information that require new policies that both promote value creation through connectivity and protect critical infrastructure against cyber attacks.

4.2.3.3 Valuation of DERs: System Benefits and Costs

The growth of DERs, where significant, will require additional valuation efforts in both planning and market design to capture the value of these new systems and services, as well as to avoid uneconomic or unintended issues. Valuation can be developed based on different cost perspectives, such as private costs that affect the ratepayers' cost of service or social costs that include the private cost of service and externalities. Valuation efforts need to be performed for system as a whole as well as for planning and compensation structures (e.g., rate design).

It is important to consider both the system cost and benefits when valuing DERs. Factors that influence DER value include constraint reduction, loss reduction, voltage control, investment deferral, environmental benefits, and reliability. These factors can vary significantly based on the size and location of the DER. Accurate valuations will depend on evaluations at a finer level or resolution than has been considered historically.

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[g] NERC requires transmission operators to ensure that resources capable of providing "reactive power" or "voltage control" in addition to electricity are online or can be scheduled because these reactive power or voltage control services regulate voltage levels that maintain grid stability.

4.2.4 Flexibility and Management of DERs, VERs, and Two-Way or Multi-Directional Flows

Resilience and flexibility might be considered complementary factors of grid modernization. Grid modernization planning should take flexibility of resources, as well as grid operations techniques, into account; architecting a flexible grid may require distinctive configurations of ICT and physical assets on the grid side, as well as the customer side, of the utility meter. Flexibility is not only a generation matter; it bears directly on the core reliability challenges of maintaining balance between generation and load.

Solar and wind (which are not synchronously connected to the grid) contribute to a net decrease in system inertia (loss of frequency control). System frequency[h] must be managed tightly around 60 Hertz; it measures how well the supply and demand of electricity are in balance, which has significant implications for how resources are deployed literally minute-to-minute. Conventional generation, such as nuclear facilities or coal-fired power stations, serve as baseload resources and as spinning reserves. These resources are synchronously connected to the grid and provide system inertia.[i] Deviations in frequency are corrected by the spinning mass and governor controls of conventional generators, which automatically adjust electricity output within seconds to correct out-of-balance conditions.

In contrast, conventional solar photovoltaic (PV) generators, storage devices, and non-frequency responsive loads do not have inertial value for grid operators. As wind and solar power (and other non-synchronous DERs) replace conventional synchronous generation, total system inertia is reduced along with the number of units available to provide frequency response services. In other words, system flexibility could be compromised in the absence of intentional mitigating actions that preserve or boost frequency response capabilities. Power electronics and advanced inverters that simulate inertia are available to add to wind and solar generators, providing a version of frequency response; but, development and deployment of these technologies may be hindered without additional policies prioritizing or enabling frequency response service.[j, 85]

Steep ramping resources will become more important as more VERs come online and increase their share of power supply. Ramping is used to follow load patterns to ensure that resources match the loads on the system. VERs expand the role of ramping from being primarily load focused to more of a role in matching increasing supply variability. For example, in California in 2015, grid operators were required to bring on approximately 10,000 MW within a 3-hour period at the end of each workday to compensate for the reduction in PV output as the sun was setting. Over time, more ramping will be needed as variable resources continue to grow.[86] There is not yet an established method for calculating the type of flexibility required to ensure reliability, especially in circumstances with high penetration of variable or DG.

Distribution systems were designed to deliver power to customers rather than receive power from them. When the same grid assets are tasked with handling power delivered to the grid, as well as power delivered to customers, the settings on many field devices (such as capacitors, feeder switches, and relays) need to be adjusted to handle multi-directional power flows. Where deployment of PV on distribution feeders may significantly exceed real-time demand, distribution system upgrades will be required. However, upgrades cannot be determined simply by evaluating grid requirements but must be configured

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[h] Frequency is the number of times per second that the electric charge reverses direction. "Electric Systems Respond Quickly to the Sudden Loss of Supply or Demand," Energy Information Administration, Today in Energy, November 21, 2011, http://www.eia.gov/todayinenergy/detail.php?id=3990.

[i] NERC defines inertia as "the ability of a machine with rotating mass inertia to arrest frequency decline and stabilize the system." See http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF_Draft_Concept_Paper_Sep_2014_Final.pdf.

[j] FERC issued a Notice of Inquiry on February 18, 2016, seeking comment on whether it should require all generators, including wind and solar, to provide frequency response service. See https://ferc.gov/whats-new/comm-meet/2016/021816/E-2.pdf.

to deal with existing and potential increases in PV deployments. Thus, the concept of "hosting capacity," much in the same way that Internet services calculate capacity requirements to serve Internet loads, will become a key decision criterion for future grid upgrades. Regulators will need to learn how hosting capacity is a relevant measure for grid planning and how cost justifications for rate purposes should be framed.

As noted, consumers are adopting renewable technologies and devices that enable them to manage their electricity use (e.g., through smart meters and energy management systems). Proactive consumers reduce demand pattern predictability, particularly when remote control of loads is involved. This complicates very near-term system planning, which, in turn, increases the need for redundancy to hedge the unexpected drops and surges in consumption that can happen. Discussion of these circumstances and policy implications can be found in Chapter II (*The Electricity Sector: Maximizing Economic Value and Consumer Equity*).

4.2.5 Visibility Is Key to Addressing the Changing Nature of Reliability

Flexibility in grid operations requires visibility into connected resources. Visibility—knowledge of "which resources are interconnected, as well as their locations and current capabilities"[87]—is a key attribute for managing the electricity system. Visibility is a necessary condition for managing rapidly changing and complex grid conditions and for providing awareness of incursions, as well as foresight for planning.

Advanced communication and information technologies facilitate visibility. Visualization requires data collection; analysis (e.g., modeling, business cases, etc.); transparency (i.e., sharing data and results); modeling (with both existing and new models); and deploying various sensing technologies, such as synchrophasors and smart meters. Creating foresight for transformation requires increasing visibility across many dimensions:

- *Temporal*—real time to planning
- *Geographic*—such as seams between balancing areas in the bulk electric system
- *Analytical*—identification and specification of computer models needed to evaluate the path to the future grid (such as finance tools, transmission planning tools, etc.)
- *Price*—the single most important mechanism for conveying information to customers and suppliers
- *Societal impacts*– associated risks taken on by the consumer may not be accounted for in price
- *Business*—business models and business-use cases for incumbent service providers and new technology providers
- *Technological*—including characteristics of new technologies and grid elements
- *Regulatory*—between different layers of jurisdiction and many different types of entities that must be synchronized to make the future grid work
- *Vertical industry boundaries*—between distribution and bulk system operations.

Integration of DER resources with ICT and other enabling technologies that provide visibility in the distribution system can give system operators the ability to react and respond to critical events with a level of efficiency and accuracy that is currently unavailable. Policies that comprehensively assess and manage DERs could help reduce associated reliability challenges. At some level of DER penetration, these policies may merit extending to encompass the interstate bulk power system. Data requirements and visibility of assets (possibly including tracking production) are important policy issues for state regulators.

The deployment of innovative visibility technologies face multiple barriers that can differ by technology and the role each technology plays in T&D systems. For example, synchrophasors are an important new technology that increase T&D operator visibility, but technology dissemination is being limited by utility concerns about vulnerabilities associated with sharing data and the fact that current regulations do not necessarily encourage investments in new technical solutions. This suggests that there is a role for the Federal Government in working with stakeholders and state regulators to identify, analyze, and develop recommendations for removing barriers to the deployment of value enhancing advanced technologies.

4.3 Growing Vulnerabilities for the Electric Grid

The electricity system requires management of risks from a wide variety of threats, each with different characteristics, not all of which are considered in a comprehensive way by decision makers. Threats and hazards to the electricity system represent anything that can cause disruption and outages, while vulnerabilities are points of weakness within a system that increase susceptibility to such threats. The physical vulnerabilities and specific risks to the electric power system vary among infrastructure components and by geographic location.

Significant Cost of System Outages

A National Research Council study of the 2003 blackout in the Midwest, Northeast, and Canada concluded that "the economic cost of the 2003 blackout came to approximately $5 per forgone kilowatt-hour, a figure that is roughly 50 times greater than the average retail cost of a kilowatt-hour in the United States."[88] Data suggest that electricity system outages attributable to weather-related events are increasing, costing the U.S. economy an estimated $20 billion to $55 billion annually.[89]

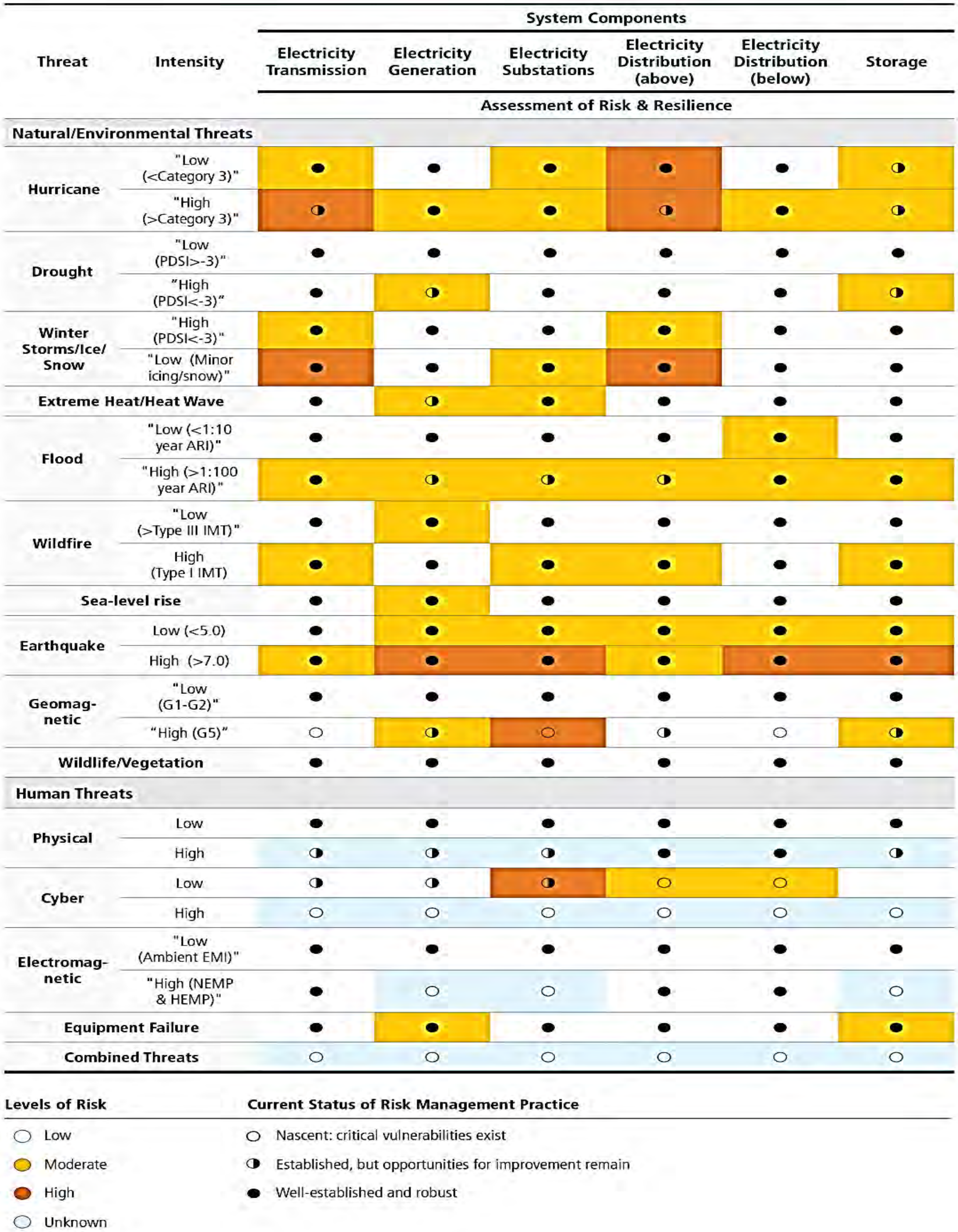
4.3.1 Grid Reliability Risk

Reliability risk is a complex mix of natural and human threats. Risk mitigation includes developing future grid designs that maximize flexibility, as well as making investments in structural, process, and technology solutions, which increase grid resilience to reduce outage events. Some strategies can help reduce risks with respect to a variety of threats, while other strategies are more threat specific. Specific measures fall into a few broad categories—such as hardening (e.g., protection from wind and flooding), modernization (e.g., investment in sensors, automated controls, databases, and tools), general readiness (e.g., equipment maintenance, vegetation management, stockpiling of critical equipment), and analytics and security upgrades.[90, 91, 92]

Grid owners and operators are tasked with managing risks from a broad range of threats, defined as anything that can disrupt or impact a system—natural, environmental, human, or other. Many threats to critical electricity infrastructure are universal (e.g., physical attacks), while others vary by geographic location and time of year (e.g., natural disasters). Threats also range in frequency of occurrence, from highly likely (e.g., weather-related events) to less likely (e.g., electromagnetic pulse). Electric utilities have long prepared for specific hazards. However, hazards that evolve over time, or combinations of hazards that occur simultaneously, require enhanced or new measures for prevention or mitigation.[93]

Cyber attacks are emerging and rapidly evolving threats that may increase the vulnerability of utilities' system operations. Understanding the various established and emerging risks to the electricity system, including characterization of historical trends and future projections, as well as the predictability of different threats, has important implications for threat mitigation and resilience.[94] Figure 4-8 depicts the scope and severity of risks where probabilities of occurrence of each threat can change significantly "without notice." This Figure illustrates the status of risk management with respect to current threats, some of which are expected to worsen in the future, suggesting a need for new risk management strategies. Current risk management practices are well suited to address common threats for most system components; however, the picture is mixed, particularly with respect to emerging threats, where there is limited data and experience. Figure 4-8 includes the current risks of system disruption (color coding) for electricity system segments (columns across) to various threats (by rows). The threats are further broken out by incidents of low and high intensity (rows). While the sector has well-established risk management practices for many current threats (indicated with filled circles), practices for other types of threats are nascent (open circles).

Figure 4-8. Integrated Assessment of Risks to Electricity Sector Resilience from Current Threats[95]



Electricity system owners and operators must manage risks in a comprehensive manner for a broad range of threats. This chart provides an integrated portrait of current risks to the electricity system and the maturity of current risk management practices. The sector generally has well-established practices for managing familiar threats (e.g., wildlife), but much more work is needed to effectively manage risks from high-impact, low-frequency events (e.g., high-intensity hurricanes), combined threats, and unfamiliar threats for which information is lacking or unknowable (e.g., cyber and physical attacks). Additional attention is needed to reduce risks for above-ground distribution systems, substations susceptible to large-scale geomagnetic disturbances. This assessment does not reflect the status of risk management with respect to threats that are expected to worsen, such as extreme weather and cyber attacks.

4.3.1.1 Grid Operator Reliability Risk Management Is Increasingly Important

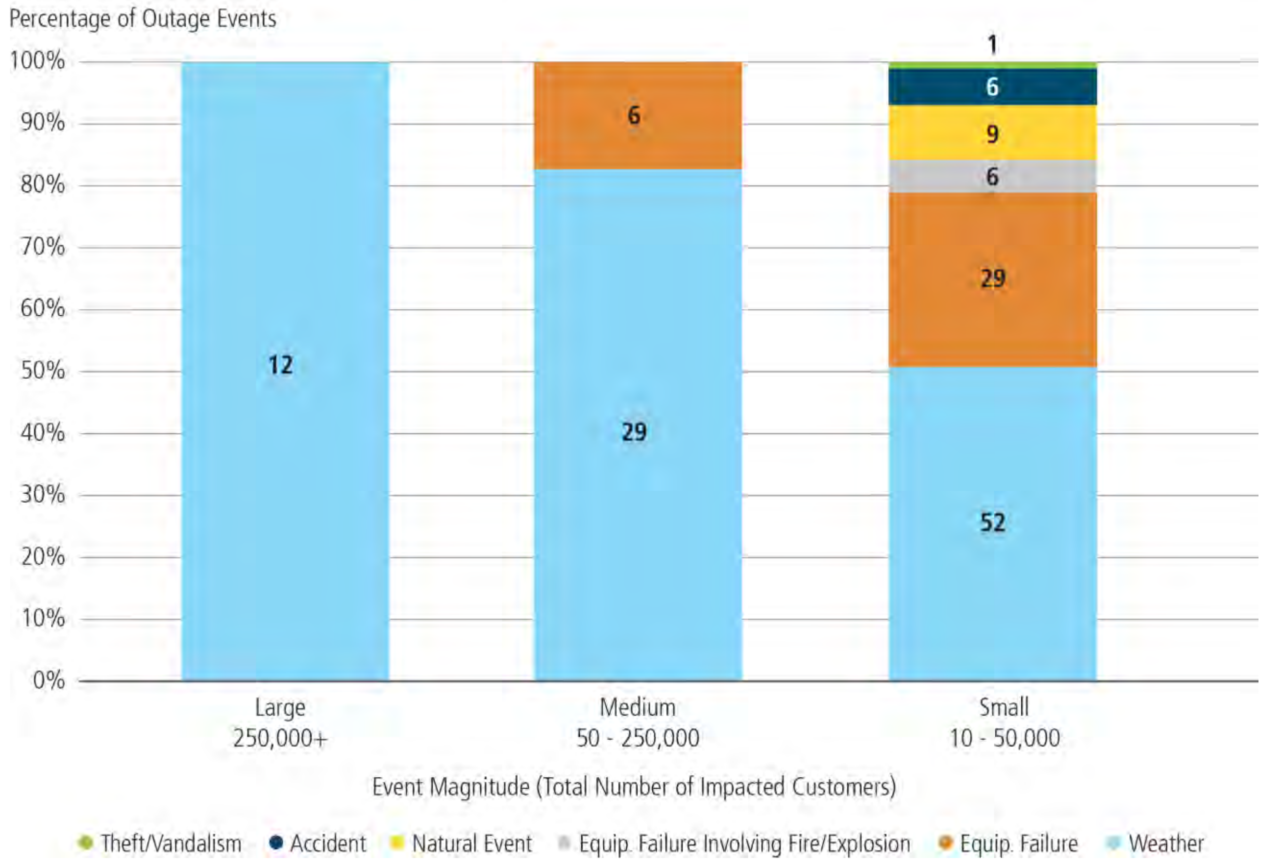
Delivery system reliability remains high and robust in today's world, but emerging threats create a higher risk profile that, in turn, creates challenges for ensuring sustained high delivery system reliability. There are many electricity sector risks that are continuously managed, such as investment risks, regulatory risks, and grid operational risks. Operational risks encompass all variables that can produce outages or disrupt frequency and voltage—from new types of power generation, to changing customer behavior, to extreme weather. Despite risk management practices, the risk of system disruption remains particularly high to certain system segments (e.g., above-ground distribution systems) or threats (e.g., large-scale earthquakes). Further, there remain evolving or dynamic threats for which the levels of risk are unknown and the risk management practices could be improved (e.g., high-intensity physical attacks, high-intensity cyber attacks, or combined threats).

Key policy questions include how investments should be prioritized, how cyber threats to ICT infrastructure should be managed, how emerging climate threats should be mitigated and planned for, and whether a highly dispersed power supply system contributes to a more resilient and secure electricity sector. Finally, longstanding high-voltage transmission and baseload power supply assets now must be analyzed as possible insurance assets for reliability

4.3.2 Extreme Weather Is a Leading Threat to Grid Reliability

Some types of extreme weather are becoming more frequent and intense due to climate change, and these trends have been the principal contributors to an observed increase in the frequency and duration of power outages in the United States between 2000 and 2012.[96] Figure 4-9 summarizes the main sources of contemporary outage events in 2015, excluding consideration of cyber-related effects.

Figure 4-9. US Electric Outage Events by Cause and Magnitude, 2015[97]

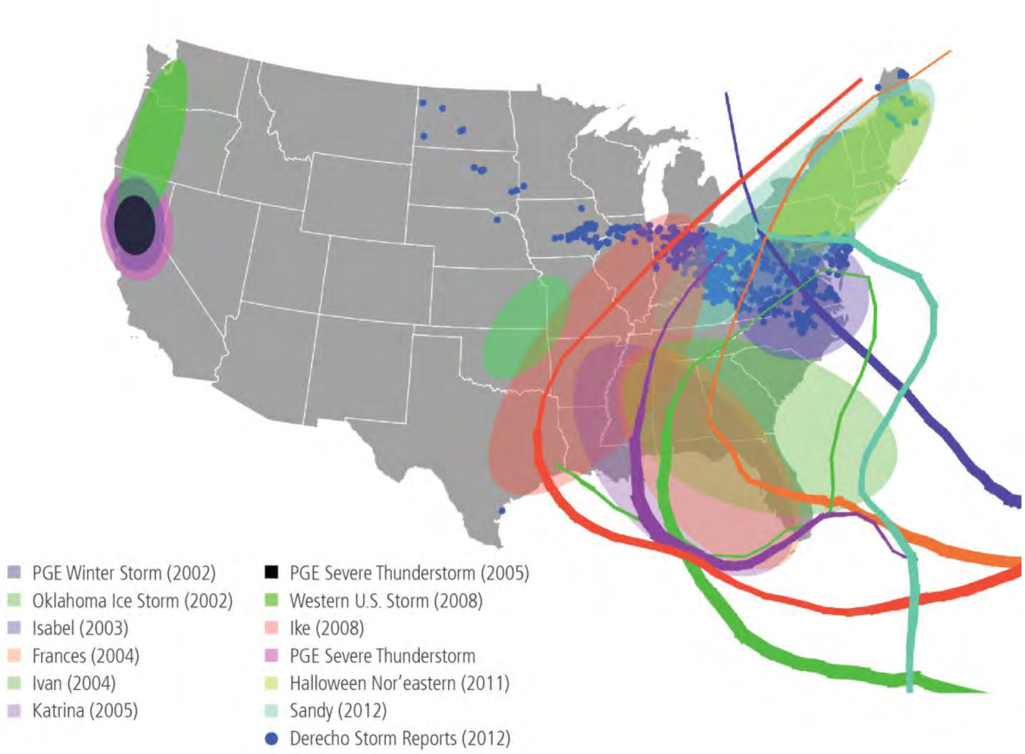


There are regional variations in weather-related outage causes in the United States. While the East and Gulf Coast regions are subject to hurricanes, large, weather-related outages in the West are more often caused by winter storms. Major outages from weather events are more common than from cascading failures.

Superstorm Sandy demonstrated the severe impacts of a large storm and the interdependencies of electricity and other infrastructures. The storm knocked out power to 8.66 million customers from North Carolina to Maine and as far west as Illinois and Wisconsin. Electric utilities deployed over 70,000 workers to the affected areas, the largest-ever dispatch of utilities workers.[98] The nearly 1,000-mile-diameter storm caused flooding and power outages that shut down many other major infrastructure components, illustrating the dependence of other critical infrastructures on electricity.[99] Oil refineries were shut in, as well as many East Coast product import terminals—which act as the primary back-up method for securing bulk product supplies during refinery outages—due to the loss of power. A week after the storm, product deliveries in New York Harbor had returned to only 61 percent of pre-storm levels, and less than 20 percent of gas stations in New York City were open for business. The Department of Defense provided 9.3 million gallons of fuel, though fuel shortages still greatly hindered the ability of emergency response personnel to respond to the crisis.[100]

Weather-related events, including lightning and storms, have historically posed the greatest operation risk to the electricity system.[101] Strong winds, especially hurricane-force winds, are the primary cause of damage to electric T&D infrastructures. Failures on the distribution system are typically responsible for more than 90 percent of electric power interruptions, both in terms of the duration and frequency of outages.[102] Damage to the transmission system, while infrequent, can result in more widespread major power outages that affect large numbers of customers and large total loads.[103] Figure 4-10 summarizes major weather-induced reliability disruptions from 2002 to 2012.

Figure 4-10. Major Weather-Related Outages Requiring a National Response, 2002–2012[104]

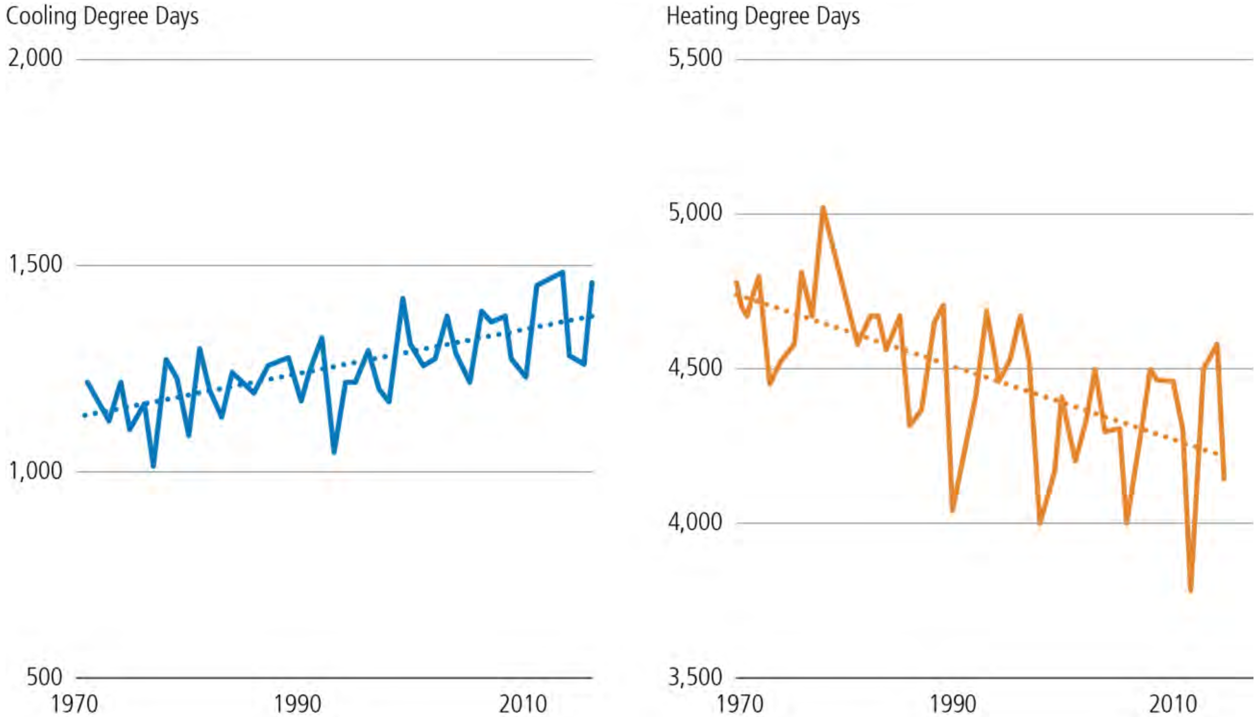


There are regional variations in outage causes in the United States. While the East and Gulf Coast regions are subject to hurricanes, large, weather-related outages in the West are more often caused by winter storms. Major outages from weather events are more common than from cascading failures.

Further, 2016 is on track to be the third consecutive year of record-breaking global temperatures.[105] Cooling degree days[k] have already increased in the United States by roughly 20 percent over the last few decades (see Figure 4-11), and this trend is projected to continue in the future.[106] These changes in temperature are expected to result in increased electricity use, particularly during the mid- to late-afternoon peak hours, primarily to meet rising demand for air conditioning.[107]

[k] The number of degrees that a day's average temperature is above 65° Fahrenheit, indicating that consumers need to use air conditioning to cool their buildings, and there is an increase in electricity demand.

Figure 4-11. Heating and Cooling Degree Days in the Contiguous 48 States, 1970–2015 (Fahrenheit)[108]

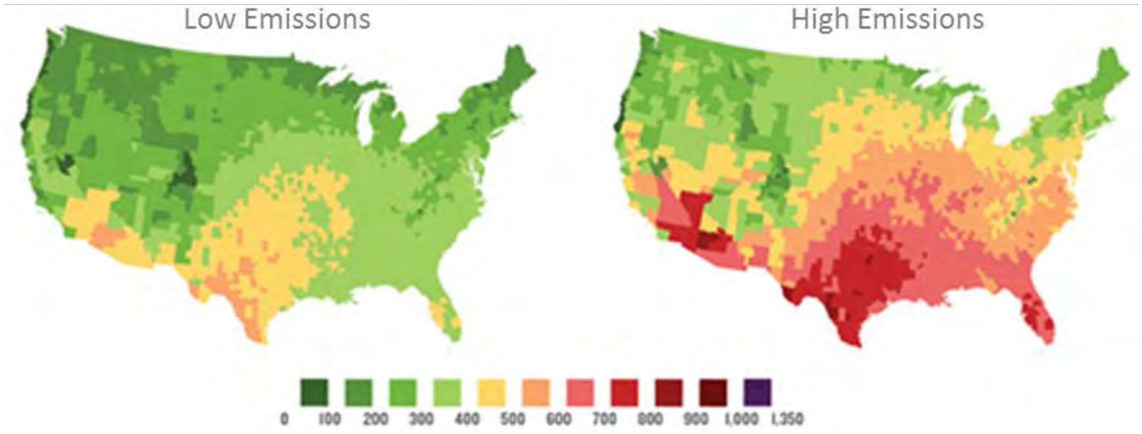


As air temperature continue to rise, since 1970, the number of cooling degree days has increased in the United States by roughly 20 percent, while the number of heating degree days has declined.

The maps in Figure 4-12 show projected median changes in cooling degree days by 2040 under two global greenhouse gas emissions scenarios, based on analysis of output from several global climate models,[l] which were downscaled to the county level.[109] This analysis found that while the average American has historically experienced around 2 weeks of days over 95°F each year, this could rise to 3 to 6 weeks, on average, by 2040.[110]

[l] To account for uncertainty surrounding future emissions pathways, the study cited here uses a plausible range of scenarios developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The highest emissions scenario corresponds to a world where fossil fuels continue to power global economic growth. The lowest emissions scenario reflects a future in which global greenhouse gas emissions are reduced through a rapid transition to low-carbon energy sources.

Figure 4-12. Median Change in Cooling Degree Days from Historical (1981–2010) Average for Average Year between 2030 and 2049 under Two Emissions Scenarios[111]



The average number of cooling degree days are expected to increase significantly by 2040, particularly in southern parts of the country. Projected changes for the higher emissions scenario (*right panel*) are much greater than under the lower emissions scenario (*left panel*).

Power-sector system costs increase with higher temperatures, particularly as additional capacity is built to meet higher peak demand. Higher air temperatures also reduce the generation capacity and efficiency of thermal generation units. Both of these factors were taken into consideration by modeling conducted for the QER. Models showed the likely range of total power system costs[m] increasing by 2 percent to 7 percent (with a median value of 4.5 percent) under the lowest greenhouse gas emissions scenario, rising to 4 percent to 11 percent under the highest emissions scenario.[112] The scale of these modeled costs illustrates why electricity system planners should consider how best to incorporate possible weather changes into load forecasting and other considerations that affect investment planning for the electric power sector. Increased earth observation and modeling of local-scale climate effects to improve forecasting would benefit electricity system planning and could reduce costs.

Extreme temperatures also increase the potential for electrical equipment to malfunction. For example, transformers do not last as long when overloaded to meet peak demand, particularly when they are simultaneously exposed to high temperatures that exceed the heat ratings for which they were designed.[113] When planning for future investments, it may become important for utilities to proactively invest in transformers with higher heat ratings to reduce the potential for overloading under future, warmer conditions.

A continuation of sea-level rise, in conjunction with storm surges caused by tropical cyclones, hurricanes, and nor'easters, will increase the depth and the inland penetration of coastal flooding, thus increasing the frequency with which electricity assets are exposed to inundation during storm events.[114] These challenges are exacerbated by the fact that some coastal areas may be experiencing load growth—rapid population growth and development in coastal areas—which is expected to continue in the coming decades.[115, 116]

Another aspect of uneven impacts is that low-income and minority communities are disproportionately impacted by disaster-related damage to critical infrastructure.[117] These communities often do not have

[m] Calculated in net present value terms, between 2016 and 2040, using a 5 percent discount rate.

the means to mitigate or adapt to natural disasters and disproportionately rely on public services, including community shelters, during disasters. As a result, there may be a Federal role in providing technical and financial resources to help states and localities prioritize resilience investments in critical public infrastructure that would protect the most vulnerable communities.

4.3.3 Electricity and Natural Gas System Interdependencies

A key interdependency (and vulnerability) for all economic sectors and critical infrastructures is reliance on electricity, making its reliability a fundamental need and requirement across the entire economy. Many of these interdependencies are growing, such as the interdependency of electric and natural gas systems.

The reliability of the Nation's electricity system is increasingly linked to the reliability of natural gas pipelines and associated infrastructure. On May 24, 2016, NERC released a special assessment of gas-electric interdependencies, which included an investigation of the potential reliability risks to the Nation's bulk power system due to increased reliance on natural gas. NERC found that areas with growing reliance on natural gas-fired generation are increasingly vulnerable to gas supply disruptions. These concerns were reinforced by NERC's latest long-term reliability assessment, which was released in December, 2016.

Unlike other fossil fuels, natural gas is not typically stored onsite and must be delivered as it is consumed.[n] In many regions, sufficient gas infrastructure is a key requirement for electric reliability. An interruption in natural gas deliveries could result from extreme weather or *force majeure* events, as well as from low-probability events that could unexpectedly remove infrastructure from service, such as a well malfunction, as seen in the underground storage leak in Aliso Canyon, California. Extreme weather events, such as in the Southwest outages of 2011, can simultaneously increase energy demand for gas and electric heating, while reducing supplies in the affected region.[118] Operators may be able to respond to disruptive events by rerouting gas onto other pipelines, as was the case during a 2016 disruption to the Texas Eastern Pipeline.[119] Electric curtailments also have the potential to reduce gas available to gas-fired generators. For example, in 2011, power outages disabled electric-powered gas compressors on well gathering lines, which reduced supplies of natural gas to New Mexico.[120] In addition to physical natural gas disruptions' impact on the electricity system, the electricity sector's increasing reliance on natural gas raises serious concerns regarding the need to secure natural gas pipelines against emerging cybersecurity threats. Thus, the adequacy of cybersecurity protections for natural gas pipelines directly impacts the reliability and security of the electric system.

The vulnerabilities due to natural gas and electric system interdependency are the subject of ongoing regulatory reforms, physical upgrade efforts, and industry collaboration. Some ISOs have undertaken surveys of critical gas facilities to ensure that these facilities are exempt from potential load-shedding plans in the event of a system emergency, and FERC has allowed communication of proprietary and other non-public operational information between the gas and electric industries to continue in order to facilitate further sharing of critical reliability issues.[121] To date, many stakeholders have performed extensive analysis to improve real-time and near-term operations and planning in order to address natural gas-electricity interdependencies. One result has been FERC issuing a final ruling requiring interstate natural gas pipelines to change their pipeline nomination schedules to better conform to dispatch

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[n] Some natural gas power plants also have the ability to operate on alternatives to pipeline-delivered natural gas, such as fuel oil and local stores of liquefied natural gas or liquefied petroleum gas. In addition, note that potential deliverability challenges for coal have also been documented. For example, see Energy Information Administration, "Coal Stockpiles at Coal-Fired Power Plants Smaller than in Recent Years," Today in Energy, November 6, 2014, http://www.eia.gov/todayinenergy/detail.cfm?id=18711. See also Department of Energy (DOE), *Natural Gas Infrastructure Implications of Increased Demand from the Electric Power Sector* (Washington, DC: DOE, 2015), v, http://energy.gov/epsa/downloads/report-natural-gas-infrastructure-implications-increased-demand-electric-power-sector.

scheduling in organized electricity markets.[122] Most coordination efforts have been focused on short-term planning and operations. Mid- and long-term planning coordination is also being explored to properly plan for long-term assets like electric transmission and natural gas pipelines. However, coordinated long-term planning across natural gas and electricity can be challenging as the two industries are organized and regulated differently.

Underground Storage Leak in California Driving Natural Gas Storage Safety and Reliability Improvements[123]

On October 23, 2015, the largest methane leak from a natural gas storage facility in U.S. history was discovered by the Southern California Gas Company at well SS-25 in its Aliso Canyon Storage Field in Los Angeles County. The leak continued for nearly four months until it was permanently sealed on February 17, 2016. In the interim, residents of nearby neighborhoods experienced health symptoms consistent with exposure to odorants added to the gas; thousands of households were displaced; and the Governor of California declared a state of emergency for the area. Approximately 90,000 metric tons of methane were released from the well, although estimates vary, and the State of California is continuing its analysis. The incident also created serious energy supply challenges for the region and prompted broader public concerns about the safety of natural gas storage facilities.

From an electric reliability perspective, the continued shutdown of this facility has been significant because it is a key component of the Southern California gas system serving customers in the Los Angeles Basin and San Diego, particularly many gas-fired power plants. Curtailments of gas deliveries were expected to cause electric reliability problems in the summer of 2016. Such disruptions were avoided, however, due to the combined effects of comparatively mild summer weather, intensified electric demand response efforts, coordinated maintenance programs, and extraordinary management of the region's gas delivery system. The possibility of gas and electric delivery problems remains a concern, however, for the winter of 2016–2017, and additional preparation and coordination are required in order to avoid gas and electric curtailments.

In April 2016, the Obama Administration convened an Interagency Task Force on Natural Gas Storage Safety to support state and industry efforts to ensure safe storage of natural gas. Congress codified the Task Force through the Protecting our Infrastructure of Pipelines and Enhancing Safety Act, which was signed into law by President Obama in June 2016. The legislation created a task force established by the Secretary of Energy that consists of representatives from the Department of Transportation, Environmental Protection Agency, Federal Energy Regulatory Commission, and the Department of the Interior. The Protecting our Infrastructure of Pipelines and Enhancing Safety Act tasked the group with performing an analysis of the Aliso Canyon event, making recommendations to reduce the occurrence of similar incidents in the future, and required that Pipeline and Hazardous Materials Safety Administration promulgate minimum safety standards for underground gas storage that would take effect within 2 years.

In October 2016, the Task Force released a report, called *Ensuring Safe and Reliable Underground Natural Gas Storage*, and 44 recommendations. These recommendations address concerns regarding the integrity of wells at underground natural gas storage facilities, public health and environmental effects from leaks like the one at the Aliso Canyon facility, and energy reliability concerns that could arise in the case of failures at such facilities in the future.

4.3.4 Combined Threats to the Grid

The stochastic nature of certain events such as hurricanes and earthquakes makes the probability of two closely spaced, co-located events very low. However, an intelligent attacker may plan to use the occurrence of one naturally occurring, high-intensity, and low-frequency event to amplify the impact of a physical, cyber, or electromagnetic pulse attack.[124] While electric power systems are generally resilient and quick to recover from failures caused by most natural and accidental events, the National Academy of Sciences concluded that an intelligent multi-site attack by knowledgeable attackers targeting specialized components, like power transformers, could result in widespread, long-term power outages from which it could take several weeks to recover.[125] Another combined threat is the simultaneous occurrence of a severe heat wave during a prolonged drought, which is expected to become increasingly likely in certain regions, such as the U.S. Southwest.[126]

4.3.5 Physical Attacks on the Grid

Incidents such as a series of as-yet unexplained attacks on exposed electricity substations—including the Metcalf incident in California and the attack on the Liberty substation in Arizona—have raised the public's consciousness about the vulnerability of the U.S. electricity grid and the need for the United States to address these vulnerabilities. With an increased focus on physical security, NERC developed Critical Infrastructure Protection (CIP) Standards (CIP-014) in 2014 to address the physical security risks and vulnerabilities of critical facilities on the bulk power system.[127] The Reliability Standard requires transmission owners that meet specific voltage criteria to identify and then protect facilities that, if rendered inoperable or damaged, could result in instability or uncontrolled separation within an interconnection. Transmission owners must also complete third-party verification of their analyses and mitigate the identified areas of concern. Per NERC, the initial risk assessments of critical facilities (including transmission stations, substations, and control centers) were completed by October 1, 2015, while the third-party review of proposed changes to security plans and mitigation strategies was to be completed by November 24, 2016.[128] All entities subject to NERC CIP-014 Standards must retain data and/or evidence of compliance, as described by NERC guidance.[129]

4.3.6 Evolving Cyber Threats to the Grid

The integration of cyber assets to electricity infrastructure presents unique and significant challenges for maintaining and planning for reliable and resilient grid operations. The current cybersecurity landscape is characterized by rapidly evolving threats and vulnerabilities juxtaposed against the slower-moving prioritization and deployment of defense measures. This gap is exacerbated by difficulties in addressing vulnerabilities in operational technologies that cannot easily be taken offline for upgrades, and the presence of significant legacy systems, as well as components that lack computing resources to incorporate new security fixes. Also, any operational changes must be implemented by the thousands of private companies that own and operate electricity infrastructure.

Sector transformation based on a two-way flow of energy and information between grids and consumers brings to the foreground the importance of Federal Government engagement in helping to manage and mitigate vulnerabilities inherent in 21st-century modernization. Interoperability standards, in particular, have the potential to enhance cybersecurity. Improved tools, analytic methodologies, and demonstrations would serve to clarify the circumstances where improved interoperability can improve grid cybersecurity by standardizing security solutions such that utilities can select 'plug-and-play' options to mitigate cybersecurity issues. To this end, there is a role for the Federal Government to facilitate state and utility adoption of interoperability standards that provide high societal net benefits through providing high-quality and trusted information to decision makers.[130]

While cyber attacks on the U.S. grid and affiliated systems have had limited consequences to date, attacks elsewhere in the world on energy systems should be seen as an indicator of what is possible. Threats can emerge from a range of highly capable actors with sufficient resources, including individuals, groups, or nation-states under the cloak of anonymity.

As noted, the 2015 cyber attack on the Ukrainian electric grid was the most sophisticated cyber incident on a power system to date. On December 23, 2015, Ukraine experienced widespread power outages after malicious actors remotely manipulated circuit breakers across multiple facilities in a series of highly coordinated attacks.[131] The event compromised six organizations, including three electric distribution companies; disconnected seven 110 kilovolts and 23 35-kilovolt substations (which would straddle Federal and state jurisdiction in the United States); rendered equipment inoperable; overwhelmed the call center with a denial-of-service[o] event to prevent people from reporting outages; and left 225,000 without power for 1 to 6 hours.

4.3.6.1 Grid Communication and Control Systems

Deploying smart grid technologies can support increased grid systems' observability and reliability by allowing more real-time awareness via sensors, which enable self-healing systems like fault location and service restoration. At the same time, deployment of smart technologies and DERs can provide new vectors for cyber attacks. While not yet a significant issue, this is a growing and significant concern in a grid with two-way, end-to-end flows of electricity. While the likelihood that a malicious actor could bring down large regions of the electric grid by manipulating distributed energy and behind-the-meter equipment is currently low, the risks may change as distributed energy and other advanced technologies increase in number, are operated in aggregation, and are used by the bulk power system to manage and shape load. Smart meters track detailed power usage and allow for two-way communication between the utilities and end users via smart grid technology, which can include remote customer connection and disconnection. Hackers targeting this technology could cause erroneous signals and blocked information to cut-off communication, cause physical damage, or more, and disconnect large numbers of customers to disrupt the grid.

Recently, some utilities have been moving toward combining their physical security and cybersecurity business centers to create a "centralized operations center" organized under a chief information security officer responsible for cybersecurity.[132] These centralized operations centers generally work toward meshing informational technologies with physical operational technologies. Other utilities have their cybersecurity risk management program located in existing information technology (IT) security departments.[133] However, some utilities suffer from a lack of practical cyber expertise. A recent survey showed that 37 percent of utilities surveyed make cybersecurity decisions at the executive level, 47 percent at the management level, and only 16 percent by professional staff.[134]

Reported cybersecurity incursions into industrial control systems (ICS) within the U.S./Canadian energy sector, have decreased slightly, from 111 reported incidents in 2013,[135] to 79 incidents in 2014,[136] and 46 in 2015.[137] This is occurring despite an overall increase in the number of reported ICS incidents across the broader economy, and so far, these incursions have been unsuccessful at inhibiting or disrupting power system operations.[138] Typical cybersecurity events impacting the grid have been mainly limited to gaining access to networks through phishing emails or infecting flash drives with the hope that they will be connected to a network. Russian hacking of utility systems as seen in the Ukraine incident, however, underscores that such events should not be viewed simply as information theft for business purposes. The more common cyber intrusions impacting the electricity subsector today could be preparatory activity for disruptive attacks in the future.

4.3.6.2 Mitigation of Threats to the Grid

Detecting anomalies and sharing information across organizations are critical measures to enhance grid security; this covers everything from prevention to mitigation and recovery from cyber attacks. However, it is difficult to identify cyber intrusions when no changes or disruptions to system operations are evident or detectible. Furthermore, utilities report a lack of intrusion detection systems,[139] which allow security personnel to identify anomalies in cyber systems and to obtain forensic data.[140] Organizations vary

[o] Distributed denial of service refers to the prevention of authorized access to multiple system resources or the delaying of system operations and functions.

monitoring systems, and nearly every utility will require distinct intrusion detection system specifications due to utility-specific IT and operational technology system configurations.[141, 142]

Even in optimized detection environments, programs and institutions that wish to facilitate sharing within and across industry and government face challenges, including human delays in sharing information, procedural barriers related to classified information, and liability and privacy concerns from industry that inhibit sharing. For example, Federal agencies maintain classified information related to cyber and physical security threats. While some of this information is shared via existing mechanisms, including the Electricity Information Sharing and Analysis Center and DOE's Cybersecurity Risk Information Sharing Program,[p] sector representatives routinely ask for more in-depth, synthesized, and timely security information.

When digital components of the grid have been compromised, manual operations[q] can be a temporary alternative. Utilities may need to maintain mechanical controls to prevent degradation and loss of operability.[143] Some subject matter experts suggest utilities are also leveraging decades of experience with mutual assistance agreements to set up cyber assistance in the event of a cyber attack, but response and recovery from cyber attacks pose distinct challenges that are generally not covered by existing mutual assistance programs. The Electricity Subsector Coordinating Council established the Cyber Mutual Assistance Task Force to convene industry experts and develop a cyber mutual assistance framework. The Federal Government could play a convening role for the electricity sector and thereby accelerate efforts to design and employ cyber mutual response programs and ensure swift grid recovery after a cyber attack.

4.3.6.3 Grid Cybersecurity Workforce Gaps

A shortage of skilled cybersecurity personnel across government and electricity industry presents challenges to meeting response and recovery needs in the aftermath of a large, disruptive cyber event. The power grid is a cyber-physical system, requiring a cross-disciplinary workforce dedicated and trained to design, manage, and protect such complex systems.[144] Companies face challenges in designating sufficient personnel for system security.[145] In addition to the challenge of incorporating sufficient cyber and physical security expertise into their businesses, recruiting and maintaining a workforce that is adequately trained is a growing challenge. To address emerging cybersecurity risks, the United States requires a workforce adept in a variety of skills, such as risk assessment, behavioral science, and familiarity with cyber hygiene.[r]

4.3.6.4 Smart Grids and Related Risk

Deployment of smart grid technologies—sensors and the ability to collect and analyze more data faster—supports increased observability of grid systems and thereby contributes to increasing grid reliability. However, in the absence of adequate cyber protections, deployment of smart technologies and DERs could increase system vulnerabilities. Because the deployment of these technologies is still in the

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[p] In partnership with industry, the Department of Energy's Office of Electricity Delivery and Energy Reliability has been supporting the Cybersecurity Risk Information Sharing Program (CRISP), which is a collaborative effort with private energy sector partners to facilitate the timely sharing of threat information and the deployment of situational awareness tools to enhance the sector's ability to identify threats and coordinate the protection of critical infrastructure. In August 2014, the North American Electric Reliability Corporation and the Electricity Subsector Coordinating Council agreed to manage CRISP for its sector.

[q] Use of mechanical switches and controls rather than computer-based controls.

[r] Cyber hygiene is a set of practices designed to maintain cyber security and keep out the "bugs" from a digital system. Just as hand washing keeps germs from entering the body, practices such as deleting data from cloud storage when it is no longer needed or prohibiting the download of non-essential applications, which might contain viruses, are intended to keep intrusions out of a computer system.

relatively early stage, electricity regulatory bodies should ensure that cyber protection planning includes advanced cyber protection protocols when execution occurs.

Automated smart meters, for example, are increasingly relied on to track actual power usage and allow for two-way communication between the utilities and end users. Hackers targeting this technology could cause disrupted power flows, create erroneous signals, block information (including meter reads), cut off communication, and/or cause physical damage. Also, some supervisory control and data acquisition (SCADA) systems rely on modern communication infrastructure or a blend of modern and conventional, (i.e., telephone lines communication channels to achieve the same ends), which could make SCADA communications more accessible to hackers and more vulnerable to disruptions. Hacking may come through access to hardcoded passwords,[s] system backdoors,[t] passwords in clear text,[u] lack of strong authentication,[v] and firmware vulnerabilities.[w, 146, 147]

Development of Security Metrics

A major impediment to common metrics is variation in how to measure benefits (or conversely, the cost of interruptions), such as “freight cost per mile” or “value at risk.” After the attack on the Metcalf substation in April 2013, the California Public Utilities Commission analyzed methods of quantifying distribution system security.[148] Metrics included copper theft, successful or unsuccessful intrusion or attack, and false or nuisance alarms; the condition of all monitoring equipment and the performance of security personnel in training exercises and on tests; results of substation inspections; instances of vandalism or graffiti; and problems with access control, number of malfunctions of security equipment, or camera coverage.

4.3.6.5 Comprehensive Vulnerabilities Assessments

Reliability requirements in the face of human and natural threats require enterprises, as well as state and Federal entities, to seriously assess vulnerabilities and prioritize investments to ensure that highly reliable service continues. These entities diligently work to identify and mitigate risks to grid reliability. However, given the scope and complexity of risks, especially related to new vectors such as cyber attacks, there may be a need to improve coordination not only around assessing event outcomes, but also around maintaining contemporary assessments of vulnerabilities, their associated risks, and professional estimates of their likelihood.

4.3.7 Gaps in National Reliability, Security, and Resilience Authorities and Information

The primary Federal entities with roles related to security and resilience of the electric grid under normal and emergency conditions are DOE, the Department of Homeland Security (DHS), the Department of Commerce, and FERC.[149] These entities’ roles span research and development, standards and guidance, information-sharing mechanisms, and the coordination of resource deployment during emergency events.

Existing authorities cover a wide breadth of Federal Government responsibilities, yet certain gaps remain in implementing comprehensive reliability, security, and resilience measures. For example, the Fixing America's Surface Transportation (FAST) Act granted the President new authorities to protect critical infrastructure against electromagnetic pulse, cyber, geomagnetic disturbances, and physical threats, but not to take anticipatory action for natural disasters and extreme weather. Nevertheless, certain extreme

[s] Passwords that cannot be changed by the user

[t] Alternative access (to secure data or functions) that bypass normal security procedures

[u] Passwords stored without encryption

[v] Not scrambling login information, which enables a digital eavesdropper to capture passwords

[w] Generic catch-all for hardware-based exploits (rather than software-based)

weather events (e.g., heat waves, hurricanes) can be easier to anticipate,[150] and to date, they have caused significantly more direct physical harm to the electric grid than have malicious acts. Taking actions in advance of an impending threat can have significant positive effects in reducing power outages,[151] so extending this authority for all hazards would be a great benefit for protecting the grid.

The lack of access to data represents another challenge to Federal agencies to enhance the security and resilience of the grid. Given that the majority of electricity infrastructure is privately owned, the Federal Government must rely on industry data collection activities to understand the vulnerability and security landscape of the electric grid**.** Furthermore, as noted earlier, utilities report SAIDI, SAIFI, and CAIDI statistics in inconsistent ways,[152, 153] limiting the ability of governments to independently conduct robust risk assessments of the grid. DOE and FERC in particular lack access to data on critical grid assets and their vulnerabilities. In order to support the President in executing new anticipatory security authorities under the FAST Act, addressing this information deficit is a priority.

NERC collects certain data, in its role of performing grid reliability assessments and supporting the development of reliability and security standards, but NERC does not make all of that data available to government agencies. DOE has some limited visibility into critical electricity infrastructure through tools like EAGLE-I[x]; additional system data, to determine, for example, where there are critical vulnerabilities, are needed to exercise the new emergency authorities granted to the President and the Secretary of Energy under the FAST Act.

One of the most prominent examples of this data gap is a lack of information on risk mitigation practices at the utility level, including information regarding participation in risk mitigation programs, a utility's specific risk mitigation practices, and spare equipment specifications and numbers for critical infrastructure, such as transformers. Without with enhanced and appropriately protected data on utility practices, component part reserves, and an increase in awareness on a range of additional topics—such as transformer configuration, the direct current resistance of various components, and substation grounding resistance values—DOE's ability to understand the extent to which infrastructure will be improved, enabling DOE to better fulfill key statutory and executive responsibilities.

4.4 Markets and Their Impact on Reliability and Resilience

Organized wholesale markets are recent innovations in the century-plus life of the electricity sector. They were developed and implemented beginning in the 1990s on the heels of state legislative and regulatory direction, but are considered Federally regulated structures that adhere to rules set by FERC and reliability standards set by NERC. Organized markets operated by ISO/RTO include time-delineated markets (e.g., day-ahead, hour-ahead, and real-time), as well as system support services such as spinning reserve and non-spinning reserve, often referred to as Ancillary Services. Commodity exchanges, such as the Intercontinental Exchange (ICE) and the New York Mercantile Exchange, offer future contracts for location-specific electricity trading (referred to as hubs in U.S. markets). These short-term markets are designed to provide price discovery on the marginal cost of power production and delivery.

Seven U.S. regions have operating ISOs/RTOs that manage centrally organized wholesale markets for energy trades (i.e., MW-hour only, as compared to capacity trades that are for MW-only transactions). Together, these trades play an important role in operating and economically optimizing regional grids and

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[x] EAGLE-I, which stands for *Environment for Analysis of Geo-Located Energy Information*, is an interactive geographic information system (GIS), created and managed by DOE. It allows participants to view and map the nation's energy infrastructure and obtain near real time informational updates concerning the electric, petroleum and natural gas sectors within one visualization platform.

ultimately delivering fair-priced electricity to the Nation's consumers. Aspects of the bilateral model exist in the RTO/ISO regions, particularly in the SPP and Midcontinent ISO. Also, several RTO/ISOs operate ancillary services markets and some run capacity markets designed to help ensure that total electricity resources will be sufficient to meet the immediate demand for electricity.

Wholesale electricity trade occurs through bilateral transactions, as well. These transactions vary in duration of contract, as well as in volume, daily timing, and duration of delivery. Trade differs regionally as a function of distinctive characteristics of regional grids. Bilateral trade volumes tend to be much larger than daily trade in ISO/RTO markets short-term markets.

There are many reasons that wholesale markets developed—from requirements for open-access transmission systems, which enable development of competitive power generation, to the need to value resources in more refined ways, which help ensure that system reliability is maintained across a broad spectrum of possible disruptive situations. For example, peak mitigation requires generators to perform differently than a traditional baseload production model might specify, and therefore, it may be more valuable than day-ahead committed baseload generation. Increasingly, frequency regulation is as important as peak mitigation, but frequency regulation methods may differ at the transmission level compared to the distribution level. For example, increasingly, distribution frequency regulation occurs at much faster millisecond speeds compared to transmission frequency regulation.

As noted, an array of new and evolving business models—aggregators, consumer generators, and an evolving generation mix—have emerged from the adoption and integration of new technologies and their associated economics. These developments are raising jurisdictional and market questions. For instance, at the bulk power (wholesale) level, short-run markets are deemed by regulators to be workably competitive, but concerns have been raised about the ability of short-run markets to address longer-term issues, such as ensuring that adequate capacity will be available when needed. Also, wholesale markets have successfully integrated independent generation into system operations, and efforts have been underway for some time to make individual DER providers (principally DR) and aggregators of DERs (also principally DR) active market participants. More visibility of and reliance on these potential resources is needed, however, to maximize their value.

At the local and utility level (retail), electricity choice markets that are intended to bring new services and lower prices to consumers have seen minor successes, and consumer demand for these services is a significant driver of change. Some states are exploring new structures that would open retail commodity trade to emulate wholesale markets. These models are under consideration in the State of New York, for instance, and are often referred to under the rubric Distribution System Operator models.

4.4.1 Organized Wholesale Markets and Reliability

Electricity production and delivery have traditionally been organized around large centralized power stations and high-voltage transmission lines. Power is shipped over long distances before voltage is stepped down to flow through distribution systems for delivery to consumers. This system often is referred to as the "bulk power system." Organized wholesale markets are structured to provide price discovery of wholesale electricity costs in the bulk power system. Costs relating to bulk power are more than half—and up to two-thirds—of most customers' electricity bill. The significance of costs to customers and the associated economic value of electricity to them is why the functioning of wholesale markets is so important to the overall operation of the electricity supply chain.

High-voltage transmission infrastructure tends to be much more networked than distribution systems. Networked infrastructure increases system resilience by enabling grid operators to reroute power flows when a single line or multi-line pathway is compromised. Transmission infrastructure already is significantly automated (through such tools as Automated Generator Control and advanced SCADA systems) and information intensive. New tools, such as highly granular system visualization solutions, synchrophasors, smart relays, and smart inverters increase network resilience. While changing weather patterns and storm intensity are impactful, the structure of most transmission networks is already hardened against such disruptive factors. What remains to be addressed more comprehensively is how transmission grids can resist cyber incursions that could paralyze wide areas of a large-scale interconnect, such as the Western or Eastern Interconnection. These considerations were discussed in the preceding section.

Stakeholder input as part of the QER process, FERC dockets, National Association of Regulatory Utility Commissioner meetings, and other venues have consistently raised the following issues as part of ongoing grid operations and planning efforts: [154]

- The roles of mandatory capacity markets in PJM, ISO-New England, and parts of New York ISO
- The ability of bulk power markets, especially in RTO/ISO markets, to incentivize new generations in addition to natural gas and state-Renewable Portfolio Standard mandated renewables, thus helping with resource diversity, resource adequacy, and long-term decarbonization
- The incorporation of state policy and environmental goals in RTO/ISO markets
- The ability to integrate increasing wind and solar generation at lower costs, while allowing remaining traditional sources of generation to earn sufficient revenue to continue to provide needed generation and reliability services
- The ways to address the increasing changes occurring at the distribution level
- The continued evolution of transmission planning and seams issues between major bulk power market regions.

In addition to the issues noted above, analysis of markets with high volumes of VERs, notably California, point to emerging impacts, which eventually will affect other regions as their VERs increase as an overall share of the resource mix. It is in these emerging issues that new resilience and flexibility considerations come into focus. A 2014 study, "Investigating a Higher Renewables Portfolio Standard in California," which involved Los Angeles Department of Water and Power, Pacific Gas & Electric, Sacramento Municipal Utilities District, Southern California Edison Company, and San Diego Gas & Electric as sponsors. The study identified emerging operations and planning issues under a 50% RPS standard (note that CAISO already consistently handles up to 40% renewable resources on its system).[155] Concerns in the study included over-generation as a critical management challenge that occurs when "must-run" generation—non-dispatchable renewables, combined-heat-and-power, nuclear generation, run-of-river hydro, and thermal generation that is needed for grid stability—is greater than loads plus exports. The principal mitigation for over-generation in many current systems is curtailing renewable resource contributions to the overall resource mix. Future systems may increase the role of storage, DR, and flexibility to manage over-generation. Second, renewable resources can change supply patterns suddenly, and as the sun sets, significant solar production disappears, requiring a need for fast ramping generation to fill in for lost solar resources.

The study also found that a variety of integration solutions can reduce the cost of a high renewable scenario. Improvements in regional coordination—which address jurisdictional challenges when state regulation cannot reach beyond state borders, and Federal regulation cannot easily reach into distribution systems—could improve integration. DR, especially advanced practices that increase overall DR reliability, can support higher levels of VER integration. Energy storage is an important technology that must be developed and deployed as a key tool for VER impact mitigation. Finally, VER portfolio diversity is a key success factor as more VER volume impacts grids.

Resilience is an important transmission network matter, but its traditional treatment has occurred as part of ongoing, FERC-approved investments to meet NERC standards and to ensure reliable operations in regionally distinct conditions. The emergence of VERs and their growing contribution to resource mixes in some U.S. regions bring with them a need to more robustly differentiate reliability investments from resilience investments. As noted, resilience in transmission networks with high VERs requires behavioral changes in system operations, as noted above. In bulk power systems with wholesale market overlays, resolving valuation matters where curtailment of VERs is a valid resilience methodology is a serious matter. To avoid complex issues of how to compensate curtailed VERs adjustments in market designs and new market developments are required. For example, in California, one element in an overall VER management model is the Energy Imbalance Market created by CAISO, which involves PacifiCorp, a large multi-state utility based in the Pacific Northwest. These initiatives tend not to be considered resilience efforts when in fact they are important contributors to both system reliability and longer-term resilience in high VER systems. In short, as resource mixes change with decarbonization efforts of grid operators and power producers, the role of resilience grows more important as a distinct compliment to established reliability management investments and techniques.

4.4.2 The Role of Markets in Downstream Electricity Delivery Services

Presently, downstream electricity delivery services provided by investor-owned and public utilities—whether integrated with retail customer service or separated into wires operations and competitive retail services—do not function with organized "retail commodity markets" that emulate upstream wholesale markets. But, there are aspects of market mechanisms that impact grid operations and provide proxies for valuing various types of grid investments for reliability assurance, system flexibility, and network resilience. For example, some distribution systems allow net metering, which involves the sale of power from consumers to grid operators. Pricing of these services is based on state regulatory and ratemaking processes, not auction platforms like those used by ISOs/RTOs. Energy Service providers, retail competitors, and aggregators compete through various sales channels for consumers interested in controlling and/or reducing energy costs, deploying onsite power generation, and adopting microgrids that optimize sources and uses of electricity as an integrated onsite system.

Downstream electricity markets may not yet value commodity electricity in a manner that allows for effective pass-through of wholesale clearing prices in real-time to end-use consumers. Wholesale and retail linkages may develop over time; the New York Reforming the Energy Vision process and consideration of distribution system operator models may provide meaningful guidance for such evolution. Whether realized or not, under appropriate and necessary requirements for visibility of such generation, downstream electricity delivery services achieve enhanced resilience by systematically promoting and integrating advanced DR and energy storage solutions into local grid operations.

Similar to wholesale markets and resilience considerations, distribution system resilience measures can be enhanced by incorporating behavioral systems and processes into specific asset-based investments that harden systems against severe weather-related impacts, physical threats, and cyber-attacks.

4.4.3 Electricity Markets, Reliability, and Resilience

Reliability investments are typically incorporated into ratemaking processes in both investor-owned and public utility institutions. Supplementary investments for recovery from outage events also are handled through established ratemaking processes. Resilience requirements tend to be valued as contributions to reliability and incorporated as part of ratemaking processes. These processes are more easily executed in structures that are traditional end-to-end, vertically integrated electricity delivery services; other market structures complicate reliability and resilience investment decision-making. Short-run markets may not provide adequate price signals to ensure long-term investments in appropriately configured capacity. Also, resource valuations tend not to incorporate superordinate network and/or social values such as enhancing resilience into resource or wires into investment decision making. The increased importance of system resilience to overall grid reliability may require adjustments to market mechanisms that enable better valuation.

4.5 Grid Operations Planning and Resilience

Resilience of the electricity system is increasingly important. Recent weather extremes, climate change impacts, physical security and cybersecurity threats, and a changing workforce have added to the challenges faced by electric utilities, prompting industry to develop new multidisciplinary all-hazards approaches for managing these issues and making the grid more resilient.

Resilience Measures Expedited Restoration after Hurricane Matthew[156]

Hurricane Matthew began impacting the southeast United States on Thursday, October 6, 2016, and the flooding caused by the storm continues to affect North Carolina and South Carolina. The initial effects of the storm were felt from Florida to Virginia, with increased rain and wind causing damage to energy infrastructure. Industry efforts to restore that damaged infrastructure are ongoing and have involved mutual assistance from utilities from across the country. More than 99 percent of customers who lost power had their power restored within 8 days, by 11:00 a.m., on October 14, 2016.

Florida Power and Light has invested $2 billion over the last 10 years, leveraging $200 million in Federal investment through the American Recovery and Reinvestment Act of 2009, to advance smart grid functionalities with technologies, such as advanced smart meters, distribution automation, and advanced monitoring equipment, for the utility's transmission system. Early damage assessments suggest that investments in resilience measures expedited Florida Power and Light's restoration timeline; without these new technologies and functions, it is estimated that restoration efforts would have taken 10–15 days. Florida Power and Light reports that 98 percent of the 1.2 million customers who lost power had their power restored within 3 days.

Government, industry, and the various state energy offices helped coordinate the national effort to restore power following the storm. Government responders helped industry crews access impacted areas, facilitated waivers requested by utilities to use unmanned aerial systems for damage assessments, and provided energy-sector situational awareness reports that informed decisions about where to place limited Federal and state resources. Government responders remained in Georgia, as well as North Carolina and South Carolina, providing assistance until restoration was complete. The response effort built on lessons learned from Hurricane Sandy of 2012.

Resilience enhancement initiatives are generally focused on achieving at least one of three primary goals: (1) preventing or minimizing damage to help avoid or reduce adverse events; (2) expanding alternatives and enabling systems to continue operating despite damage; and/or (3) promoting a rapid return to normal operations when a disruption occurs (i.e., speed the rate of recovery). Resilience relates both to system improvements that prevent or reduce the impact of risks on reliability and to the ability of the system to recover more quickly.

Unlike reliability, there are no commonly used metrics for the resilience of the electric grid, and threats to system resilience are typically associated with disasters or high-intensity and low-frequency events. An additional complication is that the responsibility for maintaining and improving grid resilience lies with multiple entities and jurisdictions, including Federal and state agencies and regulatory bodies, as well as multiple utilities. For investments in electricity sector resilience, approval is generally up to the discretion of state public utilities commissions or equivalent bodies, which are balancing competing, more near-term interests. Furthermore, from the societal perspective, building resilience of critical infrastructure to future disasters involves decision making that also considers social, cultural, and environmental issues, which have both qualitative and quantitative value, from a risk assessment standpoint.[157] Therefore, building resilience to disasters depends upon close coordination among multiple entities, which have varying approaches to measuring electricity system performance and outcomes for society.

Perhaps most relevant is the underlying barrier to prioritizing investments in reliability and resilience that utilities and regulators face.[158] There is no established method for quantifying the benefits of investments, which depend on the occurrence of some events with low probabilities. One exception to this is an order recently released by the New York State Public Service Commission;[159] however, there is a clear need for a set of commonly used methods for estimating the costs and benefits of reliability and resilience investments.

4.5.1 Real-Time Electricity System Monitoring Enhances Situational Awareness

Maintaining situational awareness is an important aspect of overall resilience management in service to maintaining high electricity system reliability. Utilities rely on field personnel to assess and report grid system conditions through site inspections. During emergency situations, utilities' abilities to assess and communicate system status after a large disruption tend to be significantly degraded. Where there is a widespread disruption beyond electricity infrastructure damage, personnel may be responding to a specific emergency situation, which limits work scope. Transportation challenges, such as road blockages and traffic, may also prevent the movement of utility personnel and equipment to assess electricity infrastructure throughout the affected area. Furthermore, wide communication system outages will also limit utilities' ability to assess system conditions. These initial assessment limitations then impede response and recovery planning.[160]

When distribution-level SCADA pairs with a distribution management system, operations can be conducted remotely, increasing the speed at which a utility can identify and locate faults on the distribution system and restore service, as well as manage voltage and reactive power to reduce energy losses and integrate distributed generation and storage technologies.[161]

Analyses of the August 2003 Northeast blackout concluded that it was preventable and that the reliability of the U.S. and Canadian power systems needed an immediate and sustained focus on investments in technologies to promote "situational awareness" and adequate responses to major disturbances.[162] New institutional structures and processes were developed to coordinate information among power pools for improved coordination across systems and across NERC regions for improved coordination of system resource adequacy requirements.

4.5.1.1 Grid Operations and Communications Redundancy

With the increasing interdependence between communications and electricity, redundancy in communications systems is essential to continuity of grid operations. Some utilities have expanded satellite communications capabilities with mobile satellite trailers that can be deployed to field staging areas and include full capabilities for email, Internet, outage management systems, voice-over Internet protocol telephones, and portable and fixed satellite phones. Others have redundant and diversely routed dedicated fiber-optic lines to enable continued operations.[163, 164]

4.5.1.2 Dynamic Line Rating Systems for Transmission Systems

Current transmission system operations rely on fixed ratings of transmission line capacity that are established to maintain reliability during worst-case conditions (e.g., hot weather). Line ratings may also be reduced if ambient conditions are abnormally hot and still. There are times when the conditions associated with establishing line ratings are not constraining, and transmission lines could be operated at higher usage levels. Dynamic line rating systems help operators identify available real-time capacity and increase line transmission capacity by 10 percent–15 percent. Dynamic line rating systems can help facilitate the integration of wind generation into the transmission system.[165] This real-time information about overhead conductors can help further enhance situational awareness, while simultaneously providing economic benefits. Incremental investments that increase the capacity of the existing transmission system can provide a low-cost hedge, as well as enhanced real-time awareness. However, economic, financial, regulatory, and institutional barriers limit incentives for regulated entities to deploy these low-capital cost technologies that could increase transmission capacity utilization.[166] NERC has an important role to play in setting relevant standards, which would drive increased operational focus on dynamic line ratings as part of overall response and recovery planning and execution.

4.5.2 Information Collection and Sharing Can Mitigate Threats to the Grid

The Federal Government has established programs and launched pilots to analyze cyber and physical threat information, share information with industry, and provide technical assistance to state and utility decision makers in their mitigation efforts. The electric sector utilizes resources and participates in these programs, while also collaborating with one another through industry-led initiatives.[y] While several Federal programs facilitate the sharing of threat information with industry, challenges remain with respect to the Federal Government's ability to provide data quickly enough to be useful. Several factors limit timely and effective exchange of information, including human delays in sharing information, procedural barriers related to classified information, and liability and privacy concerns from industry.

One particular challenge is that some government intelligence on threat indicators and vulnerabilities is classified, preventing power sector owners and operators who lack the appropriate security clearances from accessing relevant information. Many sector owners and operators and Federal employees often lack the security clearances to access this information.

Another important information gap is a national repository for all-hazard event and loss data, which would help utility regulators, planners, and communities analyze and prioritize resilience investments. In 2012, the National Academy of Sciences recommended the establishment of such a database[167] to support efforts to develop more quantitative risk models and better understand structural and social vulnerability to disasters.

4.5.3 The Grid and Emergency Response

As not all hazards to the grid can be prevented, local authorities and stakeholders focus on failing elegantly and recovering quickly. Response options can leverage existing capabilities, tools, and equipment to act immediately before, during, and after a disruptive event. Emergency response resources can be provided by public and private sectors and can include mobile incident management and command centers, mutual aid agreements, and access to specialized materials.[168]

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[y] For example, in 2011, Edison Electric Institute, in conjunction with private-sector experts and its member utilities, initiated the Threat Scenario Project to identify threats and practices to mitigate these threats. Identified threats included coordinated cyber attacks, as well as blended physical and cyber attacks. The project established common elements for each threat scenario, including likely targets, potential threat actors, specific attack paths, and the likely impacts of a successful attack. Edison Electric Institute, "EEI Business Continuity Conference Threat Scenario Project (TSP)," (presentation, April 4, 2012), 1, http://www.eei.org/meetings/Meeting_Documents/2012Apr-BusinessContinuity-Treat%20Scenario%20Project_Engels.pdf.

A utility's power restoration and business continuity planning includes year-round preparation for all types of emergencies, including storms and other weather-related events, fires, earthquakes, and other hazards, as well as cyber and physical infrastructure attacks. A speedy restoration process requires significant logistical expertise, skilled/trained certified workers, and specialized equipment. Utility restoration workers involved in mutual assistance typically travel many miles from different geographic areas to help the requesting utility to rebuild power lines, replace poles, and restore power to customers.[169]

Lessons Learned from Severe Outages[170, 171, 172]

After the immediate response to manage the adverse effects of an event, recovery activities and programs take place to effectively and efficiently return operating conditions to an acceptable level. This may entail restoring service to the same level as before the event or stabilizing service to a new normal. Recovery measures usually consist of longer-term remediation measures and include access to critical equipment, municipally owned utility activation, and after-action reporting that would make the grid more resilient to future disruptions.

Hurricane Sandy (and Katrina in 2005) caused significant damage to critical national energy infrastructure and stressed Federal capabilities to protect and restore critical infrastructure. In the aftermath, the White House and Federal Emergency Management Agency (FEMA) conducted detailed analyses of the Federal response to identify challenges and lessons learned and to make recommendations for future disaster preparedness and response efforts. Several common themes emerged about response and recovery:

Ensure mutual aid in the utility sector. In response to Hurricane Sandy, electric utilities mobilized the largest-ever dispatch of mutual aid workers (totaling approximately 70,000), primarily from the private sector but including some government workers.

Grant energy sector restoration crews the appropriate credentials to enter damaged work zones and have priority for fuel distribution. In the storm response, some energy sector repair crews were designated as first responders, giving them priority access to fuel and expediting travel into affected areas. However, not all energy infrastructure repair crews had this status or access. After Hurricane Sandy, the Department of Energy's (DOE's) Office of Electricity Delivery and Energy Reliability recommended that electrical workers, as well as refinery and terminal repair crews, be given appropriate credentials to enter damaged work zones quickly.

Coordinate Emergency Support Function (ESF) 12 functions across Federal agencies. ESF-12, under the National Response Framework, is an integral part of the larger DOE responsibility of maintaining continuous and reliable energy supplies for the Nation through preventive measures and restoration and recovery actions in coordination with other Federal Government and industry partners. In the "Hurricane Sandy FEMA After-Action Report," FEMA noted that ESF-12—coordinated by DOE—struggled to fully engage supporting Federal departments and energy sector partners in addressing energy-restoration challenges. A DOE report on the response to Sandy recommended that DOE permanently deploy DOE/ESF-12 responders to the states and regions so they could provide on-the-ground situational awareness of energy disruptions, establish relationships with State and local energy sector partners, and gain first-hand system knowledge to better coordinate energy preparedness efforts with state and local public and private sector partners.

State governments play a major role in coordinating and directing response and recovery efforts to electricity disruptions. These responsibilities received a boost through DOE grants to states and local governments to support a State Energy Assurance Planning Initiative. Grants were awarded under this initiative in 2009 and 2010 to 47 states, the District of Columbia, 2 territories, and 43 cities.[173] The grants were used over a 3–4-year period to improve energy emergency preparedness plans and to enable quick recovery and restoration from any energy supply disruption. States also used these funds to address energy supply disruption risks and vulnerabilities, with the aim of mitigating the devastating impacts that such incidents can have on the economy and on public health and safety.[174]

Each state under the Energy Assurance Planning Initiative was required to track energy emergencies, to assess the restoration and recovery times of any supply disruptions, to train appropriate personnel on energy infrastructure and supply systems, and to participate in state and regional energy emergency exercises that were used to evaluate the effectiveness of their energy assurance plans. States were also required to address cybersecurity concerns and to prepare for the challenges of integrating smart grid technologies and renewable energy sources into their plans. Because of the initiative, nearly all state and territory governments and select local governments have Energy Assurance Plans in place. A review of the State Energy Assurance Plan was recommended to occur every 2 to 3 years, and to date some states have undertaken update efforts.[175]

4.5.4 Back-Up Power and Spare Transformers for Emergency Response

During outages and emergencies, fast but safe system recovery is the mission of a utility. Part of the effort to maintain service while power is being restored involves the use of back-up power along with speedy deployment of equipment spares that may have failed.

Back-up power sources can be used to bypass existing distribution service lines until they are restored, and they are used by customers in lieu of utility service. Critical facilities, such as hospitals, maintain robust back-up power systems. Microgrids offer islanding solutions for large facilities and campuses by their integration of DG, storage, and demand side management solutions. According to an Argonne National Laboratory report, “One hundred percent of the following assessed facility groups have an alternate or back [-up] power in place: Banking and Finance; Critical Access Hospitals; Private or Private Not-for-Profit General Medical and Surgical Hospitals; State, Local, or Tribal General Medical and Surgical Hospitals.”[176] More than 75 percent of other users, including manufacturing, wastewater, hotels, arenas, retailers, offices, and law enforcement offices, also maintain some form of alternate or back-up power source.[177] Critical data centers and server centers also have robust back-up systems that enable islanding from the impacts of grid failures.

It is also important to ensure that key grid components are available in the event of emergencies. Utilities have robust supply chains and inventory management systems that help ensure that spare transformers, including the stocking of interchangeable spare transformers,[178] the ordering of conventional spares in advance, and the early retirement of conventional transformers for use as spares. Conventional spares are typically used for planned replacements or individual unit failures; but these transformer spares can also be used as emergency spares. Under this approach, the spares are identical to those transformers that are to be replaced and often stored at the substation next to existing transformers—which allows for quick energization without the transformer being moved. The close proximity of such spares to the existing transformers can lead to potential high-intensity and low-frequency physical attacks or weather events. Some utilities retain retired transformers to repurpose them as emergency spares.[179] These are transformers that have retired but not failed, which would allow their use as temporary spares until a new transformer is manufactured and transported.[180] Utilities also use mobile transformers and substations to temporarily replace damaged assets, much in the way that mobile power is used for resilience and repowering efforts.

Nuclear Regulatory Commission Requirements

The Nuclear Regulatory Commission has issued several cyber and physical security regulations for nuclear power plants covering cybersecurity plans, response and recovery strategies from aircraft crashes, and training for security personnel, among other measures. For example, 10 Code of Federal Regulations § 73.54 stipulates that licensees provide "…high assurance that digital computer and communication systems and networks are adequately protected against cyber-attacks…" Each nuclear power plant must submit a cybersecurity plan and implementation schedule, which is then reviewed by the Nuclear Regulatory Commission.[181] Additionally, the Nuclear Regulatory Commission is also required to conduct "force-on-force" exercises at nuclear power plants at least once every three years. These security exercises deploy a mock adversary force attempting to penetrate a plant's critical locations and simulate damage to target safety components. These exercises provide an evaluation of power plant security and identify deficiencies in security strategy, plans, or implementation. When these deficiencies are identified, additional security measures must be promptly implemented.[182] These regulations have led to significant investments by nuclear power plant operators.

Some utilities retain retired transformers to repurpose them as emergency spares. These are transformers that have retired but not failed, which would allow them to be used as temporary spares until a new transformer is manufactured and transported.[183] Utilities also use mobile transformers and substations to temporarily replace damaged assets. "A mobile substation includes a trailer, switchgear, breakers, emergency power supply, and a transformer with enhanced cooling capability. These units enable the temporary restoration of grid service while circumventing damaged substation equipment, allowing time to repair grid components. Mobile transformers are capable of restoring substation operations in some cases within 12–24 hours."[184]

Finally, utilities preparing for response after cyber disruptions are also taking measures to build redundancies for cyber infrastructure. Some of these measures include building back-up control centers for full functionality and developing independent, secured control mechanisms that would provide limited vital functions during an emergency.[185] NERC CIP standards require utilities to maintain back-up energy management systems to manage bulk electric system generation and transmission assets.[186]

4.5.4.1 Equipment Constraints on Speedy Restoration: Large Power Transformers

The shortage of critical electrical equipment can cause significant delays for power restoration. Specifically, the loss of multiple large power transformers (LPTs) may overwhelm the system and cause widespread power outages, possibly in more than one region, increasing vulnerability and the potential for cascading failures.

Replacement of multiple, failed LPTs is a challenge, due to the cost and complex and lengthy process involving the procurement, design, manufacturing, and transportation of this equipment. These processes can take months, depending on the size and specifications of the needed LPTs, even under an accelerated schedule and normal transportation conditions. Utilities mitigate the risk of losing LPTs through several strategies, including adopting measures to prevent or minimize damage to equipment, purchasing and maintaining spare transformers (conventional spares), identifying a less critical transformer on their system that could be used as a temporary replacement (provisional replacement transformer), and/or setting up contracts to procure a transformer through a mutual assistance agreement or participation in an industry sharing program.

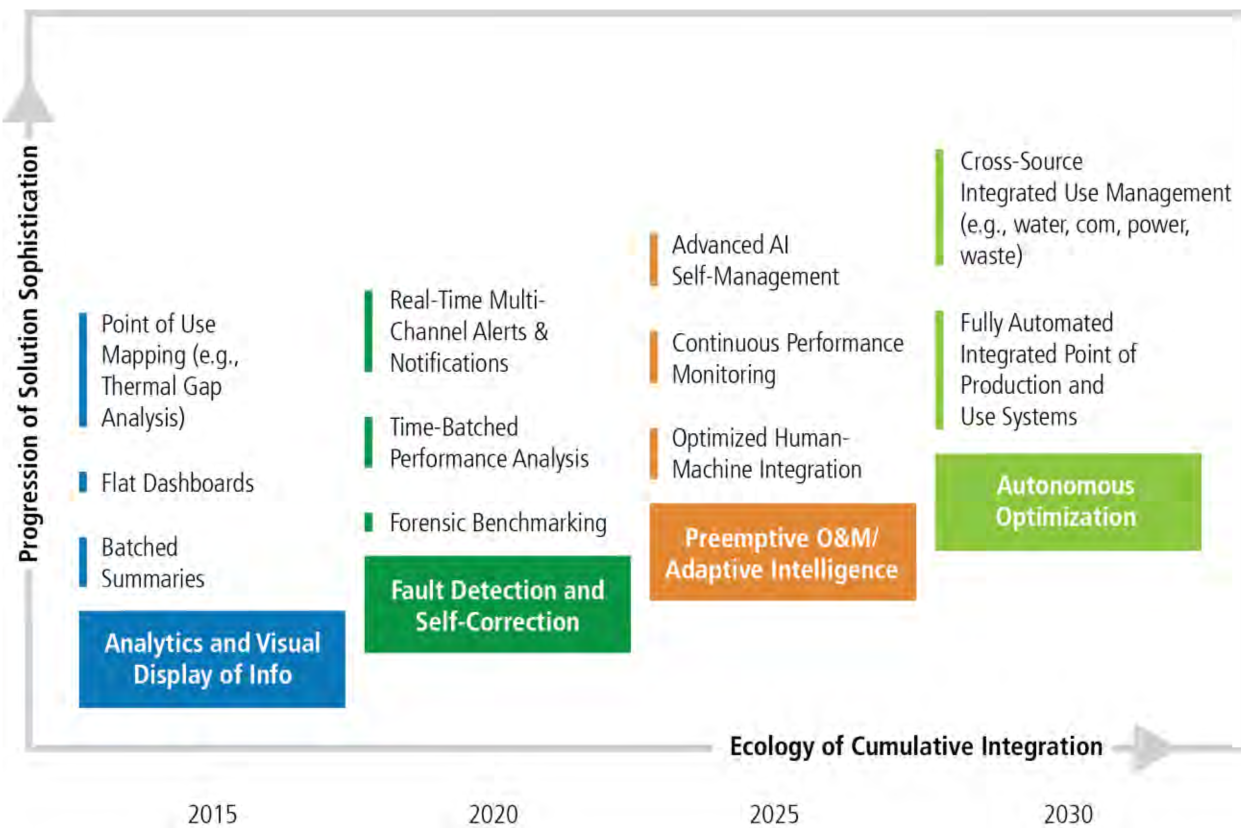
There are currently three key industry-led, transformer-sharing programs in the United States—NERC's Spare Equipment Database program, Edison Electric Institute's Spare Transformer Equipment Program, and SpareConnect. Another program, Recovery Transformer, developed a rapidly deployable prototype transformer designed to replace the most common high-voltage transformers, which DHS successfully funded in partnership with Electric Power Research Institute and completed in 2014.[187] As of December

2016, three additional programs—Grid Assurance, Wattstock, and Regional Equipment Sharing for Transmission Outage Restoration (commonly referred to as RESTORE)—are in development. QER 1.1 recommendations noted that DOE should "analyze the policies, technical specifications, and logistical and program structures needed to mitigate the risks associated with the loss of transformers."[188] In December 2015, Congress directed DOE to develop a plan to establish a strategic transformer reserve in consultation with various industry stakeholders in the FAST Act. To assess plan options, DOE commissioned Oak Ridge National Laboratory to perform a technical analysis that would provide data necessary to evaluate the need for and feasibility of a strategic transformer reserve. The objective of the study was to determine if, after a severe event, extensive damage to LPTs and lack of adequate replacement LPTs would render the grid dysfunctional for an extended period (several months to years) until replacement LPTs could be manufactured. DOE's recommendations will be published in the report to Congress in early 2017.

4.5.5 Grid Analytics and Resilience

Both grid reliability and resilience increasingly depend on highly granular data about what is happening on grids in real time. Data analysis is an important aspect of today's grid management, but the granularity, speed, and sophistication of operator analytics must increase as greater distribution system complexity occurs. Regional differences may matter, but the core analytic engines that must be developed and configured for grid operator use will be the same across regions and systems.

Figure 4-13. Information Drives Solution Sophistication, which Drives New Benefit Realization for Grids[189]



Grid information systems are expected to evolve over time, growing increasingly autonomous and self-managing. Increased autonomy and self-management also involves increased system integration, which amplifies the complexity systems and requires a degree of human-machine interdependence that is unprecedented for grid operations.

4.5.6 Smart Grid and System Resilience

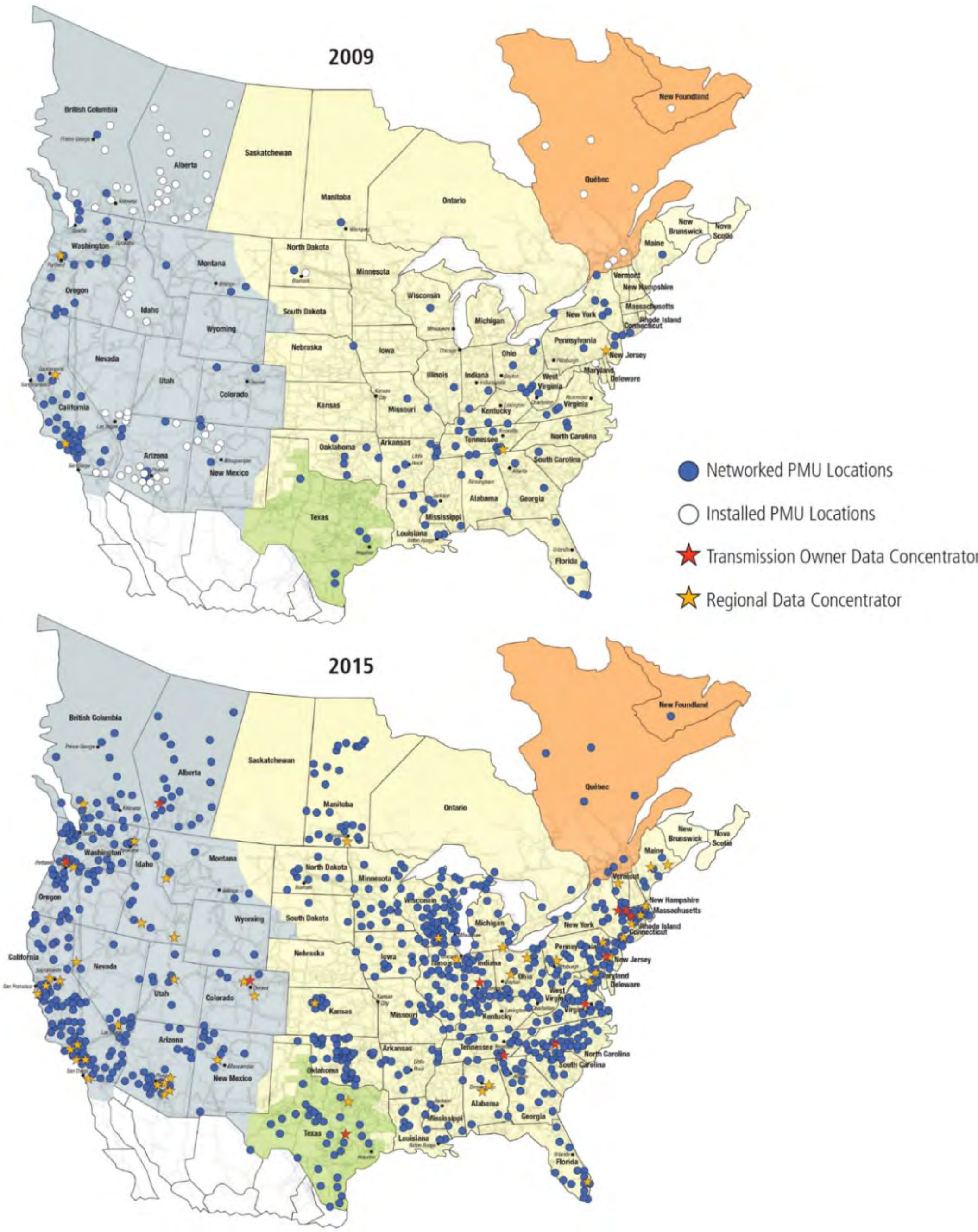
The installment and implementation of advanced meters and smart grid technology can make significant contributions to system resilience. Advanced smart grid systems can be used to expedite information flow; remotely monitor demand, performance, and quality of service; enhance system efficiency; and improve outage detection and restoration by identifying the location and description of damaged equipment. Real-time system monitoring can support hourly pricing and reactive power and/or DR programs, which allow utilities to make same-day operational decisions, near-term forecasts, and scenario evaluations. Historical data, coupled with predictive modeling of extreme weather events and the related effects on electric infrastructure, can also be used to inform management decisions, identify areas of greatest risk, ascertain system vulnerabilities, allocate resources, and help prioritize investments.

Still, system managers need better real-time information about system trends and changes, including the growth in VERs, the rise of the "prosumer," two-way electricity and information flows, and real-time load management data—which means that demands on and expectations of SCADA systems are only increasing. Grid modernization requires changes in operational systems and processes, and in the way that system planners design for grid evolution. Critical to smart grid realization is systems engineering to determine the requirements for ICT infrastructure, which includes how latency factors (communications delays) and bandwidth requirements are embedded in operations to accommodate the proliferation of intelligent assets from relays to whole substations to automated customer DR controls that grid operators can access and use.

Fortunately, as the complexity of the electricity system increases, so do computer- and network-based capabilities. The growing electricity-ICT interdependence is enabled in part by new technologies, such as sensors and software that can provide greater situational awareness of grid conditions and operational efficiencies (although much more work is needed).[190] Large volumes of data are, however, unwieldy, and developing additional ways to translate data into usable and timely information is essential. Networks are evolving to include cloud computing and IoT technologies to help reduce costs, increase efficiencies, and increase system integration.[191, 192] Smart meters, synchrophasors, and other devices have also been deployed across the grid. Even electromechanical devices, like voltage regulators, are adopting digital control interfaces.

On transmission networks, SCADA systems traditionally have been used to monitor and control power systems by measuring grid conditions every 2 to 4 seconds. Synchrophasor technology, which addresses the lack of situational awareness provided by conventional instrumentation, uses high-resolution phasor measurement units (PMUs) that provide time-synchronized data at a rate of more than 30 times per second to detect destabilizing network oscillations that would otherwise be undetectable. Strategically located PMUs connected by high-speed communications networks provide grid operators with wide-area visibility to better detect system disturbances, improve the grid's efficiency, and prevent or more quickly recover from outages. In 2009, there were 166 PMUs in the United States—there are now over 1,700 PMUs located around the country (see Figure 4-14).[193] The impact of this deployment is that it now takes 16 milliseconds for PMUs in the Western Interconnect to send signals over a dedicated fiber-optic system to transmission operators in control centers throughout the system—a system that covers western North America from Mexico to western Canada, from east of the Rockies to the Pacific Ocean.

Figure 4-14. Phasor Measurement Units, Technologies that Enable Superfast Network Management across Large Interconnected Systems, Are Being Deployed to Improve Grid Operations[194]



Note the concentration of phasor measurement units (PMUs) in regions and interconnected systems where ISOs and RTOs dominate transmission service. PMU deployment can be interpreted as a first mover in the development of smart grids and as evidence that upstream transmission systems are advancing more consistently and at a faster pace toward smart grid realization than local distribution systems, although recent rate cases and public utility budgets for larger investor-owned utilities and public power indicate that smart grid investments are beginning to ramp up quickly. However, it should not be assumed that PMU deployment at the distribution level will mirror that at the transmission level because distribution smart grid deployment is much more complex in scale and scope. Note that the Western Interconnect is in gray.

The electricity sector has also been relying on a variety of redundant communications networks for operations since its inception. Internet Protocol-based communications (networking) systems—whether fiber-optic, radio, or other means for conveying data—can be owned by utilities or provided by telecommunication firms. Utilities have invested heavily in these ICT networks over the last decade, in part spurred by funding Congress provided through ARRA. Roughly one-third of customers are connected to the distribution grid by the 60 million smart meters that serve as an essential building block to grid digitization.[195] Smart meters send data to utility control systems every 15–60 minutes through communications networks and can provide information back to customers in real time, often through the Internet. These meters enable remote meter reading, connections, and disconnections, and they allow for improved outage management and restoration. During Superstorm Sandy, smart meters reduced PECO Energy's restoration time by 2–3 days. Florida Power and Light has developed a tablet-based application for its field crews using AMI and geographic information systems data to improve emergency response; this was recently used to increase the speed of power recovery after Hurricane Matthew. Smart meters have an additional benefit—they give customers price information that enables them to respond to market conditions and reduce their electricity bills.States and RTOs/ISOs will continue in their traditional regulatory roles as the system evolves. Given the increasing technical sophistication of grid operations, state regulatory staff may need additional support from the Federal Government in evaluating technical proposals from utilities as they seek to modernize their grids. Of concern are grid security standards across distribution delivery services. Proactive planning should be considered, as well as emergency response. The impetus to invest in mitigation and preparedness may only occur following a catastrophe, but proactive investments can prevent catastrophe and ultimately benefit ratepayers in the long term. However, distribution utilities face various challenges to implementing cybersecurity measures, including outdated legacy equipment, budgetary constraints, workforce readiness, and technology availability. Recent electricity response exercises demonstrate the nascent status of coordinated industry and government efforts to jointly respond to potential cyber incidents. The electricity industry has a long history of employing mutual assistance agreements to recover from most disruptions, and the Nation would benefit from the development of appropriate mechanisms for addressing cybersecurity disruptions.

4.5.6.1 Underinvestment in Research, Development, Demonstration, and Deployment, and Implications for System Resilience

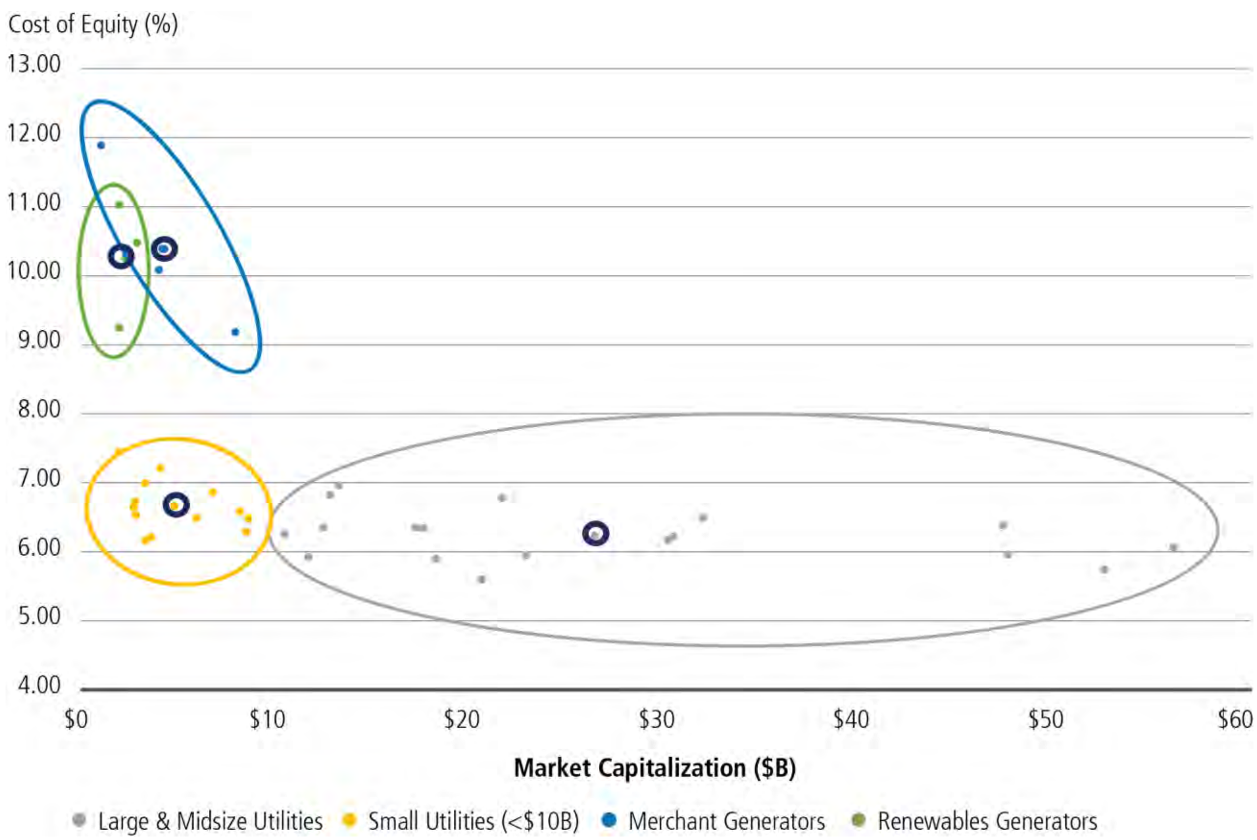
This chapter has emphasized the importance of resilience to overall grid reliability. From an investment perspective, high grid reliability is a key factor in the treatment by investors of utilities (both public and private) as low risk investments with predictable returns. Analysis suggests that in an increasingly complex grid management environment, more focused investments are needed to ensure continued high system reliability and resilience. Future investments must focus on innovations that help mitigate new sources of system disruption, including VERs, extreme weather, and physical and cyber attacks; these investment must occur in an environment that does not necessarily favor increased utility funds being used for research, development, demonstration, and deployment (RDD&D).

Despite existing RDD&D funding and activity in the electricity sector, there is systemic underinvestment in RDD&D of technologies, as described in 3, *Building a Clean Electricity Future.* Also, private industry serving the electricity sector lacks incentives for investments in infrastructure resilience, in part, due to uncertainties in emerging risks.[196] Utilities acquiring resilience assets and solutions face rate proceedings that have an inherently conservative perspective on new technologies and approaches, which limits the ability to test new approaches in a timely manner and move to deploy successful efforts at an accelerated pace compared to traditional electricity sector norms. The lack of incentives, and preference for existing methods, constrains the innovation options that are pursued and tested, then enter the innovation process supply chain. These characteristics drive the need for additional Federal RDD&D opportunities to improve the resilience of electricity systems, as well as system security, rapid response, and recovery from disruptions.

Entities that operate distribution systems—the grid components most critical to reliability, security, and resilience—operate almost universally on the basis of cost-of-service. The combination of stable revenues and low operational risk enables these entities—investor-owned utilities, Munis, Coops, and other entities—to acquire capital at lower rates (see Figure 4-15). Investors view these entities as relatively low-risk investments compared with other electricity sector opportunities that face more competitive pressures.

As the operational characteristics of the industry evolve, traditional utility returns may not be compelling for investors, if sector transformations cause utilities to take on more or different types of risks. New types of regulatory structures may be needed to provide appropriate incentives to plan for an increasingly uncertain and more complex risk environment, as well as incorporate new approaches and technologies, which enable the kind of resilience investments that may be needed but not otherwise funded.

Figure 4-15. Cost of Equity by Company Type and Size for Sampled Power Sector Companies[197]



Regulated utilities, with their predictable revenues and low risks, tend to be viewed as safe investments, exhibiting a low cost of equity compared to the rest of the sector. As the industry addresses increasing risks and uncertainties, existing regulatory structures may evolve to meet risk appetite.

4.5.7 Planning Is Essential for System Reliability and Resilience

The responsibility for maintaining and improving grid reliability and resilience resides with a complex mix of entities with overlapping and sometimes inadequate jurisdictional responsibilities, which include Federal and state agencies and regulatory bodies, regional and national reliability organizations, and multiple utilities with various business models.

There are many existing planning platforms for reliability planning that are well understood by utilities, stakeholders, and other responsible entities. New, value-added planning contributions can help grid operators make tradeoffs among multiple investment options, strengthen the system, and help ensure resilience and reliability, which are needed for transforming a dramatically changing electricity system. Rigorous tradeoff analysis implies and includes rigorous risk analysis. Planning elements that should be added to existing platforms to accommodate system changes, challenges, threats, and opportunities include the following:

- Regional integrated resource planning that includes both T&D
- Integration of end-to-end options for optimal resource mix and operational integrity into existing planning
- Analyses with proposals for how to mitigate vulnerabilities.

In many parts of the country, investor-owned utilities conduct integrated resource planning in accordance with state requirements that were established through legislation or regulatory actions. While more than half of states in the Nation have integrated resource planning requirements, other states have adopted "Long-Term Procurement Planning" or other similar processes.[198, 199] Only a small number of distribution utilities conduct planning[200] in response to state policies,[201] aiming to increase resilience to extreme weather events or stressful system conditions. Also, with few exceptions, very few utilities take emerging threats from climate[202, 203] or cyber attacks into consideration when conducting integrated resource planning and distribution planning.[204]

In most cases, cybersecurity efforts are often funded out of the overall rate base. This means that funding for cybersecurity comes at the expense of profit or other investment needs, which may have a disproportionate budgetary impact on smaller distribution utilities. In rarer cases, distribution utilities have a separate security recovery factor in their rate structure.

4.5.7.1 Integrated Planning Considerations

The changing role of the consumer that drives the transformation of distribution also drives a need for new distribution planning approaches and tools to effectively integrate DERs into the grid and to understand the benefits and costs for developing forward-looking investment plans. New solutions like smart inverters bring important issues to center stage, like whether such solutions can be fully valued prior to deployment. Because consumer preferences and needs are changing faster than the pace of grid planning, there may be misalignment of operating circumstances. Whatever investments are planned are likely to require revisions as actual events diverge from what is planned in advance. Continued and rapid changes on the customer side of the meter may require adjustments in regulatory processes to assist grid owners and operators in keeping systems up to date.

Methods are under development in leading states (e.g., California and New York) to incorporate DERs, and the growing role of ; “prosumers” -- consumers that produce power for the grid; and third parties into the distribution system planning processes. Important considerations for the development if such methods should include hosting capacity of distribution feeders for DERs and probabilistic DER growth scenarios, as well as balance utility investments in system upgrades versus the services provided by DERs (e.g., in energy supply, supply/load balancing, storage, and support of both frequency and voltage regulation). These planning processes will need sufficient transparency to permit all stakeholders, including DER service providers, to participate in supporting long-term capacity and energy requirements. Contractual provisions between utilities and DER service providers will need to be established to ensure grid reliability and security, which might benefit from the development of standard offer DER contracts. As capacity and energy are increasingly being delivered at the distribution system level, distribution- and transmission-level planning will need to be integrated.

4.5.7.2 Integrated Probabilistic Planning as an Emerging Tool

Typically, reliability decisions are based on a deterministic, binary decision—a new facility is approved if it resolves a violation of a reliability standard. In contrast, economic decisions are based on a scenario framework, where the expected value of a facility is evaluated across a range of likely scenarios. The changing system topology, uncertain regulatory frameworks, decentralized market decisions, and evolving vulnerabilities introduce economic and reliability uncertainties and risks that cannot be adequately assessed through a deterministic framework.

Probabilistic risk assessment (PRA) methodologies offer a framework to consider underlying uncertainties and risks. PRA methods in transmission planning are still at a research stage and are not implemented widely. Currently, PRA is used to model topological changes, such as variations in renewable generation levels; variations in load level due to weather and DER output; generation and transmission equipment performance; variations in hydro-generation; and physical threats like weather.[205] However, considerable barriers to implementation of PRA approaches in transmission planning include the following:

- Tradition of planning for worst-case scenarios using a deterministic approach
- Lack of industry-wide accepted approach for reliability indices in PRA framework
- Lack of standardization and availability of historic reliability data
- Lack of qualified workforce, skillset, and awareness of PRA approaches
- Lack of modeling tools for implementing PRA methodologies
- Lack of commercial tools for system security assessment under PRA framework.[206]

4.5.8 The Grid of the 21st Century

The electricity sector's long history is one of managing continuous, albeit slow, change while sustaining the same high reliability year in and year out. The stock of the sector is incrementally refreshed as needed, but changes highlighted in this chapter and other chapters of QER 1.2 call attention to several factors that place new emphasis on the sector's effort to sustain high reliability, security, and resilience.

A transformed 21st-century grid is likely to be one that invests more in flexibility and resilience to achieve the same desired outcome that is the prime directive of grid operators—sustained, high-service reliability. How the grid is managed depends on the capabilities built into the stock of assets that make up the end-to-end supply chain, but managing real-time operational flows also requires specific systems and processes to continuously succeed. The complexity of grid operations requires grid control tools that enable granular visibility and certain operational algorithms that help grid operators stay on top of second-to-second and millisecond-to-millisecond changes. The era of enhanced grid operations through artificial intelligence is here. Execution, however, must occur in a context that assiduously assures deflection of cyber attacks that could cripple grids; it must also occur through market mechanisms to help value and ensure cost-effective outcomes.

State and Federal regulatory bodies and policymakers play key roles in helping ensure system integrity, safety, and the ongoing financing of the electricity sector. Planning, which is central to ensuring long-term stock and flow integrity, must evolve as the sector itself evolves. More robust modeling, improved risk analysis, and better optimization realization at the two-way interface of information and energy flows between consumers and grid operators are important improvements that are likely to be significant contributors to enabling a transformation that ensure today's service reliability and quality can continue, if not improve.

This is the state of sector grid management as the Nation continues its march deeper into the 21st century. The scope of transformation required to adapt to new security concerns, coupled with the organic evolution of a sector that is qualitatively changing as consumers have more direct and indirect influence on grid reliability, are non-trivial costs that must be financed and paid for. There are many ways to facilitate transformation and assist grid operators and other stakeholders in the sector in adapting to the sector's changing physical and cyber "topography." QER 1.2 turns now to addressing the "how to" question in the final chapter, where recommendations designed to assist the Nation in maintaining a highly reliable electricity sector are mapped for consideration by policymakers and sector leaders alike.

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V 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 chapter begins with an overview of the current workforce and key trends that have shaped employment in this sector. It then discusses the demographics of the sector, including the underrepresentation of women and minorities in employment and leadership. Next, the chapter identifies challenges to replacing retiring workers, the incompatibility of available worker skills and electricity workforce needs, and possible approaches to developing a skilled workforce for future sector demands.

Key Findings

The broader changes in the electricity industry have created both new opportunities and new challenges for the electricity industry workforce. Opportunities include new workforce potential in the renewable energy industry and information and communications technologies; challenges include 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 workers affected by employment loss in other industries that may be geographically distant and require different skills.

- 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.[1]
- 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.[2]
- 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.[3] 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.[4, 5]
- Employment in the natural gas industry is regionally and temporally volatile; 28,000 jobs were lost between January 2015 and August 2016.[6] Shifts in locations pose challenges for employees and the economies of the areas where they live and work.[7]
- 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.[8, 9] In 2015, annual coal production was at its lowest level since 1986, and it is forecast to continue declining over the coming decades.[10, 11]
- 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. As of November 2016, according to BLS data, the coal mining industry employs about 53,000 people.[12,a]
- 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.[13]
- 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.[14]

[a] The 2017 *U.S. Energy and Employment Report* records 74,084 jobs for Coal Fuels employment in March 2016. The BLS data from November 2016 is relied upon here to illustrate both the recent trends and the historical record over many decades.

- 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.[15,16]
- A dip in the number of electricity industry workforce training programs in the 1980s contributed to a currently low number of workers in the electric utilities able to move into middle and upper management positions—creating a workforce gap as the large number of baby boomers retire.[17]
- 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.[18, 19]
- Electricity and related industries employ fewer women and minorities than the national average, but have a higher proportion of veterans.[20, 21] 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.[22, 23] 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.[24] 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 fatal work injury rate.[25]
- While data on energy sector workforce are improving, there are still major shortcomings in the data availability, precision, and categorization of energy sector jobs.[26]

5.1 A Modern Workforce for the 21st Century Electricity Industry

The evolving demands on the electricity industry are causing a number of workforce challenges for the electricity industry, which include large shifts in skills needed and in geographic location of jobs, a skills gap for deploying and operating newer technologies, changes occurring during a period when the industry is facing high levels of retirements, and challenges recruiting and retaining a workforce that reflects the gender and racial diversity of the Nation. At the same time, the evolution of the industry is also creating a number of new workforce opportunities, including jobs in renewable energy, natural gas, and information and communications technology (ICT).

The electricity sector's full potential will only be realized if its workforce is able to appropriately adapt and evolve to meet the needs of the 21st-century electricity system. A skilled workforce that can build, operate, and manage this modernized grid infrastructure is an essential component for the sector's development. Addressing the workforce challenges identified here will create well-paying jobs that contribute to the economic health of local communities, support the increased use of efficiency technologies, reduce injuries and improve worker safety enable employees in the electricity industry to support a modernized 21st-century energy system, and ensure a resilient electricity system.

This chapter provides an overview of the composition of the electricity industry workforce, as well as the challenges the sector faces in maintaining an adequate and skilled workforce for the 21st-century electricity system. This chapter further examines how qualities and characteristics of the electricity workforce are shifting in light of the ongoing transformation of the energy sector, and it provides an overview of how industry and government action can respond to challenges facing the industry.

5.2 Overview of the Electricity Industry Workforce

The electricity system depends on a workforce that fills a diverse set of jobs—from the coal miner extracting fuel from the ground for electricity generation, to the utility worker repairing a distribution line, and everything in between. The following section provides an overview of the number and types of jobs related to the electricity industry.

5.2.1 Workforce Size

The Bureau of Labor Statistics (BLS) reports that nearly half a million people are employed in electric power generation, transmission, and distribution (see Table 5-1).[27] Of the 290,000 employees in the electric power transmission and distribution subsector, over a quarter million are employed with distribution companies. There are an additional 600,000 jobs in extraction and mining industries, though only a portion of those jobs are directly attributable to the electricity industry.[28]

Table 5-1. Direct Employment and Income in Industries Related to Electric Power Supply as Tracked by BLS, 2015[29]

Industry Sector/Subsector	Jobs	Percent Related to Electricity Industry	Average Annual Income
Electric power generation	192,000	100 percent	$116,000
Electric power transmission and distribution	290,000	100 percent	$99,000
Electric power total	482,000	100 percent	$106,000
Coal mining[b]	71,000	~80 percent	$82,817
Oil and gas extraction[c]	540,000	~10 percent to 20 percent	$113,022
Mining and extraction total	611,000	Unknown	$110,000

More than 80 percent of the coal mined in the United States goes to power production.[30] The oil and gas extraction sector is not subdivided and includes many non-power uses. About 35 percent of the natural gas and roughly 1 percent of petroleum usage in the United States is for power production.[31]

In addition to the 482,000 jobs in the electric power generation, transmission, and distribution subsectors, BLS reports that 169,000 people are employed in the Power and Communication Line and Related Structures Construction industry. Some of these employees work constructing transmission lines, substations, and power plants.[32]

The electricity industry is a dynamic industry with changing sources of employment and job categories. As a result, the direct employment figures captured by the BLS job categories provided in Table 5-1 do not include all employment related to the electricity industry, particularly those related to construction, solar, wind, and energy efficiency workers.[33] In 2015, the Department of Energy published the first edition of the *U.S. Energy and Employment Report* (USEER), which provided a broader depiction of electricity industry employment than the BLS data based on supplemental employment surveys. A second edition of the USEER, published in January 2017, finds that about 862,000 people are employed in jobs related to electric power generation. Another 1,082,746 are also employed in jobs related to fuels extraction and mining, although not all of these are directly attributable to the electric power sector (see Table 5-2).

[b] Includes supporting North American Industry Classification System (NAICS) industry categories

[c] Includes supporting NAICS industry categories

Table 5-2. Electric Power Generation and Fuels Extraction and Mining Employment Estimates by Technology, First Quarter 2016[34]

Technology	Electric Power Generation (Employment Estimates)	Fuels Extraction and Mining (Employment Estimates)
Hydroelectric	65,554	-
Coal	86,035	74,084
Natural Gas	88,242	309,993
Nuclear	68,176	8,592
Solar	373,807	-
Wind	101,738	-
Geothermal	5,768	-
Bioenergy	7,980	104,663
Oil	12,840	502,678
Combined Heat and Power	18,034	-
Other	32,695	82,736
Total	**860,869**	**1,082,746**

The *U.S. Energy and Employment Report* (USEER), provides a broader accounting than the BLS data presented above, and finds that as of the first quarter of 2016, over 800,000 people were employed in the electric power generation industry, most of which are related to the construction and buildout of new solar and wind generation capacity. Another 1,082,746 are also employed in jobs related to fuels extraction and mining, although not all of these are directly attributable to the electric power sector. As noted above over 80 percent of coal, 35 percent of the natural gas, and merely 1 percent of petroleum usage in the United States is for power production. [35]

USEER finds that the BLS estimates are particularly low for jobs associated with solar, wind, geothermal, and biomass electric power generation.[36] These low estimates result from classifying many jobs in these industries as construction or business and professional services employment. For instance, most solar company installers are classified as electrical contractors.[37]

Though BLS does not estimate employment in energy efficiency jobs, USEER found that 2.2 million people are working in industries directly or partially related to energy efficiency—more than 2.5 times the number employed by electric power generation. Of those 2.2 million, 1.4 million are in the construction industry.[38] Energy efficiency employment includes both the production of energy-saving products and the provision of services that reduce end-use energy consumption. However, USEER estimates only include work with efficient technologies or building design and retrofits. They do not capture employment related to energy-efficient manufacturing processes. If process efficiencies were included, estimates for the energy efficiency workforce would be even larger.

5.2.2 Skills and Training

The electricity industry offers diverse jobs, which require a variety of skills. Table 5-3 includes job descriptions and educational requirements for selected job categories across the utility portion of the electricity industry. Traditional jobs, such as lineman, will continue to be needed, but the increase of renewable energy, as well as an increased ICT component to the electricity industry, will change the skillset required for many jobs in the electricity system of the 21st century.

Table 5-3. Typical Electricity Workforce Roles and Required Education or Training[39]

		Required Education						
Job Category	**Job Description**	**High School**	**Vocational**	**Apprenticeship**	**Associates**	**Bachelors**	**Masters**	**Doctorate**
Lineman	Responsible for the installation and repair of overhead and underground distribution and transmission lines, poles, transformers, and other equipment.	X	X	X				
Power Plant Operator	Responsible for the maintenance and operation of all primary and auxiliary equipment required to generate electricity or meet natural gas customers' demands.	X	X		X	(X)		
Technicians (Transmission and Distribution)	Responsible for the repair of both electrical and mechanical equipment. This includes inspecting and testing electrical equipment in generating stations and substations.	X	X		X	(X)		
Technicians (Generation)	Responsible for the construction, assembly, maintenance, and repair of steam boilers and boiler house auxiliary equipment.	X	X		X	(X)		
Pipefitters and Pipelayers (Generation)	Responsible for the installation and maintenance of pipe systems and related equipment for steam, hot water, heating, sprinkling, and industrial production and processing systems.	X	X		(X)			
Power Engineers	Focus on electrical systems, equipment, and facilities rather than on mechanical systems and other non-electrical systems involved in electric and natural gas energy services. It includes people involved in planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation, transmission, distribution, consumption, and control of electricity.					X	X	(X)
All Other Engineers	Focus on non-electrical systems, processes, equipment, and facilities involved in electric energy services. It includes people involved in the planning, research, design, development, construction, installation, and operation of equipment, facilities, and systems for the safe, reliable, and economic generation/supply, transmission, distribution, consumption, and control of electricity.					X	X	(X)

The electricity workforce includes several job categories, each with specific educational requirements (shown in orange). The striped orange boxes show where a specific level of education is sometimes required or infrequently required.

One ongoing challenge for maintaining the electric industry workforce is the amount of time required to train new workers. For example, training to become a journeyman line worker can take up to 7 years.[40] if enrollment in apprenticeships and training programs increases during a period of worker shortage, the new employees would not be prepared for the full range of line worker duties for several years.[41] The electricity industry appears to have made progress on maintaining a pipeline of skilled labor; the number of pre-apprenticeship training programs has more than tripled since the 1990s.[42, 43] Furthermore, skilled workers coming from related industries—such as construction electricians—may not require as much training and would be ready for duty in a shorter timeframe.

In addition to the electricity workforce job categories shown in Table 5-3, the electricity industry also employs thousands of corporate services employees engaged in jobs such as customer service, finance, management, and human relations. Skills required in these jobs are often more transferable between industries and require less specialized electricity industry training.

Training Programs in the Electricity Industry between the 1980s and Today

The economic outlook of an industry often determines the availability of training programs. During the 1980s and 1990s, the electricity industry experienced much lower demand growth than the decade before. A conservative outlook on demand growth coupled with an increased focus on productivity in anticipation of impending industry deregulation led utilities to scale back hiring and internal training programs.[44]

The 1980s and 1990s also coincided with a shift away from technical education as the primary tool to train the next generation, toward a larger emphasis on four-year college programs. This shift further decreased the interest in technical and vocational training, previously a main pillar of education for the electricity industry workforce, which led to the closure of many technical high schools, shrinking the pool of available applicants for the electricity industry even further.[45] The future workforce is now educated through a variety of means, including community colleges, apprenticeship programs, and certificate programs. This has led to a lack of uniformity of standards and curricula, which is a challenge for electric companies, as they often have to retest skills to ensure that applicants have the necessary education. While the 2000s have seen a rebuilding of some of the training and apprenticeship programs, the dip in training programs in the 1980s contributed to fewer workers in middle management in the electric utilities—creating a gap as the large number of baby boomers retire.[46]

5.2.3 Electricity Utility Worker Health and Safety

The electricity industry has made progress in improving workplace safety. From 1995 to 2013, the number of injuries[d] per 100 employee-years in electricity utilities decreased from 4.7 to 1.3.[47] In 2015, the workplace injury rate across electricity generation, transmission, and distribution companies was slightly more than half the national rate.[48] 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 fatal work injury rate.[49]

For electricity utility workers, the injury rate is highest among the 21–30-year-old age group at 3.7 percent (see Figure 5-1). This segment only makes up 10.7 percent of the sector workforce, but has higher rates of injury due to "fewer years of experience and a higher proportion of young workers employed in higher risk occupations, performing physically demanding or higher risk tasks."[50]

[d] Injury rates reported here are for injuries resulting in a worker missing at least one full day of work after the injury date.

Figure 5-1. Injury Rates and Employee Age Group Distribution for Electricity Utilities, 1995–2013[51]

Overall injury rates are highest among the 21–30-year-old group, although employees between 41 and 50 years of age comprise the largest group of employees, with 32.9 percent.

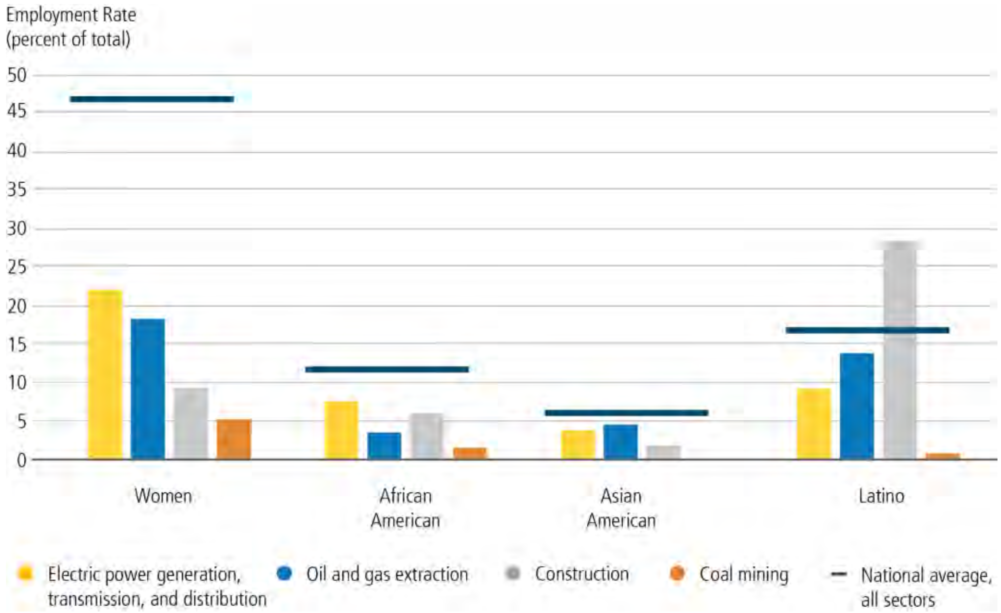
Injury rates for electricity utilities are not only unevenly distributed by age group, they also differ regarding the nature of the job. Welders, line workers, and meter readers accounted for the highest proportion of injuries among all electricity power sector occupations.[52] The specific causes of worker injuries and fatalities can be generally grouped into four categories: a misunderstanding or non-compliance with safety concepts, poor communication, absence of leadership, and/or lack of experience and qualified employees.[53]

As the electricity sector modernizes, there may be opportunities to leverage technological advances to improve worker safety and reduce rates of injury. New equipment, processes, and infrastructure design can complement innovations in training practices to improve workplace safety in the electricity industry through reducing electrical exposures, instances where utilities deploy crews and trucks, as well as instances where crews work at elevated heights.

5.2.4 Electricity Industry Workforce Inclusion

The electricity and related resource extraction industries employ fewer women and minorities than the national average (see Figure 5-2). Women constitute 22 percent of the electric power generation, transmission, and distribution industry workforce, compared to 47 percent of the entire workforce. African Americans constitute just 8 percent of the electricity workforce but are 12 percent of the workforce as a whole. Oil and gas extraction, construction, and coal mining industries employ even fewer women and African Americans. Asian Americans are not statistically represented in the coal mining industry, and again, lag the national average for the other industries surveyed here. Latino employment in the construction industry is the only minority demographic that is higher than the national average for the population groups and industries included here.[54]

Figure 5-2. Electricity and Related Industry Employment Demographic Indicators, 2015[55]



The electricity industry ranks far below the national average in employment of women, African Americans, Asian Americans, and Latinos. The oil and gas extraction and coal mining industries have similar demographic characteristics. The construction industry, where energy efficiency jobs are mostly located, has a higher percentage of employment of Hispanic or Latino Americans.

The lack of diversity in the electricity industry extends to the executive level as well—only 5 percent of the boards of utilities in the United States in 2015 include any women, and approximately 13 percent of board members among the top 10 publicly owned utilities were African American or Latino.[56, 57]

Veterans make up a slightly higher proportion of electricity industry jobs than their representation in the national workforce. A recent study found that veterans make up 8 percent of the current workforce and 10 percent of new hires across the electricity utility, natural gas utility, and nuclear energy industries.[58] The solar industry employed an estimated 16,835 U.S. veterans in 2015, and the percentages of veterans working as solar manufacturers, solar installers, and solar project developers each exceeded the total percentage of veterans in the broader national workforce.[59]

Underrepresentation in or lack of access to science, technology, engineering, and mathematics (STEM) educational opportunities and programs contribute to the underrepresentation of minorities and women within the electricity industry. For instance, African American and Latino students are critically underrepresented in STEM programs in high schools and colleges, and STEM education is often necessary for entry into many positions in the electricity sector. Two-thirds of public high schools with a majority of African American students do not offer calculus, and more than half do not offer physics.[60] These curriculum deficits result in lower STEM college graduation rates among underrepresented communities. In the 2013–2014 school year, African Americans and Latinos received only 7.2 percent and 9.5 percent of all STEM bachelor's degrees, respectively.[61]

While the renewable portion of the electricity industry is seeing dynamic job growth, workforce inclusion in renewable energy also tends to lag behind the national average. Women represented 24 percent of the solar workforce, which is well below the national average workforce participation levels. However, the number of women in the solar industry has been steadily trending upward from 19 percent in 2013. This trend is reversed for African Americans and Latinos, who are trending downward, with African Americans comprising 5.2 percent of the solar workforce in 2015 (down from 5.9 percent in 2013) and Latinos accounting for 11 percent of the workforce in 2015 (down from 16 percent in 2013). The number of veterans in the solar workforce is also trending downward—9.2 percent in 2013 and 8.1 percent in 2015, but it is still above the national average.[62]

5.3 Electricity Industry Workforce Challenges

The electricity industry is facing several changes that present challenges for maintaining a skilled workforce. New technologies require new and evolving skillsets for industry employees, as high levels of retirees take with them industry experience, and regional mismatches are emerging between the needed and available workforce. These changes could create skills gaps for the industry and workforce, as well as recruitment challenges in attracting appropriately trained and qualified employees. The time required to train new, qualified workers in the sector serves to limit the industry's ability to respond to rapid shifts in the workforce and limit the employment appeal to prospective employees faced with alternative career options. Workforce challenges facing the industry are exacerbated by the lack of robust, reliable data and by forecasts on industry needs and workforce supply—especially as business models evolve. Meanwhile, new technologies like distributed generation, smart home devices, and electric battery storage have led to the proliferation of many new business, job types, and employment opportunities. These new business models are expanding the definition of electricity industry jobs, and they present new workforce development challenges related to skills transferability and uniform safety and security practices and services.

The electricity system of the 21st century will require an adaptable and flexible workforce with additional areas of expertise and capabilities than the current workforce. The integration of variable renewable sources, storage systems, smart grid, and demand management will require new training and skillsets. Sector engineers need to have well-developed expertise in traditional topics such as electrical engineering, while also possessing knowledge of information technology, communications, and other relevant topics. Maintaining existing training programs for the legacy systems while also focusing on the skillsets of tomorrow's workers will be a unique challenge. As an example of these new workforce needs, the increased ICT component in the smart grid of the 21st century requires a wide array of new and different skills.[63]

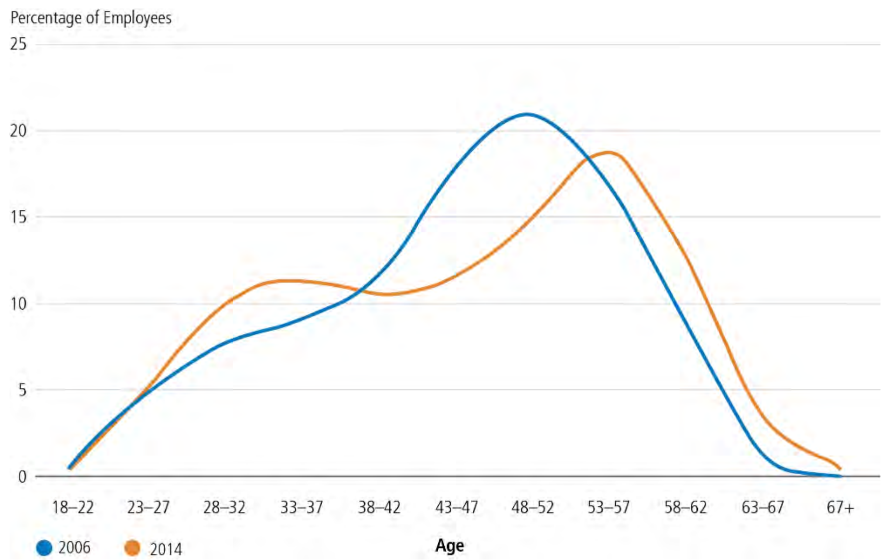
With the issue of cybersecurity increasingly at the forefront of electricity industry concern, the industry will require a workforce adept in risk assessment and behavioral science, as well as familiar with cybersecurity risk factors.[64] A 2010 report from the President's Council of Advisors on Science and Technology, *Designing a Digital Future*, highlighted challenges stemming from the lack of a dedicated and trained cross-disciplinary power grid workforce that can comprehend, design, and manage cyber-physical systems (CPS).[65] In the future, the electricity industry faces dual challenges of growing a workforce with new requirements and qualifications, while also competing with other industries that are demanding CPS trained workers. Training, curriculum, and education in CPS remains nascent. The shortage of CPS-trained workers could place constraints on the evolution of the 21st-century electricity system. Addressing those ICT and sectoral skills challenges requires a strategic approach to talent management, focused on upgrading skills for existing employees and recruiting new employees with needed skills.

5.3.1 Electricity Industry Capacity Gaps

Much of the utility and electricity sector workforce is nearing retirement. The aging workforce of the electricity sector is not unique in the U.S. economy, yet its specific skills requirements and the importance of the industry to national security and economic prosperity elevate the importance of its workforce management. Electricity utility, natural gas utility, and nuclear generation industry surveys indicate that roughly 25 percent of employees will be ready to retire in the next 5 years.[66] Noting demographic trends within the industry, in 2006, the North American Electric Reliability Council (NERC) raised concerns about worker and skills gaps among electricity industry employees, stating that "industry action is urgently needed to meet the expected 25 percent increase in demand for engineering professionals by 2015."[67] Spurred by this and other reports, the industry has pursued multiple initiatives and programs to address the looming increase in demand for skilled workforce.

Although the industry has made some progress on recruiting and developing the next generation workforce through hiring (see Figure 5-3), the capacity gap remains stubbornly persistent due to a workforce that continues to age, recruitment difficulties, a rapidly changing industry and specific training and certification needs.[68] A recent industry study forecasts the need for 105,000 new workers in the smart grid and electric utility industry by 2030, but expects that only 25,000 existing industry personnel are interested in filling those positions.[69] The remaining 80,000 employees in this supply-demand mismatch will need to be filled through recruiting and training. However, the industry is not expected to meet the forecasted need with its current recruitment and training rates.[70] In one recent survey, 43 percent of utilities surveyed stated that they see the aging workforce and the increased rate of retirements as one of their top three most pressing challenges.[71]

Figure 5-3. Age Distribution in Electric and Natural Gas Utilities in 2006 and 2014[72]



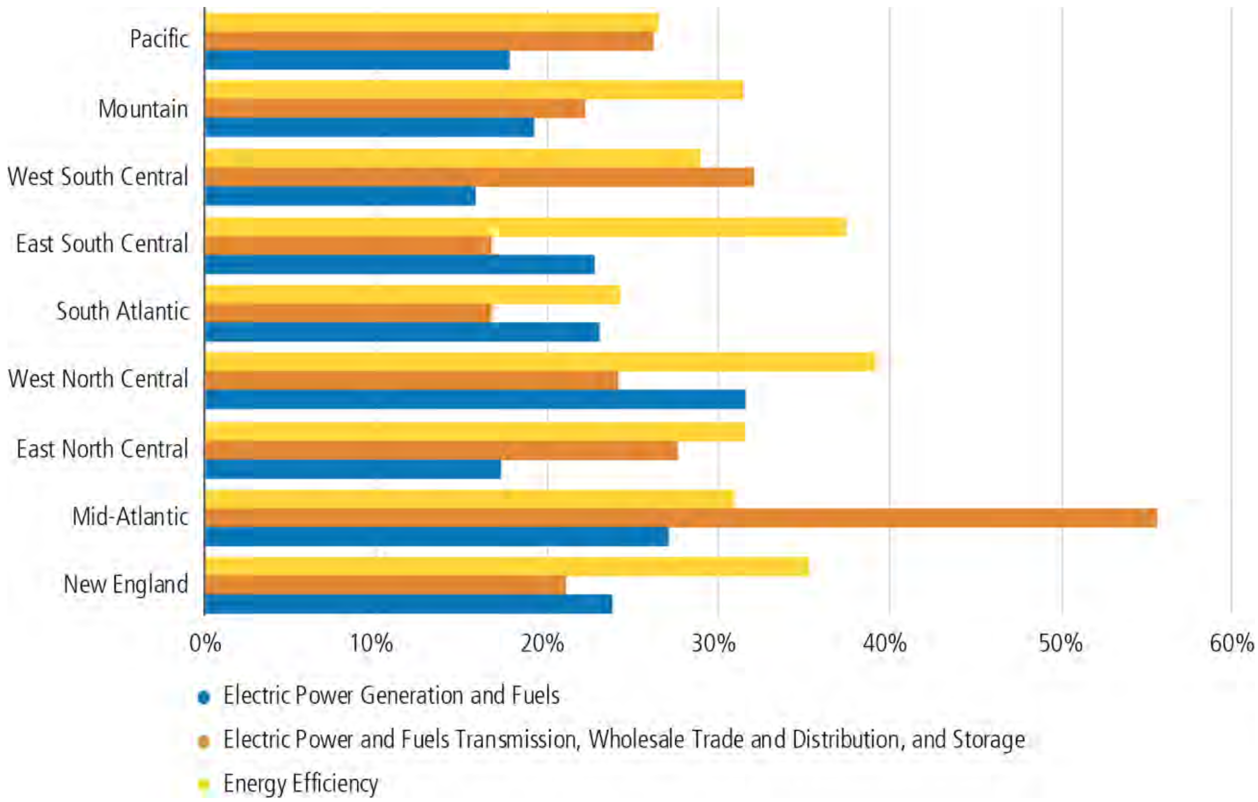
The age distribution in electric and natural gas utilities has shifted between 2006 and 2014, reflecting both the higher proportion of the workforce that is nearing retirement and industry efforts to address the aging workforce by hiring younger employees.

5.3.2 Electricity Industry Employee Recruitment Challenges

As workers retire, the electricity sector is experiencing challenges in hiring replacement personnel. 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.[73] This lack of experience can, in part, be attributed to hiring slow-downs in the 1990s and 2000s that have resulted in a current shortage of mid-career professionals with the experience to take on supervisory roles (see "Training Programs in the Electricity Industry between 1980 and Today" textbox).[74]

According to survey responses, over half of employers in the Mid-Atlantic region report very high difficulty with hiring in the electric power and fuels transmission, wholesale trade and distribution, and storage subsector, while no more than 32 percent of employers in other regions reported hiring difficulty in this field (see Figure 5-4). The Mid-Atlantic region, home to more than 40 million people and Washington, D.C., also reports among the highest rates of difficulty hiring in the energy efficiency and electric power generation and fuels industries.[75, 76]

Figure 5-4. Percentage of Employers Reporting Very High Hiring Difficulty by Census Region and Subsector (Q4 2015)[77]



Over half of employers in the Mid-Atlantic region report very high difficulty hiring in the electric power and fuels transmission, wholesale trade and distribution, and storage subsector, while no more than 32 percent of employers in other regions reported hiring difficulty in this field. The Mid-Atlantic also reports among the highest rates of difficulty hiring in the energy efficiency and electric power generation and fuels industries.

The employment supply and demand imbalance is already evident in the electric power transmission industry. One analysis finds that 10 states were experiencing a shortage of worker for electric power transmission in 2014. The same analysis projects that the number of states that will experience a shortage of worker supply will grow to at least 12 by 2018.[78]

5.3.3 Training Capacity and Timeline

One of the challenges for maintaining the electric sector workforce is the amount of time required to train new workers in order to respond to changing industry needs. Even if enrollment in apprenticeships and training programs increased today, sector employees would not be ready to enter the job market until several years from now. For example, initial training to become a fully educated lineworker is between 4.5 and 7 years.[79] And, due to the closure of many training programs in the 1980s because of lower need (see "Training Programs in the Electricity Industry between 1980 and Today" textbox), there is also a dearth of mid-career employees within the electricity sector that might otherwise fill these roles (see Figure 5-3).[80]

5.4 Electricity Industry Sectoral and Regional Variations, Training Opportunities

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 separate regional and sectoral dislocations in these industries. Each industry has distinctive workforce characteristics, skills requirements, and geographic concentrations, which means that employment gains in one industry do not always translate to opportunities to workers affected by employment loss in other industries that may be geographically distant and require different skills.

In many cases, changes in the electricity industry result in new businesses and sources of employment, especially with the growth of natural gas production and the renewable energy industry. In other parts of the country where employment is heavily dependent on a single industry, like coal, the economic consequences of the shifts in the electricity industry can be significant; employment in the coal mining industry has fallen by nearly 70 percent over the last three decades, largely in rural America.[81] Even in sectors experiencing long-term growth, employment can be volatile; the oil and natural gas extraction industry has lost about 14 percent of its workforce since the beginning of 2015 (through August 2016).[82] These changes in employment not only impact the labor force, but also the communities in which they live, work, and contribute to funding public infrastructure and services like roads and schools. While the shift from jobs in coal to natural gas and renewables is a recent example of job dislocation, this issue is not limited to coal or to the energy industry as a whole. Job dislocation has been, and will continue to be, a critical issue across many industries as the Nation's economy grows and changes.

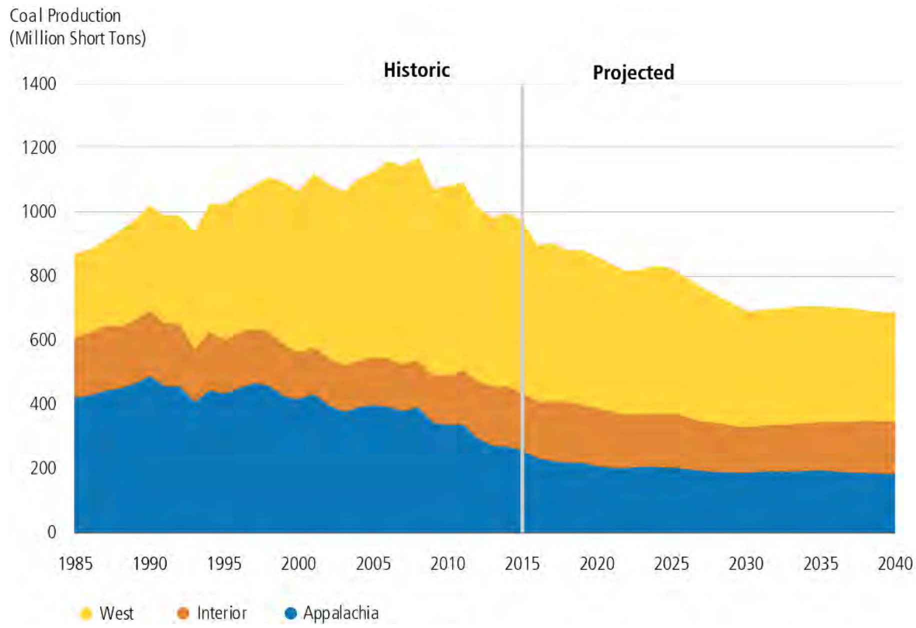
5.4.1 Falling Demand for Coal Has Reduced Coal-Related Employment

In 2015, the electricity industry consumed over 80 percent of domestically produced coal.[83] Recent shifts away from coal for electricity generation and toward natural gas and renewable energy technologies—largely driven by recent reductions in natural gas prices and renewable generation costs—have sharply reduced overall coal demand over the past several years. Annual coal production in 2015 was at its lowest level since 1986.[84] Because of the reduction in electricity industry demand and other shifts in the economy, coal production is forecast to continue declining over the coming decades (see Figure 5-5).

Coal production in the Appalachian region began falling in 1990, even as total U.S. coal production increased through 2007. The primary reason for coal's reduced market share in Appalachia is its higher relative price compared to coal in the western United States; in 2015, the price of coal from West Virginia was four times as much per ton as coal from Wyoming.[85]

Differences in mining efficiency and ownership cause the higher cost for Appalachian coal. Mines in the West tend to be larger and use surface mining techniques, which result in lower production expenses compared to the mix of underground and surface mining used in Appalachia.[86] While most mining in Appalachia occurs on private lands, 80 percent of coal production in the western United States occurs on Federal lands, where companies pay lower royalties and fees.[87] Appalachian coal's relative economic disadvantage is forecast to continue for the coming decades (see Figure 5-5).[88]

Figure 5-5. Historic and Projected Coal Production, 1985–2040[89, 90]



Coal production in the United States peaked in 2008 after a period of decreasing production in Appalachia and increasing production in the West. Production is forecast to continue to fall in the business-as-usual scenario shown here.

Coal mining jobs in the United States have declined over the last several decades. Between 1985 and 2000, employment in the coal industry shrank nearly 60 percent. During this period, 105,500 domestic coal jobs were lost. While national coal mining employment experienced a minor increase from 2000–2011, 36,000 coal mining jobs were lost between 2011 and September 2016, a reduction of 40 percent.[e] Of these losses, nearly 90 percent were in the Appalachian region. As of November 2016 the BLS reported employment of about 53,000[f] people in the coal mining industry. (see Figure 5-6).[91]

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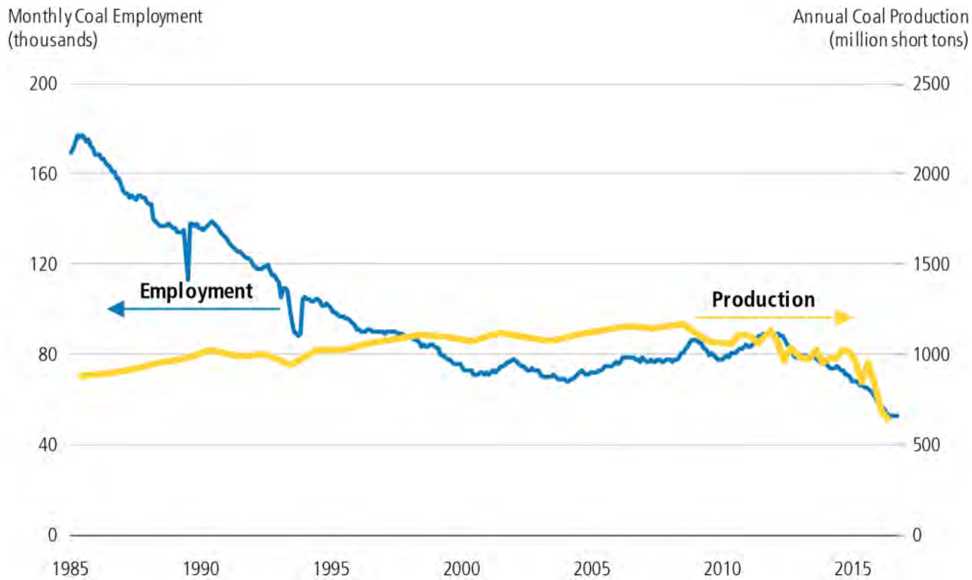
[e] 2011 is used as the base year for this comparison because it was the peak year for domestic coal production this century. Since then, coal mining jobs have been declining, while natural gas and oil extraction jobs have been on the rise overall.
[f] The 2017 *U.S. Energy and Employment Report* records higher Coal Fuels employment numbers in comparison to BLS due to differences in terms, categorizations, and survey methods; reporting 74,084 Coal Fuels jobs in March 2016, as shown in

Table 5-2. The BLS data is relied upon here to illustrate both the recent trends and the historical record over many decades.

Figure 5-6. Coal Industry Employment and Production, January 1985–September 2016[92, 93]

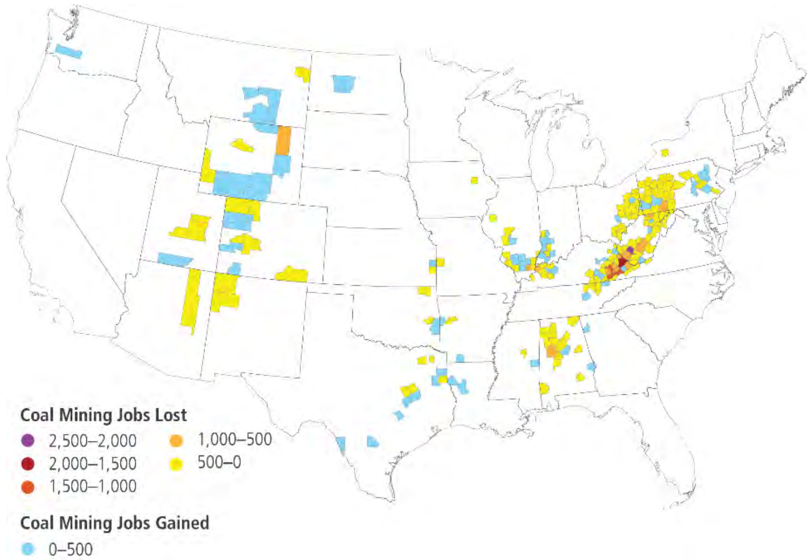


Employment in the coal industry fell from 1985 through 2003, while production increased due to mechanization and a shift to western coal that has much higher labor productivity than Appalachian mines. Over 23,000 jobs were lost between 2011 and 2015; nearly 90 percent of those losses were in the Appalachian region. Note: Data from 2010 to 2016 are quarterly, extrapolated to annual estimates.

This loss of coal jobs can be attributed to increased efficiencies in mining and, later, a reduction in coal demand over the last several decades. Between 1985 and 2001, coal production increased 28 percent, as industry employment fell by 59 percent, due to the increased efficiencies in the industry and by the shifting of production and lower sulfur coal produced by shifting production from Appalachia to the Western U.S., especially within the Powder River Basin.[94, 95] From 2001 to 2015, annual mining productivity in Appalachia ranged from 5,100 tons per employee to 8,100 tons per employee; in the West, it ranged from 35,000 tons per employee to 45,000 tons per employee.[96]

Coal miners provide crucial economic support for communities in which they live, which tend to be concentrated in rural areas. In 2011, at the peak of coal mining employment in this century, coal mining jobs accounted for over 5 percent of employment in 64 U.S. counties and over 20 percent in 12 counties, not including indirect employment supporting the coal sector. Fifty of the counties with over five percent coal mining employment experienced job losses between 2011 and 2015.[97, 98] The total net job loss in the 64 counties was over 20,000 jobs, with 12 counties losing over 10 percent of their entire workforce.[99, 100] These counties that have been hit particularly hard by recent employment declines are located primarily in central and northern Appalachia (see Figure 5-7).

Figure 5-7. Change in Coal Mining Employment by County, 2011–2015[101]



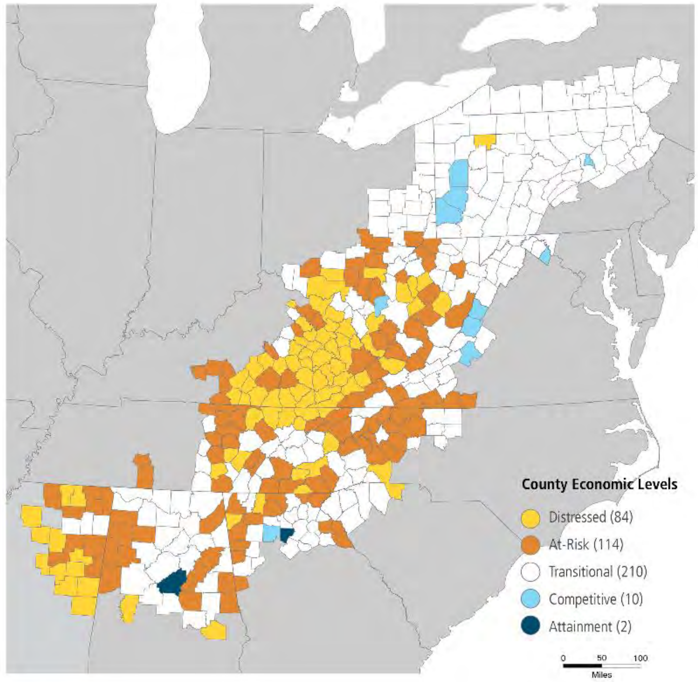
Nationally, 161 counties experienced coal industry job losses between 2011 and 2015, when over 20,000 jobs were lost in total. The most severe job losses are concentrated in central and northern Appalachia, where some regions have a high proportion of their workforce in the coal industry.

Coal mining is a major economic driver within many rural communities. Coal mining jobs pay well relative to other available occupations in those areas; miners earn roughly 40 percent more than the average wage for all U.S. workers.[102] The combination of relatively high income and employment concentration means that many local economies are very sensitive to changes in the industry.[103] A reduction in jobs lowers municipal tax revenues, severely impacting support for public schools, local infrastructure, and public services. Less spending at local businesses depresses the local economy, causing more unemployment, and further reducing public revenue.

There are 1.8 million people living in Appalachian counties with ongoing coal-mining activity and classified as “economically distressed” or “economically at risk” by the Appalachian Regional Commission (ARC) based on a combined index of unemployment, poverty, and income levels.[g, 104] These counties are heavily concentrated in West Virginia, eastern Kentucky, and southern Ohio, largely overlapping with regions facing coal industry employment losses (see Figure 5-8).

[g] The Appalachian Regional Commission ranks all U.S. counties according to a combined index of unemployment, poverty, and income, and considers counties in the bottom decile for the country to be ‘distressed’ and the bottom quartile to be ‘at risk.’

Figure 5-8. Economic Wellbeing of Appalachian Counties, 2016[105]



There are 1.8 million people living in Appalachian counties with ongoing coal-mining activity and classified as "economically distressed" or "economically at risk" by the Appalachian Regional Commission. The Appalachian Regional Commission ranks all U.S. counties by a combined index of unemployment, poverty, and income. It considers counties in the bottom decile for the country to be 'distressed' and the bottom quartile to be 'at risk'.

More than 45 percent of the mining workforce is over 45 years old.[106] For these employees, finding alternative employment—especially at a similar income level—can be more challenging than for younger workers with more time ahead of them in the labor force.[107] Underfunded pension and retiree healthcare obligations put these older workers, retired miners, and their communities in a particularly vulnerable position. Federal efforts to support economically vulnerable communities and workers are discussed in later sections of this chapter.

Coal-miner pension funds are in financial distress, putting retirees and surviving dependents in jeopardy of losing their planned retirement and healthcare benefits. As coal employment has declined, mine-worker pensions have some of the highest ratios of retirees to current workers of any pension programs in the United States, which can drain the principal balance of the fund faster than it can be replenished. The largest coal-miner pension fund, United Mine Workers of America's 1974 Pension Plan, has 90,000 beneficiaries, with only 8,000 working members still contributing to the fund—a 9 percent ratio of contributing workers to active beneficiaries.[108] On average, 37 percent of pension participants in Federally guaranteed, multi-employer pensions are still working and contributing to their pension funds.[109]

The financial crisis and the bankruptcy of three of the largest coal mining companies in the United States between 2014 and 2016 have further imperiled these pension and healthcare programs. These bankruptcies have allowed several large coal companies, including Patriot Coal and Alpha Natural Resource, to default on some or all of their obligations to these pension and healthcare funds.[110, 111] The miners' pension funds are insured by the Pension Benefit Guaranty Corporation (PBGC), a Federal corporation analogous to the Federal Deposit Insurance Corporation and funded out of insurance premiums paid by member pension funds. The 1974 Pension Plan is so large that its default could lead to the insolvency of the PBGC, imperiling retirements across the economy.[112] Retiree health insurance programs have no similar Federal guarantee.[113] Typically, a single employer providing retiree health insurance is not required to pre-fund such obligations, and, in bankruptcy, may be relieved of the obligation to fulfill its commitments.[114] Historically, the Federal Government has intervened to support coal miner retiree benefits in times of crisis through legislative and administrative actions.[115] President Obama's fiscal year (FY) 2016 and FY 2017 budgets included the transfer of Federal funds to protect the health and pension benefits of retired coal miners and their families, as did bipartisan legislation in the Senate and House. However, the 114th Congress adjourned at the end of 2016 without passing this legislation and instead only extended healthcare coverage to retired miners and their dependents through the term of the Continuing Resolution (April 28, 2017).

Continued reductions in coal production in Appalachia are also frustrating efforts to protect community health and the environment against land and water degradation from pre-1977 mining activities. Since 1977, the coal industry has taken responsibility for the remediation of the lands and waters affected by mining, as required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). However, prior mining activity has left an estimated $4 billion of high-priority, health-related and safety-related issues with abandoned mine lands in the United States[116] and up to $9 billion of abandoned coal mine sites needing restoration.[117] SMCRA created the Abandoned Mine Lands Reclamation Fund (AML Fund) to reclaim land damaged before 1977 using funds collected through a small per-ton fee—currently less than 1 percent of retail value—on all coal mined in the United States.[118]

Declining coal production has reduced funding for abandoned mine reclamation. AML Fund receipts have declined from a peak in 2007 of $305 million to $197 million in 2016.[119] At this revenue level, it would take 20 years to fully fund the high-priority, health-related and safety-related coal mine reclamation in the United States—the majority located in Appalachia.

The current formula for distributing AML Fund resources poorly matches regional needs. Until 2023, SMCRA requires that 50 percent of the fees collected for AML Fund restoration are spent in the state in which they are collected. Most U.S. coal is produced in the western United States, where little need for pre-1977 mine reclamation remains. Meanwhile, disbursements to Appalachia, the historic heart of coal production where mine reclamation needs are most severe, have fallen due to declining coal production in that region. The President's FY 2016 and FY 2017 budgets proposed to invest $1 billion over five years from the remaining unappropriated balance in the AML Fund. The proposal would allow states and Native American tribes across the country to accelerate efforts to clean up abandoned mine lands and polluted waters, then link those projects with economic development strategies to revitalize coal communities impacted by the downturn of the coal industry. In February 2016, the Revitalizing the Economy of Coal Communities by Leveraging Local Activities and Investing More (commonly known as RECLAIM) Act (H.R. 4456), a bill consistent with the President's proposal sponsored by Congressman Hal Rogers, was introduced in the House and gained a bipartisan group of 27 co-sponsors by the end of the 114th Congress.

Coal Power Plant Closures

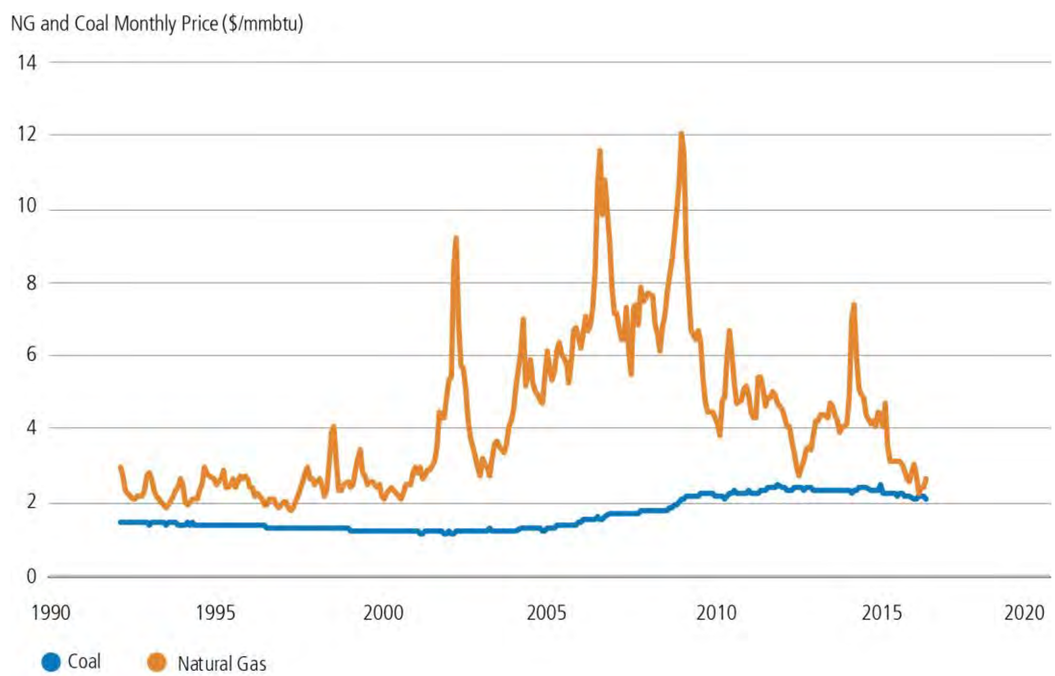
From 2011 to 2015, 345 coal-fired generators were shut down and 20 were added, resulting in a loss of 33 gigawatts, or 10 percent, of the 2011 coal-fired generating capacity.[120, 121] The number of power plants reporting coal as their primary fuel source dropped from 589 to 427.[122] Not all of these numbers represent closures of entire plants—many plants have multiple generating units, and some units have been switched to natural gas rather than shut down, retaining much of their workforce. Nevertheless, fossil fuel electric power generation employment fell 5 percent from 2011–2015.[123] The loss of power plant jobs in rural communities can have effects similar to those described above for coal mining job losses.

Several factors help mitigate, though not eliminate, the effects of coal-fired power plant job losses.[124, 125] For example, in 2012, American Electric Power began planning for plant closures affecting 570 jobs that would occur by 2016. As closures occurred, almost half of the employees moved to positions at other plants. Some retraining occurred, but many employees received similar jobs. Other positions remained vacant after normal retirements, and many employees were retirement eligible at the time of closure due to the advanced age of the workforce.[126] These closures still affected workers and communities, but the utility's planning efforts lessened the effect.

5.4.2 Natural Gas Employment Trends Reflect Shale Boom

Beginning around 2009, the influx of new supply from unconventional sources reduced natural gas prices to pre-2000 low price levels (see Figure 5-9).[127] Low prices relative to coal increased demand for natural gas from the electric power system—now the largest consumer of natural gas in the United States. From 2008 to 2015, electricity generation from natural gas rose 51 percent.[128]

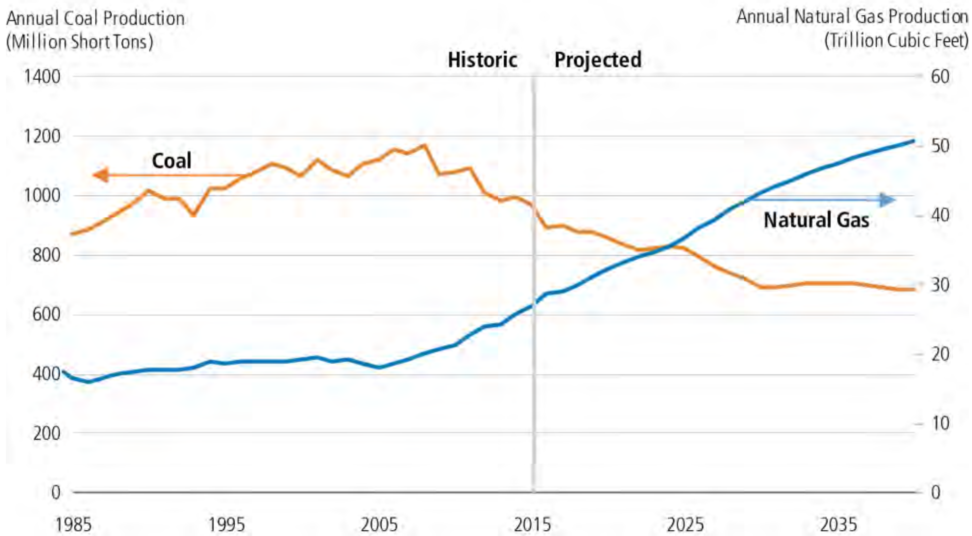
Figure 5-9. Average Monthly Cost of Delivered Fossil Fuels in the U.S. Electricity Industry, 1993-2015[129]



Natural gas prices fell back to pre-2000 prices around 2008. This price drop and increase in the price of coal has made natural gas more competitive than coal in many regions of the country.

The changing relative prices of natural gas and coal and the subsequent change in generation mix led to a large net increase in jobs over the last decade. The natural gas and oil extraction industry added about 80,000 jobs from 2004 to 2014.[130] When support activities, pipeline construction, and associated machinery construction are included, this number increases to about 400,000.[131] Recently, natural gas and oil extraction employment has declined by around 25,000 jobs between early 2015 through November of 2016.[132] However, unlike coal production, natural gas production is projected to increase over the coming decades, sustaining natural gas industry employment (see Figure 5-10).[133, 134]

Figure 5-10. Historic and Projected Annual Coal and Natural Gas Production, 1985–2040[135, 136, 137]



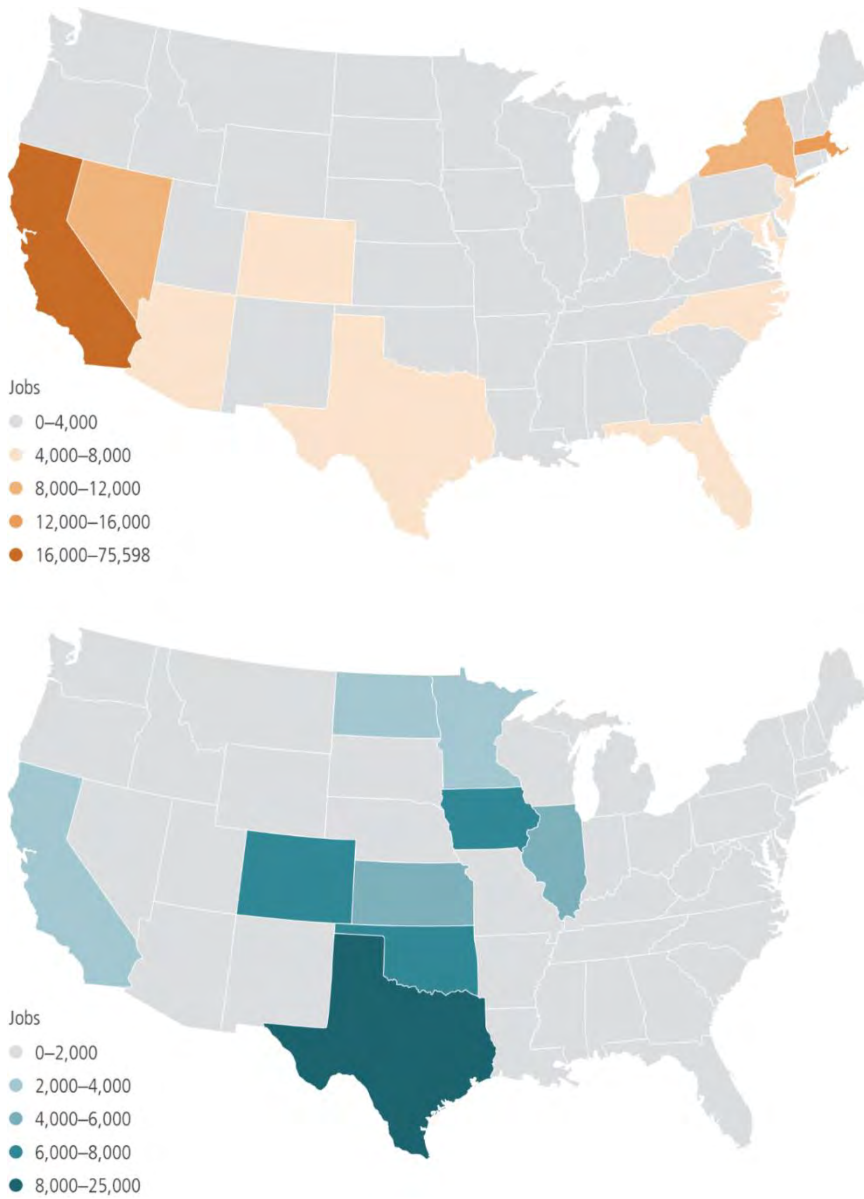
Coal production is projected to decline in the coming years in the business-as-usual scenario shown here, while natural gas production is forecast to increase substantially. These changes imply the employment prospects within these two industries. Though the oil and gas industry has lost a substantial number of jobs in 2015 and 2016, the industry is forecast to increase production in the long term.

Despite potential employment growth from the expected increase in natural gas production in the coming years, jobs in the natural gas industry pose several workforce challenges. As revealed by the recent shale boom, jobs in the oil and natural gas production industry shift location regularly—posing challenges for employees and the economies of the areas where they live and work.[138] Rapid influx of workers can strain local housing availability, and subsequent outflows of workers can leave partially constructed housing in its wake.[139] While average incomes in oil and gas extraction are high (see Table 5-1), job security is low, as the industry fluctuates in response to global markets and as extraction regions experience boom and bust cycles.[140] These rapid transitions are characteristic of the oil and natural gas industry, while changes in the coal industry have played out over longer periods.

5.4.3 Sector Employment in Renewable Energy Continues to Grow

In 2016, the traditional energy sector employed approximately 4.1 million workers. Of these, electric power generation and fuels technologies directly employed more than 1.9 million workers. And, job growth in the renewable energy industry remains strong. Wind power constituted the largest portion of generation capacity additions in 2015.[141] 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, just under 375,000 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 108,000 workers employed at wind firms across the Nation. The solar workforce increased by 25% in 2016, while wind employment increased by 32%.[142] Of the 375,000 individuals working in solar, nearly half of these are in the solar installation industry, requiring distinct skillsets compared to traditional generation technologies. Solar industry jobs are relatively high paying compared to all jobs nationally, with a significant range of earnings across occupations within the industry. Currently, renewable energy jobs are geographically concentrated according to high-value wind and solar resources and state-specific renewable portfolio standards; over half of all the solar jobs in the United States are found in only four states (see Figure 5-11).[143]

Figure 5-11. Distribution of Solar Industry Jobs (*top*) and Wind Industry Jobs (*bottom*) by State, 2015 [144, 145]



Solar industry jobs are primarily located on the coasts, while wind industry jobs are prevalent in the central United States. Together, wind and solar employment cover much of the United States. Job locations are driven by resource availability and by state policies.

5.4.4 Coal, Natural Gas, and Renewable Energy Shifts Create a Mismatch in Electricity System Job Opportunities

While there is potential for long-term job growth in renewable energy and natural gas extraction and further declines in coal mining, these jobs are not substitutable. Several factors prevent the employment opportunities in the renewables and natural gas industries from reaching those communities most affected by erosion of job opportunities:

- **The geographic locations of electricity sector job losses and gains are currently not well correlated.**

  Job losses from the coal mining industry are largely concentrated in southern Appalachia, while growth in natural gas extraction and the renewable energy industry is located elsewhere.

- **Income discrepancies between industries is a challenge for reemployment.**

  The median wage for solar installers is higher than the median wage across all occupations. It remains more than 20 percent less than the median wage for coal mining jobs, [146] *and solar manufacturing jobs in the United States pay 10 percent less than U.S. manufacturing jobs generally.* [147] *While there is an income discrepancy between coal and solar jobs, solar jobs are rapidly increasing. Retraining and creating more localized solar jobs is important.*

- **The skills required for employment vary between industries experiencing growth and those experiencing decline.**

  Natural gas and coal jobs are largely extraction focused, whereas wind and solar energy jobs are significantly manufacturing-based (almost 50 percent for wind and 40 percent for solar) and construction-based (20 percent for wind and almost 30 percent for solar).[148] *Significant retraining would be required to transition between these jobs.*

Employment in the Nuclear Industry

The *U.S. Energy and Employment Report* finds that 68,000 people are employed in the nuclear generation industry.[149] Employment in the industry may fall as nuclear power plants retire. Since 2013, six nuclear reactors have shut down prior to the end of their existing licenses. Closure announcements have been made for another 10 reactors to cease operation over the next 10 years, 8 will close before the end of their current operating licenses. Recent state actions, pending any legal challenges, may enable four of those to continue operating. However, the net employment impact of plant closures may be mitigated through employee retirements and transfers to other power generation facilities.[150]

Construction of nuclear power plants requires thousands of skilled construction workers.[151] To ensure an adequate supply of highly trained workers for the construction of nuclear reactor units at Plant Vogtle in Georgia, North America's Building Trades Unions and Georgia Power created an apprenticeship-readiness training program under the Helmets to Hardhats initiative. The program focuses on increasing workforce inclusiveness and providing job opportunities to veterans.[152]

Employment in uranium production (mining, milling, and processing) has trended with production levels. Though employment numbers are unknown prior to 1993, uranium production over the last two decades was a fraction of average annual production from 1960 to the early 1980s.[153] The uranium production industry employed 625 people in 2015, down from a 21st-century peak of 1,563 in 2008.[154]

Employment trends in the uranium industry closely mirror resource prices; these have fallen from a peak of over $100 per pound of triuranium octoxide (U_3O_8) in 2007 to below $30 in 2015.Prices are anticipated to remain low due to growing inventories owned by nuclear power owners and operators. Total inventories in 2015 were enough to fuel two years of nuclear power production at use-rate averages over the last decade.[155]

5.4.5 Skills Training and Workforce Development

Companies, industry representatives, and labor unions have pursued a variety of skills training and workforce development programs to overcome workforce skills deficiencies.

Many utilities operate their own line worker schools, joint labor management apprenticeship programs, and other training programs, while others recruit from line worker training schools that offer introductory programs.[156] Additional programs include a uniform nuclear curriculum program and a power plant technology program.[157] In FY 2014, 7,253 apprentices were enrolled in registered apprenticeship programs for line installer/repairers, line maintainers, and line erectors.[158]

In 2006, the major industry trade associations and many leading companies formed the non-profit Center for Energy Workforce Development (CEWD). "CEWD was formed to help utilities work together to develop solutions to the coming workforce shortage in the utility industry. It is the first partnership between utilities, their associations, contractors, and unions to focus on the need to build a skilled workforce pipeline that will meet future industry needs."[159] Today, CEWD includes the five major utility trade associations, the industry's two principal unions, and more than 100 companies that employ over 90 percent of utility workers. CEWD is organized through more than 30 state consortia that are focused on working with local educational institutions, their union apprenticeship programs, and other stakeholders to create a high-quality, diversified workforce.

Construction industry training programs are particularly important for energy efficiency. Nationally, North America's Building Trades Unions operate over 1,600 Joint Apprenticeship Training Committees (JATC) with their construction employers. These JATC's train 74 percent of all construction apprentices in the United States at a cost of $1.3 billion annually.[160]

As the electricity industry relies increasingly on ICT components in creating a smart grid, the labor intensity of the electricity grid of the 21st century may decrease. Critically important industries that face similar challenges have already used redesigned work processes and innovative workforce practices to increase efficiency. The increased use of technology—for example smart meters to reduce the need for meter readers, smart grid components that isolate faults and reduce outages, or aerial inspection technology to improve damage assessments—might also increase workforce efficiency.

Smart Grid Workforce Training and Development under the American Recovery and Reinvestment Act of 2009

In 2010, the Department of Energy awarded nearly $100 million of funding appropriated under the American Recovery and Reinvestment Act of 2009 to support 54 workforce training programs in the utility and electrical manufacturing industries. Funding for these programs was cost-shared with community colleges, universities, utilities, and manufacturers, and it is estimated to have trained approximately 30,000 people.[161]

5.4.6 Electricity System Workforce Outreach and Inclusion Programs

In addition to government programs, private partnerships with non-profit organizations are also focused on increasing the inclusiveness of the energy sector workforce. GRID Alternatives, together with SunEdison, created the Realizing an Inclusive Solar Economy Initiative, which focuses on recruiting members of underrepresented communities for jobs in the solar industry—providing solar installation training, working with the solar industry to identify needed skills for the trainings, linking trained candidates with available employers, and ensuring the retention of a diverse workforce in the industry.[162]

Additional targeted initiatives include the Utility Industry Workforce Initiative, where CEWD joined with the Departments of Energy, Labor, Defense, and Veterans Affairs; the International Brotherhood of Electrical

Workers; and the Utility Workers Union of America to increase hiring rates of veterans in the industry.[163] Helmets to Hardhats, run by the North American Building Trades Unions, also trains veterans for the construction and utility industries.[164]

Department of Energy Workforce Inclusion Programs

Several outreach programs have been established to build a more inclusive work environment in the energy sector. The Department of Energy (DOE) launched the Minorities in Energy Initiative in 2013 to "strive to ensure that our energy workforce more fully reflects the diversity and strengths of the country."[165] The Department, through the National Nuclear Security Agency, also sponsors the Minority Serving Institutes Partnership Program and the Cybersecurity Consortium at Historically Black Colleges and Universities.[166] In 2014, DOE also created the Solar Ready Vets® program through its SunShot Initiative.[167] The program trains exiting service members to become solar installers and has developed a program that provides on-base training through the Department of Defense SkillBridge program during the last six months of service. Other programs are more broadly focused on improving participation among women and minorities in science, technology, engineering, and mathematics (STEM) fields and career pathways. Specific DOE initiatives for STEM outreach include the Clean Energy Education & Empowerment initiative and the Mickey Leland Energy Fellowship Program.[168, 169]

5.4.7 Federal Workforce Data and Coordinated Programs

In response to the lack of high-quality and discrete energy jobs data, the Department of Energy launched the Jobs Strategy Council, which commissioned USEER, making significant strides in improving the availability of data and insights for the energy and electricity industry workforce.[170] The second edition of the report will provide more precise job categorization—particularly for natural gas industry employment estimates—and will be published in January 2017.

Title X of H.R. 6, the 2007 Energy Bill, established the Energy Efficiency and Renewable Energy Worker Training program for the Department of Labor to administer.[171] In addition to the training program, H.R. 6 required the Secretary of Labor to collect and analyze labor market data to track energy-related workforce trends, award competitive National Energy Training Partnerships Grants to implement training for economic self-sufficiency, and develop an energy efficiency and renewable energy industries workforce. Finally, the Secretary of Labor was required to award competitive grants to states to administer labor market research, information, and labor exchange research programs, as well as renewable energy and energy efficiency workforce development programs.[172] To date, this program remains unfunded by Congress.

5.4.8 Support for Communities Experiencing Economic Dislocation

The United States has a long history of providing adjustment and training programs to workers in industries undergoing transition. The Trade Adjustment Assistance program for workers in trade-exposed industries with increased import competition was established in 1962, and the broader Job Training Partnership Act was passed in 1982.[173] The Clean Air Employment Transition Assistance Program, included in the Clean Air Act Amendments of 1990 and subsequently repealed, provided training, adjustment assistance, employment services, and needs-related payments to workers who lost jobs due to a business's compliance with the Clean Air Act.[174, 175] Current changes in the electricity sector are rapid and significant; targeted assistance may aid in addressing this transition. An alternative approach for older workers in regions with few economic opportunities could also provide a financial bridge to retirement in areas of rapid transition.

The Appalachian Regional Commission (ARC) is a regional economic development agency created in 1965 to help the Appalachian region reach socioeconomic parity with the rest of the Nation. ARC funds business development, workforce development, infrastructure investment, and community capacity building through Federal appropriations. Despite ongoing economic challenges in the region, ARC's non-highway appropriated budget has fallen from roughly $600 million in the early 1970s to below $100 million in the 1980s. Its budget has averaged below $100 million per year until 2016 when it grew to $146 million.[176, 177]

The continued fiscal difficulties of coal miner pensions threaten the solvency of PBGC. Ensuring the continued fiscal health of PBGC would support retired workers and their spouses and provide sources of economic wealth in communities with decreasing sources of local government revenues.

While local governments experience losses in tax revenue, it is essential to ensure that children have access to adequate education. The Federal Government previously assisted in similar situations through the now-expired Department of Agriculture Secure Rural Schools (SRS) program, which provided grants to schools in communities that were suffering from the precipitous decline in logging on Federal land in the 1990s.[178] In FY 2015, the SRS program paid $222 million to localities in 41 states and Puerto Rico to invest in school systems and road infrastructure.[179, 180] The amount of support required in coal communities is likely significantly less than in the SRS program, which reached 9 million children.[181] All of the central Appalachian states spend within 10 percent of the U.S. average of $10,600 per student per year, and fewer than 100,000 students live in counties where at least 1 percent of the population works in coal mining.[182, 183, 184]

The AML Fund's inability to fully support 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. Ensuring funding and appropriate design for the AML Fund will help prevent mines that were once a source of prosperity for these communities from becoming sources of sustained financial and community health challenges.

The Partnership for Opportunity and Workforce Economic Revitalization (POWER) Initiative

The POWER Initiative is a coordinated Federal effort designed to assist communities that are negatively impacted by changes in the coal and electricity industries by funding investments in economic revitalization and workforce training in coal communities across the United States. The Appalachian Regional Commission and the Department of Commerce's Economic Development Administration administer the program.[185] Several first and second round grantees provide workforce development and training opportunities for workers displaced by the contraction of the coal industry in addition to economic development planning assistance.[186, 187]

The recommendations based on the analysis in this chapter are covered in Chapter VII, *A 21st-Century Electricity Sector: Conclusions and Recommendations*.

5.5 Endnotes

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VI Enhancing Electricity Integration in North America

This chapter details the interconnectivity of the United States', Canada's, and Mexico's[a] electric systems and opportunities for enhancing integration. First, the chapter outlines the existing consensus between the nations to improve integration and the regional variation in transmission capacity that exists. The next two sections explore the integration of the United States with Canada and Mexico, respectively, and provide in-depth discussions of relevant country-specific policies. The chapter concludes with possible policy options to improve integration as well as ongoing and potential opportunities for collaboration.

[a] Due to the nature of electricity system interconnections and for simplicity of terminology, the term "North America" will be used in this chapter to refer narrowly to the continental United States, Canada, and Mexico.

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 subregional basis.[1]

One model for power-sector collaboration across national borders is demonstrated by the reliability planning under the North American Electric Reliability Corporation; however, this engagement has been limited to Canada, the United States, and the Baja California region of Mexico.[2] The Canadian, Mexican, and United States governments have all made significant climate commitments and have indicated a desire to shift toward greater renewable energy penetration.[3] In June 2016, the United States, Canada, and Mexico announced a goal for North America to strive to achieve 50 percent clean power generation by 2025. Greater cross-border integration could be a tool to maximize gains from the deployment of clean energy generation and energy efficiency, but the complexity and current asymmetry of national and subnational policy frameworks may impede implementation.[4]

The design of domestic U.S. clean energy policies, both at the Federal and state level, has 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.[5]

Continued study of the context and levels of integration of each subregional, cross-border interconnection will allow for a deeper understanding of policies that have shaped current levels of cross-border trade (Table 1-1).

Canada has additional hydropower resources that could be exported to the United States to provide a reliable source of firm, low-carbon energy.[6] There are concerns among stakeholders that increased imports of Canadian hydropower could reduce U.S. clean energy competitiveness; however, there are examples of arrangements where Canadian hydropower decreases curtailments of U.S. clean resources.[7]

Trade has been increasing across the North American bulk power system,[8] but cross-border flows, especially between Canada and the United States, are now using the full capacity of existing transmission infrastructure.[9, 10]

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: (1) the lack of a dominant exporting country on the U.S.-Mexican border; (2) the different regional approaches to integration on the U.S. side; (3) the nascent regulatory framework in Mexico; and (4) the differing legal instruments for open-access transmission agreements and reliability coordination between the United States and Mexico.[11]

Mexico's ongoing electric 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.[12] A transition in Mexico from oil to natural gas in electricity generation could have tremendous impacts in the manufacturing sector, reducing electricity prices, boosting manufacturing output, and increasing overall gross domestic product 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 greenhouse gas-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 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 essential reliability services.[13]

6.1 Cross-Border Electricity Integration

6.1.1 Consensus to Enhance North American Electricity Integration

The potential for electricity integration to provide economic benefits and support the development of more modern and resilient energy infrastructure has been a long-standing theme for North American diplomacy.[14, 15] Leaders in the United States, Canada, and Mexico have publicly and repeatedly affirmed support for the concept of increasing energy integration,[16] and there is a general understanding across the continent that the benefits of cross-border electricity trade can be improved with deeper system integration. 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. In particular, the United States, Canada, and Mexico announced a goal for North America to strive to achieve 50 percent clean power generation by 2025.

A number of additional recent developments make a discussion of cross-border electricity integration[b] especially relevant:

- The completion of transformational energy reforms in Mexico in the oil, gas, and electricity sectors.
- Canada's framework on clean growth and climate change, charting an accelerated path to achieve deep greenhouse gas (GHG) emissions reductions and green infrastructure development.
- The shale gas boom in the United States, which presents new opportunities for natural gas generation, as well as raises questions about land use and emissions.
- The Paris Agreement and the steps needed to implement nationally determined contributions globally.
- All three countries' sustained interest in stimulating strategic opportunities in clean energy development and energy efficiency.[17]
- The acceleration of the deployment of renewable energy technologies, which creates opportunities for grid management through integration.

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 suggest that North America has much to gain from collaborative planning, strategy, and cooperation in the power sector.

6.1.2 Regional Variation in Integration across North America

There is international consensus that electricity integration brings great value to Mexico, Canada, and the United States, but the details of planning and implementing electricity integration require the

[b] While the discussion of power sector integration has been of intense international interest, moving from aspirational objectives to actionable policy steps requires a clear, yet nuanced, definition of "integration" (or its close homologue, "harmonization"). While these terms are commonly discussed among a broad range of cross-border power sector stakeholders, there is no single definition for their use. For the purposes of this discussion, we define integration to include basic information sharing in policy making and planning, as well as the coordination of policies and decision making, often with the result of enhancing flows of cross-border trade. For the power sector, this includes any level of coordination in planning, system operations, or regulation.

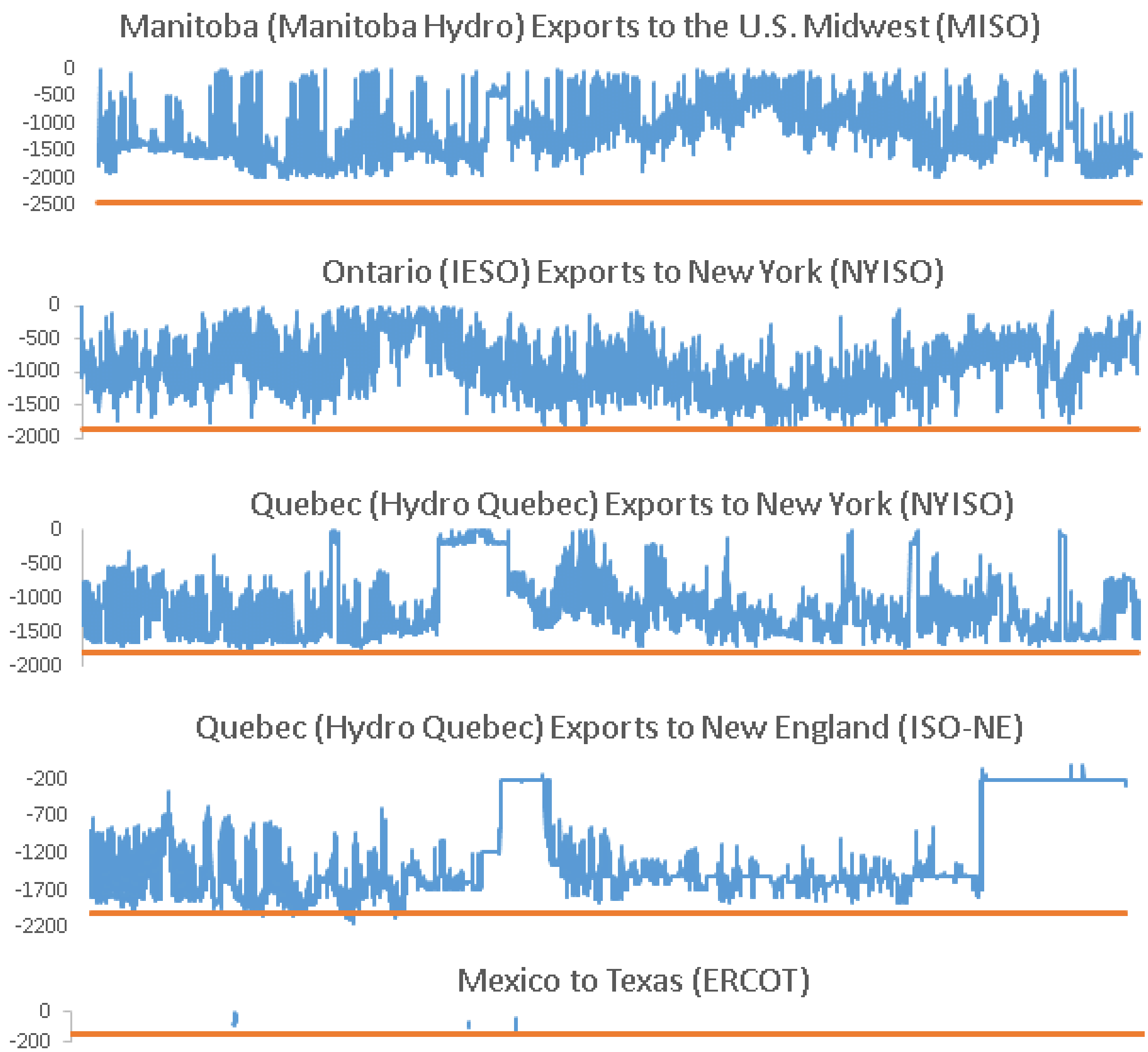
navigation of national, regional, and local interests through the engagement of a broad set of public and private stakeholders.[18] The North American electricity system is heterogeneous; operations and planning primarily take place through regional entities, and every part of the system has evolved with different characteristics and structures.[19] This leads to complex and asymmetrical jurisdictions and regulations, as well as cases in which international, cross-border coordination is sometimes greater than subregional coordination within a specific country. U.S.-Canadian integration is often greater than between Canadian provinces.[20]

A subregional lens is necessary to understand the many varying contexts of integration between Canada and the U.S. Pacific Northwest, Midwest, and Northeast Regions, as well Mexico and the southern border region with Arizona, California, New Mexico, and Texas. These contexts include different levels of integration that range from physical, asynchronous interconnections geared towards emergency trade (such as in the Electric Reliability Council of Texas (ERCOT)-Mexico cross-border interactions), to extensive, synchronous interconnections that enable Canadian cross-border participation in U.S. competitive electricity markets (such as in the Manitoba Hydro-Midcontinent Independent System Operator [ISO]). Because of this diversity, there are additional opportunities for enhanced integration that should be examined in order to bring maximum benefit for the greatest number of stakeholders at a minimum cost.

For example, additional cross-border transmission infrastructure with Canada has been projected to lead to lower overall system costs in U.S. border regions, and it could enhance reliability, backstop variable renewable energy development, and enable lower overall emissions of U.S. power consumption.[21, 22] Greater cross-border planning of transmission and operations between the United States and Mexico could maximize efficiencies for commercial opportunities for U.S. generators to sell into a higher-priced market, while lowering the electricity costs paid by industrial consumers in Mexico.[23, 24] Additional trading in electricity between Mexico and the United States could have further impacts, including possibly on long-term price stability and other market factors, which will need to be further analyzed. Coordination of the United States' and Mexico's clean energy incentives and programs, such as Clean Energy Certificates, could lead to additional opportunities for clean energy research, development, and deployment, as well as reductions in carbon emissions.[25]

The barriers to deepening integration are also regionally nuanced. Increasing cross-border integration, and especially increasing cross-border trade, raises important questions regarding the economic impacts of enhanced integration on domestic power generators and jobs; the reliability of power supply; the environment; costs for consumers; and increased reliance on international sources of power. In most border regions, increasing electricity flows would require the construction of additional transmission infrastructure (see Figure 6-1) since current lines between the United States and Canada are operating at or near capacity, and the connections between the United States and Mexico tend to have low capacity. Developers of new infrastructure will need to strategically align planning across borders in order to overcome opposition.

Figure 6-1. Transmission Capacity and Electricity Trade across Major Interconnections (June 2015–May 2016)



Blue lines show hourly export data from Canada and Mexico to the United States in negative megawatt-hours (MWh); red lines indicate maximum export capacity, recorded hourly from June 9, 2015 to May 19, 2016. As the blue lines reach the red limit of maximum capacity, transmission in that region is full and cannot be expanded on current lines. The proximity of hourly export flows to the maximum export capacity suggests that transmission lines are often fully utilized, especially in the U.S. Northeast. Flat-lined regions in Hydro Quebec figures are attributed to maintenance outages.

6.2 U.S.-Canada Integration

6.2.1 Historical Overview

The United States and Canada serve as a global model of highly functional, cross-border electricity coordination. Cross-border electricity trade and coordination of operations, policy, and regulatory planning are extensive, mature, and efficient, and they have led to economic and reliability benefits on both sides of the border.[26] Significant levels of cross-border transmission interconnect both countries, and electricity trade has been growing overall since 2005, increasingly dominated by flows from Canada to the United States.[27, 28] Total U.S.-Canada trade (including flows in both directions) in 2015 was 77 million megawatt-hours (MWh), accounting for a total of U.S. dollars (USD) $2.6 billion in revenues (Canadian dollars $3.4 billion).[29] With the notable exception of trade in the Pacific Northwest, which continues to be bidirectional (with the United States acting as a net exporter to Canada since 1999), in all other regions, Canadian exports to the United States have significantly overtaken flows in the opposite direction (Figure 6-2).[30]

These recent trends reinforce a longer historical trajectory. Since the first electricity developments led to trade between the two countries in the early 1900s, Canadian private hydropower generators have prioritized exports to the United States over pan-Canadian trade, due to a number of factors.[31] In accordance with Section 92A of the Canadian Constitutions Act of 1867, Canadian provinces have near-complete authority over their individual electricity systems. Many hydropower-producing provinces (such as British Columbia and Quebec) have vertically integrated utilities with regulated pricing structures. Markets with more diversified generation mixes (such as Ontario and Alberta), however, have implemented varying levels of restructuring, resulting in a system in which neighboring provinces often host asymmetrical market structures that aren't conducive to trade.[32] Transmission infrastructure development is determined by Canada's spatial population distribution: 75 percent of the Canadian population lives within 100 miles of the U.S. border and is clustered along the coasts.[33] Canadian hydropower producers, who have the greatest potential to increase capacity to serve other loads, have focused on extending transmission the short distances from Canadian population centers to the U.S. border, rather than on more costly east-west transmission to other provinces.[c, 34] The high level of north-south integration between Canada and the United States, guided by jurisdictional, population, and geographic factors, means that cross-border coordination often surpasses east-west coordination among provinces, states, or ISOs within either country.[35] Primary interconnections link single Canadian provinces to markets in the United States: The Pacific Northwest to British Columbia; Manitoba to Midcontinent ISO; Ontario and Quebec to New York ISO; and Quebec to ISO New England.

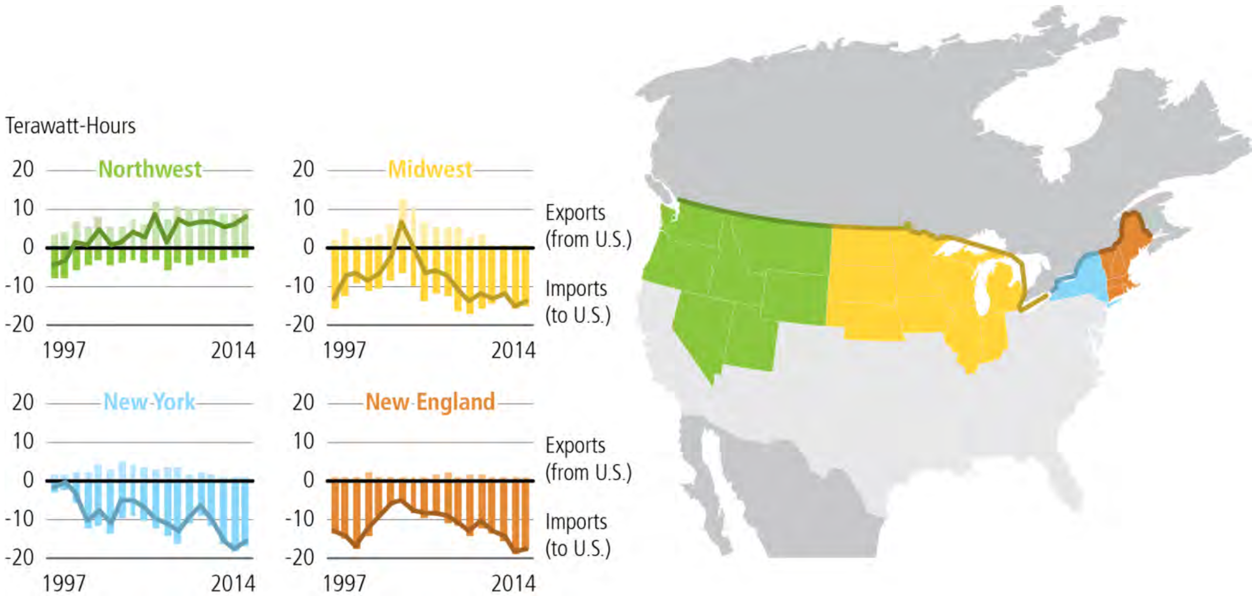
High levels of integration between the United States and Canada exist across the border and are facilitated in a variety of ways. For example, since 1964, the Columbia River Treaty has contributed substantially to the economic progress and safety of both countries through coordinated flood-risk management and clean, renewable hydropower within the Columbia River Basin in the Pacific Northwest. Ongoing negotiations on a new formal treaty with Canada to extend this arrangement beyond 2024 are critically important to the economy of the Pacific Northwest region, particularly for flood management and hydropower optimization.

The significant level of integration between the United States and Canada also has reliability implications. Two large-scale, cross-border blackouts, the Great Northeast Blackout of 1965 and the Northeast Blackout of 2003, among other factors, significantly shaped the current policies regarding reliability. Those events played a role in spurring the subsequent establishment of the North American Electric Reliability Corporation (NERC), the Energy Policy Act of 1992, and the Federal Energy Regulatory Commission (FERC)

[c] The Maritime Link Project, which links New Foundland, Labrador, and Nova Scotia, as well as discussions about exporting hydropower from British Columbia Hydro's Site C Clean Energy Project to Alberta suggest this might be changing.

orders to open transmission access.[36] See the History and Trends Appendix for additional detail on these events.

Figure 6-2. Overall U.S. Electricity Trade with Canada in Four Regions[37]



The graphs show U.S. electricity trade with Canada (1997–2014) in the Northwest, Midwest, New York, and New England. While the Pacific Northwest has been steadily increasing electricity exports to Canada, the Midwest, New York, and New England have been increasing imports over time.

6.2.2 Benefits and Barriers to Increasing Cross-Border Electricity Trade

There is high potential to increase Canadian hydropower exports to the United States. The Canadian Hydropower Association estimates that Canada has a technical hydropower-generation potential that could more than triple current levels, up to 236 gigawatts.[38] As a resource, hydropower has several advantages: it is flexible, reliable, and cost-competitive with other sources of power, and it produces nearly zero carbon emissions.[39, 40] Hydro reservoirs can provide energy storage, and hydropower generation can be adjusted relatively quickly, making it a natural complement to intermittent resources such as solar and wind power.[41] Some dams also serve additional functions, such as managing flood control or storing potable water. Already, the climate and energy security benefits of Canadian-U.S. hydropower trade may be substantial. By one estimate, trade in hydropower between Quebec and its neighbors (New England, New York, Ontario, and New Brunswick) can be credited with 20.6 megatonnes of avoided emissions from 2006–2008.[42]

Electricity imports can serve as a cost-effective supply for wholesale power markets in the United States. The External Market Monitor of ISO New England concluded that importing electricity from Quebec and New Brunswick "reduces wholesale power costs for electricity consumers in New England."[43] Similarly, a New England States Committee on Electricity study on incremental hydroelectric imports from Canada found average annual economic benefits associated with reduced electricity prices in New England to be in the range of USD $103 million to $471 million.[44]

Cross-border trade between the United States and Canada is mature and highly integrated, but enhancing integration—especially with the objective of increasing cross-border trade—faces interrelated barriers. First, there are concerns from generators within the United States that increasing cross-border trade would have a negative impact on domestic markets and give Canadian suppliers market power.[45] In the 2000s, Canadian hydropower was viewed as one of the most cost-effective electricity sources, which presented a double-edged sword: it could lower prices for U.S. customers, but it could also outcompete U.S. generators in the natural gas and renewable energy sectors. In recent years, low U.S. natural gas prices have shifted the business case for increasing cross-border trade by reducing the extent to which imports from Canada would lower costs for electricity users.[d, 46] Continued, thorough examination of the long-term implications of integration for consumers and generators will be needed in the future.

Second, increasing electricity trade would require additional transmission capacity. While several transmission projects have already been proposed to increase capacity in the Midwest and Northeast, the complexity of these projects raises a variety of stakeholder concerns that lead to long development times and unexpected delays.[47] Concerns range from the environmental impacts of transmission infrastructure to the potential implications of greater Canadian imports on local and regional economic development.

Siting and permitting decisions are made at the state and local level, including for international transmission lines. Continued integration and transformation of the North American electricity system requires effective siting and permitting capabilities at all levels of government. Planning and permitting new cross-border transmission infrastructure, including managing ecological impacts across jurisdictions and with a wide range of domestic and international stakeholders, is uniquely challenging. State, provincial, local, and tribal governments, assisted by federal agencies, need to build capacity to minimize safety and security consequence and protect the environment, while limiting permitting-related delays.[48, 49] Government efforts at the federal and local levels should ensure that project developers have a clear understanding of expectations, best practices, and priorities during the permitting of cross-border transmission projects. The issuance of recent cross-border Presidential permits for the Great Northern Transmission Line[50] in Minnesota and the New England Clean Power Link[51] in Vermont are both examples of the application of collaborative principles of early engagement with stakeholders detailed in the new Integrated Interagency Pre-Application Process.[52] Additional study of and updated information on cross-border regulation can assist with establishing a clear understanding of requirements at the federal and state levels for the permitting of cross-border transmission facilities.

6.2.3 Clean Energy Development in the Cross-Border Context

Many states have established renewable portfolio standards (RPSs), not only to reduce GHG emissions, but also to stimulate local development of clean energy. Currently, many U.S. clean energy policies are not designed to allow existing Canadian hydropower imports as a compliance option. The additional concern about negative environmental impacts of large-scale hydropower have led a number of states to adopt RPSs that exclude large-scale hydropower, leading to a “non-counting” of Canadian hydropower, regardless of the positive impact such imports would have on the state’s emissions. Currently, Minnesota, Vermont, and Wisconsin are the only U.S. northern border states that have RPSs that allow for the accounting of some forms of large-scale hydropower, including imports from Canada, as a clean energy resource.[53] Completed analysis of the economic and environmental impacts of increased levels of hydroelectric imports from Canada indicates that the potential for cumulative reductions in GHG emissions ranges from 58 million to 97 million megatonnes.

There are examples of Canadian hydropower supporting greater renewable energy development in the United States.[e] A 2013 MISO/Manitoba Hydro study explored the potential for Canadian hydropower to

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[d] According to the Energy Information Administration, natural gas prices for electric power fell from USD $9.26 per thousand cubic feet in 2008 to USD $3.37 per thousand cubic feet in 2015.

[e] This association is also suggested by the preliminary ReEDS projection shown for New York ISO in Figure 6-6.

provide balancing for U.S. intermittent energy (primarily wind) and found that greater deployment of this arrangement provides economic and environmental benefits on both sides of the border, with annual modified production cost savings ranging from $228 million to $455 million for 2027, and annual load cost savings ranging from $183 million to $1,302 million for 2027.[54] Variations in planning and market design may require a different approach by region. In addition, lessons learned from examining the creation of economic and environmental benefits across international borders should be explored and disseminated when possible.

6.3 U.S.-Mexico Integration

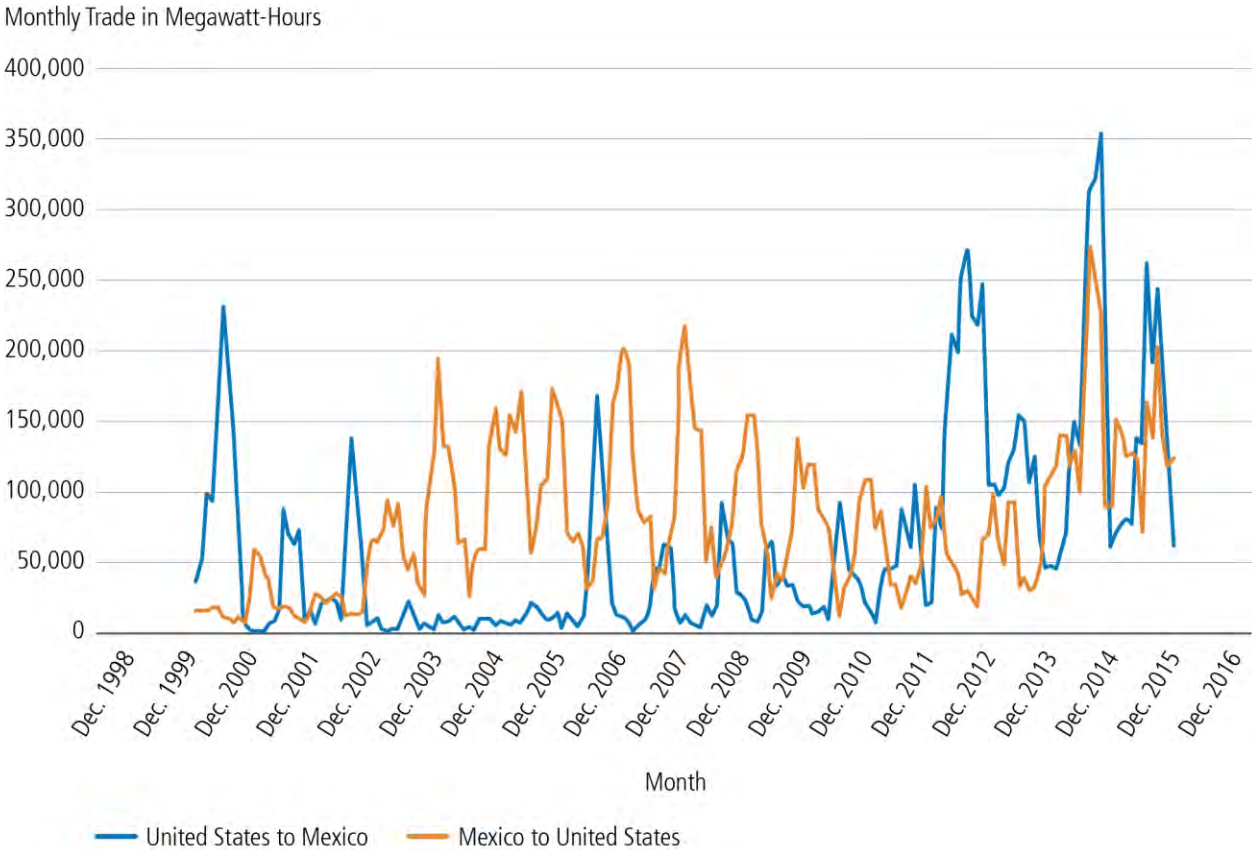
6.3.1 Mexico's Energy Industry Reforms

Due to a combination of historical, geographic, and resource factors, there is significantly less electricity integration between the United States and Mexico (Figure 6-3). According to the Energy Information Administration (EIA), in 2015, the United States and Mexico traded approximately 7.69 million MWh total (compared to 77.2 million MWh traded between the United States and Canada), with the United States exporting 0.39 million MWh and importing 7.3 million MWh.[f]

A number of factors explain the differences: both countries' border regions have experienced electricity shortages and lack reliable excess-generation resources[55] to export to the other; Mexico's states along the U.S. border have some of the lowest population densities in the country;[56, 57] and the border regions include areas with low (or insufficient) levels of existing transmission capacity. Two U.S. states, Texas and California, dominate the cross-border interactions with very different visions for integration. ERCOT shares the longest border with Mexico of any U.S. state, but all transmission connections between the Mexican grid and ERCOT are asynchronous, and trades are primarily for emergency backup, as illustrated in Figure 6-1. Baja California is not connected to the rest of the Mexican federal grid, and therefore, robust California-Baja California cross-border integration may not lead to more integration opportunities in the absence of more domestic, long-distance transmission in Mexico.

[f] U.S. and Mexican estimates of U.S.-Mexico electricity trade vary significantly—a disparity that is being addressed by energy information institutions in both countries under the North American Energy Information Cooperation. Mexico's regulatory agency (Comisión Reguladora de Energía) and wholesale market operator (El Centro Nacional de Control de Energía) estimate total trade to be 4 million MWh in 2014, nearly double the EIA estimate.

Figure 6-3. Electricity Flows Between the United States and Mexico[58]



Monthly cross-border electricity trade between the United States and Mexico shows a number of differences with U.S.-Canada trade; it occurs at lower volumes and is more sporadic/seasonal and bidirectional. Like U.S.-Canadian trade, however, it has been increasing overall since 2011.

Mexico's 2013 energy industry reforms, which included transformational structural reforms across the oil, gas, and power sectors, are highly relevant to cross-border electricity integration (Figure 6-3).[g] Until 2013, the Mexican Federal Electricity Commission (CFE), the vertically integrated, state-owned utility, served as the sole producer, provider, and distributor of electricity in Mexico,[59] and private participation in the sector was reserved for the state except in limited situations (small power production, cogeneration, and independent power production). The existing framework, however, faced significant stress in the 1990s and early 2000s, caused by a mixture of external and structural factors, including high energy prices, low industrial competitiveness, government subsidization of electricity, lagging domestic fossil fuel production, and under-investment in the power sector. Projected growth of power demand over the next decade led the government to pass extensive energy reforms in 2013, followed by a series of implementing laws that unbundled CFE and established a new wholesale electricity market to foster competition with private-sector participation (Figure 6-4). Under the new framework, the private sector is now free to participate in all aspects of the generation and sale of electricity, while CFE maintains physical control of transmission and distribution infrastructure and remains the sole provider to residential users with regulated tariffs, and the National Energy Control Center is now the ISO in charge of the operational control and administration of the new wholesale electricity market.[60] Many power

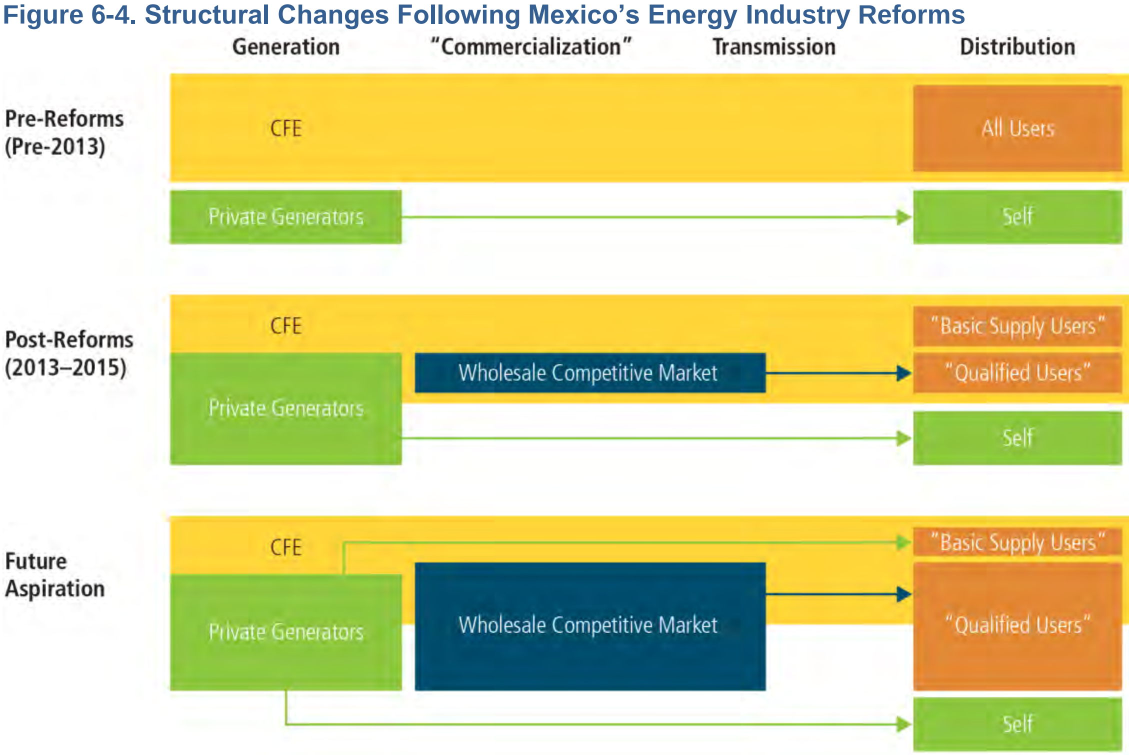
[g] Unlike U.S. and Canadian power sector governance, which defers a number of authorities to state and provincial governments, Mexico's federal government is more centralized and also has near-complete authority in the power sector.

sector stakeholders have called the reforms groundbreaking and admirable, including for reducing the strain of electricity consumption costs on industry in Mexico (Figure 6-5).[61]

The reforms are focused on the overall goal of competitiveness, with twin objectives of helping consumers pay less for electricity and have cleaner electricity.[62] Currently, the industrial sector in Mexico faces costs per MWh of electricity that are almost double electricity costs in the United States, making production and goods more expensive for all of North America. In seeking lower energy prices for its consumers, Mexico is focusing on switching from fuel oil and diesel-fired generation in the power sector to natural gas (in part through greater imports from the United States[63]); reducing transmission and distribution losses (estimated at 16 percent of total generation in 2010); and increasing renewable energy deployment.[64] The impacts for Mexico's northern border region, specifically, could be significant as the region includes a number of industrial centers in Ciudad Juárez, Matamoros, Mexicali, Nogales, Nuevo Laredo, Reynosa, Tecate, and Tijuana.[65] One economic analysis estimates that transitioning from oil to natural gas for electricity production could have tremendous impacts in the manufacturing sector, where it could reduce electricity prices by 13 percent, boost manufacturing output by up to 3.9 percent, and increase overall gross domestic product by up to 0.6 percent.[66, 67]

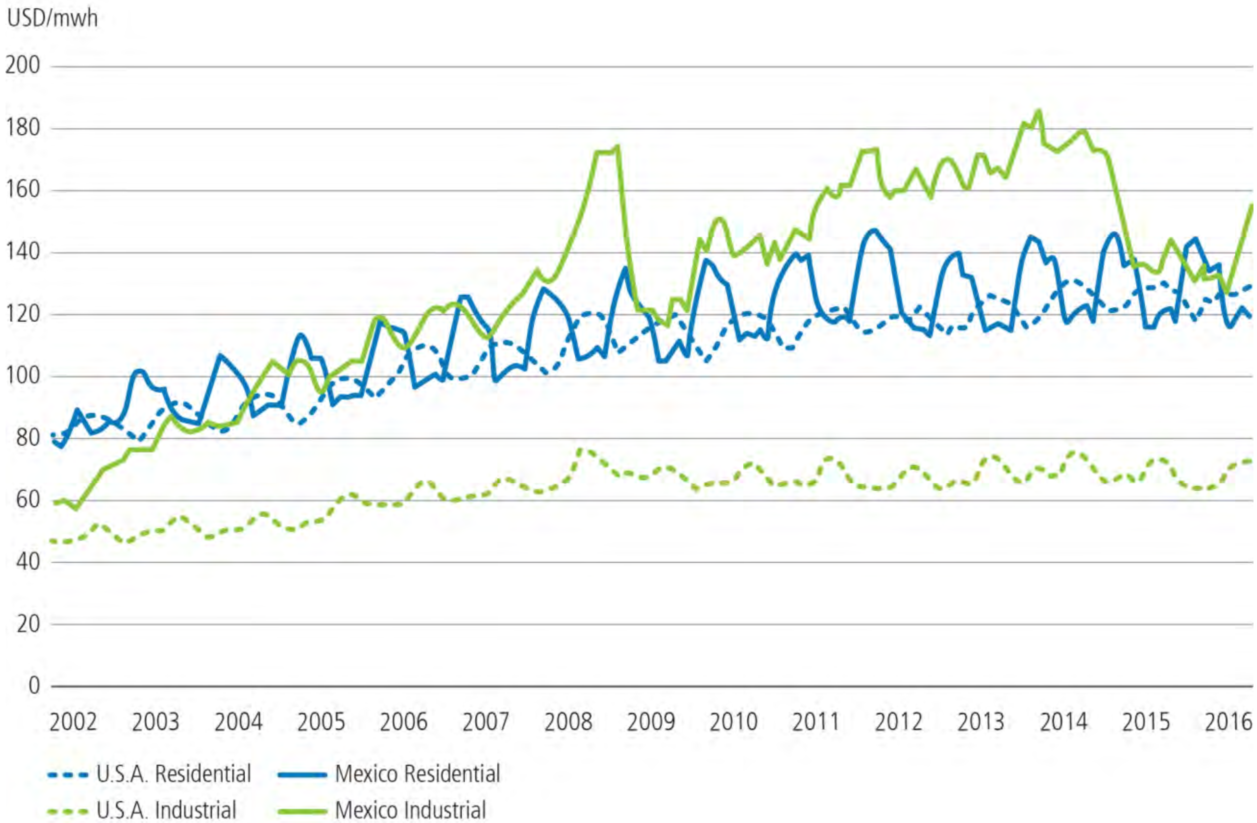
As is natural for such a transformational change to the sector, the full implementation of the reforms is still in development, and uncertainties about the final form of the new framework exist.

Figure 6-4. Structural Changes Following Mexico's Energy Industry Reforms



A simplified schematic showing the adjustments in the Mexican power sector, pre-reforms, post-reforms, and future aspirations. Pre-reforms, CFE was vertically integrated and responsible for the generation, commercialization, transmission, and distribution of electricity to nearly all users, with exceptions for some forms of self-generation. The reforms created a wholesale competitive electricity market in which private generators can participate, and divided users into "basic supply" users (those who consume under a given threshold and continue to receive direct service from CFE) and "qualified users" (those who consume over that threshold and are serviced by the wholesale competitive market). Over time, the wholesale market is intended to supply the majority of consumers. CFE continues to maintain control over transmission and distribution post-reforms.

Figure 6-5. Industrial and Residential Electricity Rates in the United States and Mexico, 1993–2013[68]



Different policies regarding industrial electricity and residential tariffs in the United States and Mexico, as well as different electricity generation sources (over the given period, Mexico used greater diesel/heavy fuel oil-fired generation, while the United States was more reliant on coal and natural gas) have led to a significant differential between U.S. and Mexican electricity rates. Of particular note, industrial rates in Mexico were slightly less than double U.S. rates in 2013, which impacts Mexican industrial competitiveness. Rates include government subsidies to Mexican residential consumers.

Mexico is already seeing reductions in electricity prices; though the recent low oil and natural gas prices are likely a contributing factor, this trend is also likely to be stimulated by the reforms. From December 2014 to December 2015, electricity rates fell between 30 to 42 percent for industry. The wholesale electricity market also began to operate in January of 2016 and renewable electricity-generation capacity increased by 8.5 percent from 2013–2014 alone.[69] However, a differential in prices still exists: in the first six months of 2016, average wholesale prices in most locations of Mexico have ranged from $48/MWh to $60/MWh;[70] while in Texas, the ERCOT North 345-kilovolt peak wholesale prices over the same period were $22/MWh.[71]

6.3.2 Projected Actions and Potential Opportunities

Mexico's energy industry reforms may shift the cost-benefit analysis of enhanced integration in meaningful ways: these reforms were intended to increase generation in Northern Mexico (including a number of industrial centers); stimulate private-sector investment in the power industry; lower energy costs; increase flows of natural gas from the United States; and increase renewable energy and energy efficiency deployment. All of these objectives could have implications for the attractiveness of increasing cross-border coordination and electricity trade.

According to analysis done by EIA, Mexico plans to build an additional 57 gigawatts of generation capacity from 2016 to 2030 and double natural gas imports from the United States from 2013 to 2018,[72] which will lead to a decline in electricity subsidies. The Program for Development of the National Electricity System, an annual report known by its Spanish acronym "PRODESEN," also demonstrates the intent to increase transmission capacity within Mexico, with some developments that could have impacts on cross-border trade, including connection of the Baja California Peninsula to the Mexican federal system by 2021 and construction of a new 150-MW asynchronous connection between Nogales, Sonora, and Arizona.[73, 74] The government of Mexico is also studying the possibility of a larger east-west transmission line along the U.S. border, with the objective of enhancing transmission capacity in Northern Mexico and facilitating cross-border trade.[75] Policy, regulatory, infrastructure, and economic changes in Mexico may lead to a number of other new opportunities. The smart grid is a key area of focus; the PRODESEN report supports a smart grid program every three years to evaluate projects for the integration of new technologies into transmission; new wide-area monitoring systems; diagnostics and protections coordination using phasor measurements; and automation and modernization of substations. These investments will likely stimulate interest among U.S. generators to export electricity to Mexico; increase potential for flows from Mexico to the United States to supply U.S. demand for clean energy and essential reliability services; expand trade flows in both directions to enhance reliability; and/or improve cooperation to stimulate clean energy development; and reduce GHG emissions. Mexico's increasing importation of U.S. natural gas has been and will remain 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 boost overall North American competitiveness and opportunities to integrate supply chains.[76]

As for clean energy development, Mexico has established a program of clean energy certificates, which bears a resemblance to California's renewable energy credit system. Mexico's Transition Strategy has a significant focus on promoting clean technologies and fuels, with goals of reaching 35 percent clean energy generation by 2024.[77] A variety of tools, such as the Clean Energy Zone Atlas, will help Mexico plan for the development of clean energy power plants and the expansion of the grid, similar to the Competitive Renewable Energy Zones in Texas. Two long-term clean energy auctions in 2016 produced record-low prices for energy, capacity, and clean energy certificates, and in the first auction, contracts were awarded with an average certificate price of USD $47.76; these projects will start operations in 2018. In the second auction, renewable projects including solar, wind, geothermal, hydro, and combined-cycle natural gas (only for capacity) produced three record-low prices for Latin America: a wind price of $32/MWh and a solar price of $27/MWh. These recent auction results indicate the opportunities in Mexico for renewable energy development. There are even instances where projects in Mexico qualify for California's RPS—the Energia Sierra Juarez project, a wind farm constructed miles from the California border, is one example of a Mexican project that has received certification to qualify. The Mexican government is fully committed to capitalizing on these opportunities, and its federal authority is sufficient to implement widespread changes.

Enhanced cross-border electricity integration with Mexico does present challenges. Mexico's sector continues to experience high levels of technical and non-technical losses,[78] and it will need significant investments to improve system functionality to achieve greater efficiencies, especially in a scenario that includes significant increases in power trading with the United States' bulk power system. Mexico has different protections for open access to transmission from the United States and Canada. Though rules exist for access to government-owned transmission in Mexico, these are dissimilar to FERC Order Nos.

888 and 890.[79, 80] Additionally, both sides of the border have experienced power shortages in the past decade, suggesting that at this time, neither border region has developed significant and reliable excess power to sell to the other on a firm basis. The limitations of trade between Texas and the rest of the United States, vis-à-vis the Federal Power Act, do not apply to, and therefore are not a limitation on, ERCOT's electricity trade with Mexico.

Though ERCOT has maintained a more isolated domestic trade strategy for electricity, the same Federal Power Act issues that drive these policies should not impact ERCOT-Mexico trade in electricity. But the combination of challenges to trade, even though ERCOT shares the longest border with Mexico of any U.S. state, suggests that it will take a very compelling business case to enhance cross-border flows.

6.4 Emerging Integration Opportunities across North America

6.4.1 Carbon Trading and Pricing to Address Emissions in Mexico and Canada

In recent months, the federal governments of both Canada and Mexico have announced plans for new policies to address carbon dioxide emissions. For several years, provinces and the private sector have pursued various forms of carbon accounting, charging, and trading. The electricity sector has and will play an important leading role in reducing economy-wide emissions of carbon dioxide. Given the highly integrated nature of the U.S.-Canada electricity system and the increasingly integrated state of the U.S.-Mexico electricity system, it will be important to explore the effects of implementation of new federal carbon reduction policies across North America.

Subregional carbon markets are present all around the United States, including in states that border Mexico and Canada. The Regional Greenhouse Gas Initiative was the first mandatory carbon market in the United States, and it includes a cap-and-trade program for carbon-dioxide emissions from power generators in the Northeast, Delaware, and Maryland (see Chapter III, *Building a Clean Electricity Future* for additional detail). California and Quebec have had linked carbon markets since 2014, and Ontario will join those markets in 2018. Mexico and the province of Manitoba are also considering joining. As these arrangements evolve, the implications of these new markets for carbon trading should be examined further.

Table 6-1. New Carbon Trading and Pricing Policies in Canada and Mexico Are a First for North American Federal Governments

Canada	Mexico
	
Most of Canada's provinces have implemented initiatives to reduce carbon-dioxide emissions from the power sector,[h] and 80 percent of Canadians live in a province where there is pollution pricing.[81] In September 2016, the federal government announced a "floor" carbon tax that will be introduced in 2018 at $10/ton of carbon. Under the federal program, the carbon price will rise $10/ton per year until 2022, when the price will freeze at $50/ton. Provinces have considerable implementation flexibility. The price can be in the form of a specific tax or levy or as a cap-and-trade program, provided provinces set emissions caps that correspond to the expected reductions from the carbon price. The carbon tax will be revenue-neutral for the federal government, which will return funds to provinces from federally imposed carbon taxes. Any province can also levy the carbon tax and collect revenue itself, without involving the federal government, to meet the carbon pricing requirement.[82, 83] A number of provinces, including British Columbia,[i] Alberta,[j] Ottawa, and Quebec,[k] are already in compliance with a carbon price for 2018, though the rising federal price of carbon will necessitate additional action from all provinces by 2022.	A carbon tax on the use of fossil fuels was introduced in Mexico in 2014. The initial price on carbon was set at USD $3.5/ton of carbon.[84] In November 2016, Mexico launched its first federal initiative to deal with carbon, a pilot project with voluntary participation for study purposes of Mexico's new cap-and-trade program. The information will inform implementation of the 2018 launch of Mexico's new cap-and-trade program. The program is being guided by the Secretariat of Environment, the Mexican Stock Exchange, and the Mexican Carbon Platform, a private trading platform established in 2003. The platform involves voluntary participation of approximately 60 companies from various industries, including steel, cement, and chemicals, which combine to annually generate 70 million tons of carbon dioxide. Historically, the state of Baja California has been involved in California's carbon trading and clean energy policies for several years. To formally launch cap-and-trade in 2 years, Mexico will need to establish a cap on GHG emissions and create a program for monitoring and verification.[85, 86]

The electricity sector has and will continue to play an important leading role in reducing economy-wide emissions of carbon dioxide across North America. Table 6-1 briefly describes recent announcements and actions by the federal governments of Canada and Mexico to address carbon dioxide emissions from the electricity system.

[h] Prince Edward Island has no current targets or initiatives in place; the territory of Nunavut is implementing climate adaptation strategies that do not address power generation. All other provinces and territories either have some form of emissions-reduction target and/or carbon pricing in place, including but not limited to mass-based targets, cap-and-trading, and RPS. Two territories, Northwest Territories and Yukon Territory, have voluntary energy efficiency targets in place for households and businesses that will reduce emissions from the power sector.

[i] British Columbia currently has a carbon tax of $30/tonne.

[j] Alberta will levy a carbon tax on fuels at a rate of $20/tonne beginning in January 2017. One year later, the levy will increase to $30/tonne.

[k] Carbon was trading at $17 Canadian/tonne in May 2016 for the cap-and-trade market that includes Quebec and will include Ottawa (according to the International Carbon Action Partnership).

6.4.2 Improving Grid Security and Reliability

Protecting the grid against vulnerabilities is a shared responsibility across North America. Most recently, the United States and Canada have agreed upon goals to: (1) protect today's electricity grid and enhance preparedness; (2) manage contingencies and enhance response and recovery efforts; and (3) build a more secure and resilient future electric grid.[87] The joint U.S.-Canada Grid Security Strategy promotes improvements to information sharing, vulnerability assessment, emergency response and continuity, and management of new and evolving risks from grid technologies and design.[88]

The United States and Canada have developed respective national action plans to address and improve grid security. Going forward, there are key areas of mutual interest where joint cooperation can continue to grow between the United States and Canada. These include the Department of Energy and Natural Resources Canada working, in coordination with the Department of Homeland Security and Public Safety Canada, to

- Inform and support the private energy sector in response to a significant cyber incident
- Improve tools, frameworks, protocols, and methods for information sharing, risk assessment, and situational awareness
- Coordinate with existing table-top exercise formats
- Develop standardized curricula and training materials for utilities to educate their workforces on protection against threats, including cybersecurity.

Coordination of grid security efforts can lead to a more proactive approach to addressing emerging threats across North America. As Mexico's interconnections with the United States grow in number and capacity, it will be important for ongoing discussions of grid security goals and objectives to be informed by Mexico's experiences and perspective.

Mexico is working closely with NERC to achieve well-interconnected, secure, and stable electricity grids. Currently an inter-ministerial body (The Ministry of Energy, the System Operator, and the Regulatory Commission) has been set to produce a first version of Mexico's proposal of a Memorandum of Understanding with NERC. Along with this proposal, the group is working very closely with the staff of the Department of Energy, FERC, and the Western Electricity Coordinating Council to ensure consistency with other specific agreements.

As more interconnections are planned and built between the United States, Canada, and Mexico, the North America bulk power system must not only remain secure but reliable. High-level cooperation between all three countries on energy issues should maintain a focus on the shared goal of a reliable electricity system for the continent. From coordination on high-level principles for reliability, to modeling and analysis to inform operations of the future bulk power system, cooperation across North America on reliability will complement efforts to improve security and ensure economic competitiveness.

6.5 Policy Options for North America

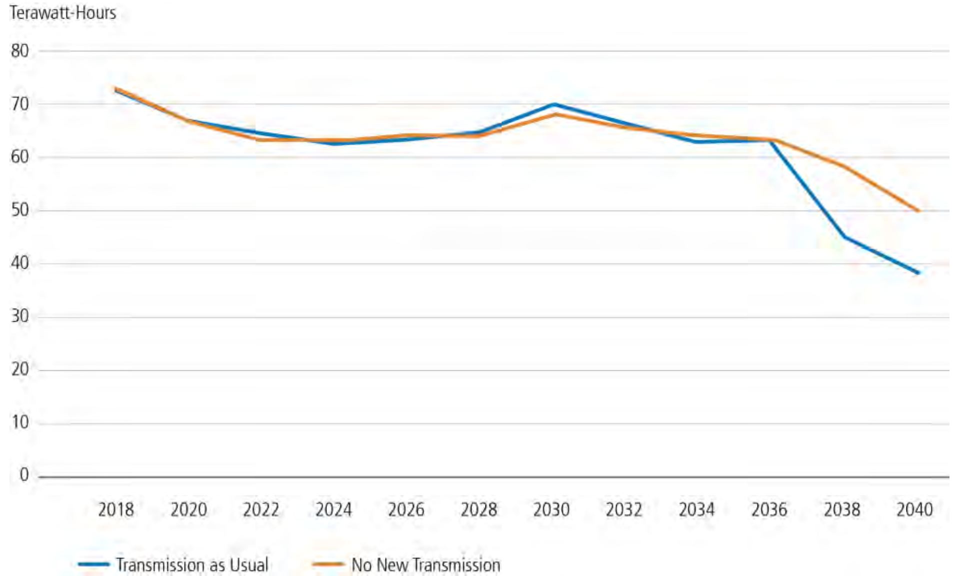
There are a variety of policy options that all three countries, and the United States individually, can take to support targeted action to enhance integration: (1) engagement—often high-level and internationally through bilateral and trilateral dialogues and other cooperation mechanisms; (2) analysis—both cooperative and independent carried out through working groups and projects); and (3) policy-level actions—primarily executed by domestic federal and state entities. Specific recommendations are described more thoroughly in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

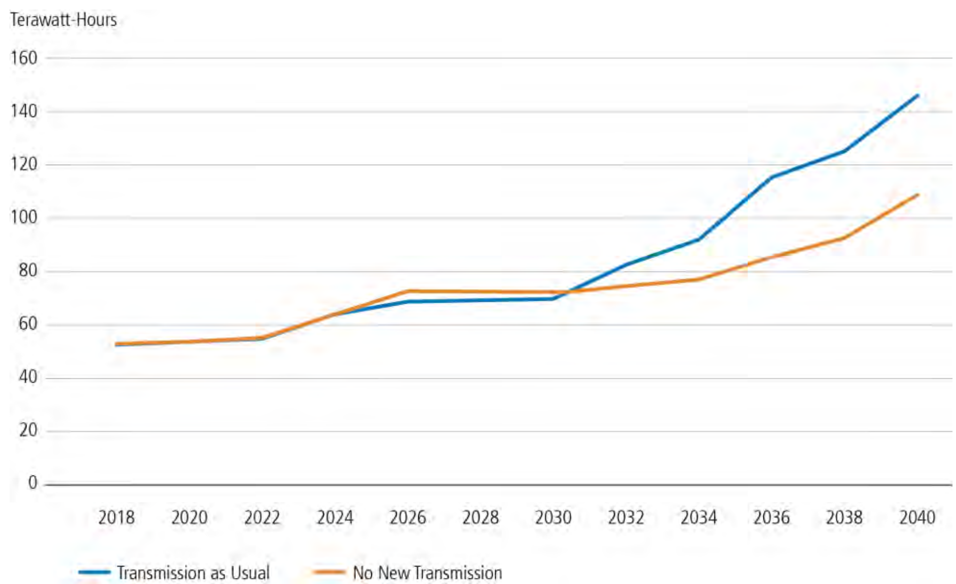
6.5.1 Key Existing Efforts to Analyze Cross-Border Electricity Policy

While many detailed electricity sector modeling tools exist for the United States (and in some cases, the United States and Canada), modeling tools capable of analyzing the economic, environmental, social, or reliability impacts of electricity integration throughout North America are relatively coarse. Improved models would lead to more informative and useful results to enable better stakeholder decisions.

While there is a diversity of power sector modeling tools to analyze U.S. grid or market operations at varying levels of detail and accuracy, such tools do not yet exist at a robust level for the combined power system of Canada, Mexico, and the United States, limiting the ability of modeling to estimate costs and benefits of increasing cross-border trade.[89] One exception is the Regional Energy Deployment System (ReEDS), which does represent both the United States' and Canada's power systems.[90] Sample, preliminary analysis from this model is highlighted in Figure 6-6. The Department of Energy's Office of Energy Efficiency and Renewable Energy is working with the National Renewable Energy Laboratory to expand this model to Mexico in cooperation with the Mexican Secretariat of Energy and the Mexican National Energy Control Center. Final results will be used to understand the implications of a variety of U.S.-Mexican energy scenarios; inform decision-making about renewable energy integration and cross-border energy markets; and establish the analytical framework for long-term strategic thinking about a shared North American energy future. The U.S. Department of Energy, Natural Resources Canada, and Mexico's Secretariat for Energy are also supporting a 3-year effort through the North American Renewable Integration Study (NARIS) to share data and enable modeling and analysis of coordinated planning and operations across North America under high-market-penetration renewable energy scenarios. The ReEDS United States, Canada, and Mexico models will be used to inform the NARIS study scenarios. The NARIS study will be completed in 2018.

Figure 6-6. Possible Long-Term Impacts of Cross-Border Transmission on Regional Generation Mix in the United States, 2018–2040 in the Regional Energy Deployment System Model





Under a low-carbon future scenario, results from ReEDS show that transmission with Canada becomes increasingly important for sustaining emissions reductions and has a significant impact on the generation mix in border regions. In ISO New England, greater cross-border transmission capacity reduces domestic natural gas generation. In New York ISO, additional transmission capacity with Canada is associated with an increase in domestic renewable generation.

Though not scenario-based, complementary qualitative analyses (Table 0-2) can allow policymakers to understand the current status of integration and the relevance of specific factors to impact cross-border trade opportunities.

Table 6-2. Analysis of Variables That Have Led to Current Levels of Cross-Border Trade in Cross-Border Trade Relationships

Criteria	Pacific Northwest	Midwest	NYISO/Can	ISO-NE/ Quebec	California-Baja	ERCOT-Mexico
Integration enhances electric reliability	Sufficient for needs in an expanded trade scenario	Sufficient for needs in an expanded trade scenario	Sufficient for needs in an expanded trade scenario	Sufficient for needs in an expanded trade scenario	Sufficient for current needs	Moderately available; expansion/adjustment already in process
Coordination in cross-border operations and planning	Sufficient for current needs	Sufficient for needs in an expanded trade scenario	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Present but insufficient for current needs
Economic opportunities stimulate greater cross-border trade flows	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Moderately available; expansion/adjustment already in process
Regulatory certainty: transmission access agreements	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Sufficient for current needs	Moderately available; expansion/adjustment already in process	Present but insufficient for current needs
Sufficient transmission capacity	Sufficient for current needs	Moderately available; expansion/adjustment already in process	Moderately available; expansion/adjustment already in process	Moderately available; expansion/adjustment already in process	Moderately available; expansion/adjustment already in process	Sufficient for current needs
Clean Energy/Climate incentives stimulate cross-border trade	Not present, N/A	Moderately available; expansion/adjustment already in process	Not present, N/A	Not present, N/A	Moderately available; expansion/adjustment already in process	Not present, N/A

Color Legend:	Sufficient for needs in an expanded trade scenario	Sufficient for current needs	Moderately available; expansion/adjustment already in process	Present but insufficient for current needs	Not present, N/A

The analysis, done by the Office of Energy Policy and Systems Analysis, demonstrates the variables that have contributed to differences in the level of cross-border integration observed in each cross-border interaction, with robust cross-border integration between the United States and Canadian counterparts, and less developed integration between the United States and Mexico. Cross-border ties with Arizona and New Mexico were not included, due to their small capacity.

Table 0-2 assesses the degree to which cross-border electricity trade in each region has met the criteria that must be present in order to increase international trade in electricity. Cross-border trade in electricity must: provide for customer demand across the border; enhance reliability; provide sufficient transmission capacity; coordinate cross-border operations and planning; and provide regulatory certainty. Additionally, incentives for clean energy can also influence cross-border trade and have been included in this table. Looking at the assessment, it is clear that some key factors required for enhanced integration are still emerging on the U.S.-Mexico border, while supporting factors for cross-border trade in regions shared by the United States and Canada are already in place. This table points also to areas for further work and cooperation among regional stakeholders and governments, including for transmission capacity development.

6.5.2 Explanation of Policy Option Types

6.5.2.1 Engagement

Engagement between Canada, Mexico, and the United States will serve to align national objectives. For example, trilateral and bilateral dialogues or mechanisms for cooperation, including the North American Leaders' Summit, North America Energy Ministers' Meetings, and the Working Group on Climate Change and Energy; trilateral and bilateral memoranda of understanding; the U.S.-Canada Regulatory

Cooperation Council; and bilateral dialogues with Canada (U.S.-Canada Clean Energy Dialogue, U.S.-Canada Energy Consultative Mechanism) and Mexico (U.S.-Mexico High Level Economic Dialogue, U.S.-Mexico Task Force on Clean Energy and Climate Policy, U.S.-Mexico Bilateral Framework on Clean Energy and Climate Change) provide a comprehensive set of diplomatic and working group opportunities for leaders to provide a high-level commitment to action, establish national priorities, establish working groups and task forces to explore specific topics in greater detail, and coordinate developments internationally. Additionally, meetings of leaders at which commitments are made, including the recent goal of 50 percent clean power generation by 2025 for North America, can provide an important forum for engagement. All of these efforts can help to align development and technical assistance efforts; expand networks beyond governments to include key stakeholders from the private sector and other relevant power sector institutions or multilateral development institutions; and stimulate new interest in analysis of other policy options.

Descriptions of recommended engagements to enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.5.2.2 Analysis

The extraordinary complexity of the North America bulk power system means that policymakers and other stakeholders will require robust and extensive analysis to understand the implications of any specific action. Three main elements comprise what is necessary for analysis:

- Access to consistent energy information and data from all three countries (including information regarding generation, transmission, and distribution functions and expansion plans, electricity flows, and pricing).
- Access to information on existing policy, regulatory, and operational features of the power system at the national, state/provincial, ISO, and local levels.
- Rigorous power-sector modeling capabilities that can provide estimates of economic, environmental, social, and operational benefits and costs at varying levels of detail.

Descriptions of analyses that will enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.5.2.3 Specific Policy-Level Actions

Finally, at the most granular level, specific policies can be implemented, strengthened, or adjusted to support enhanced integration. These policy actions range from domestic financial incentives that affect cross-border trade (e.g., tax policy, export tariffs, clean energy incentives), to regulatory frameworks that could be improved to ensure more coordinated yet robust functioning of existing governance (e.g., permitting processes).

Descriptions of policy actions that will enhance North American electricity integration can be found in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*.

6.6 Endnotes

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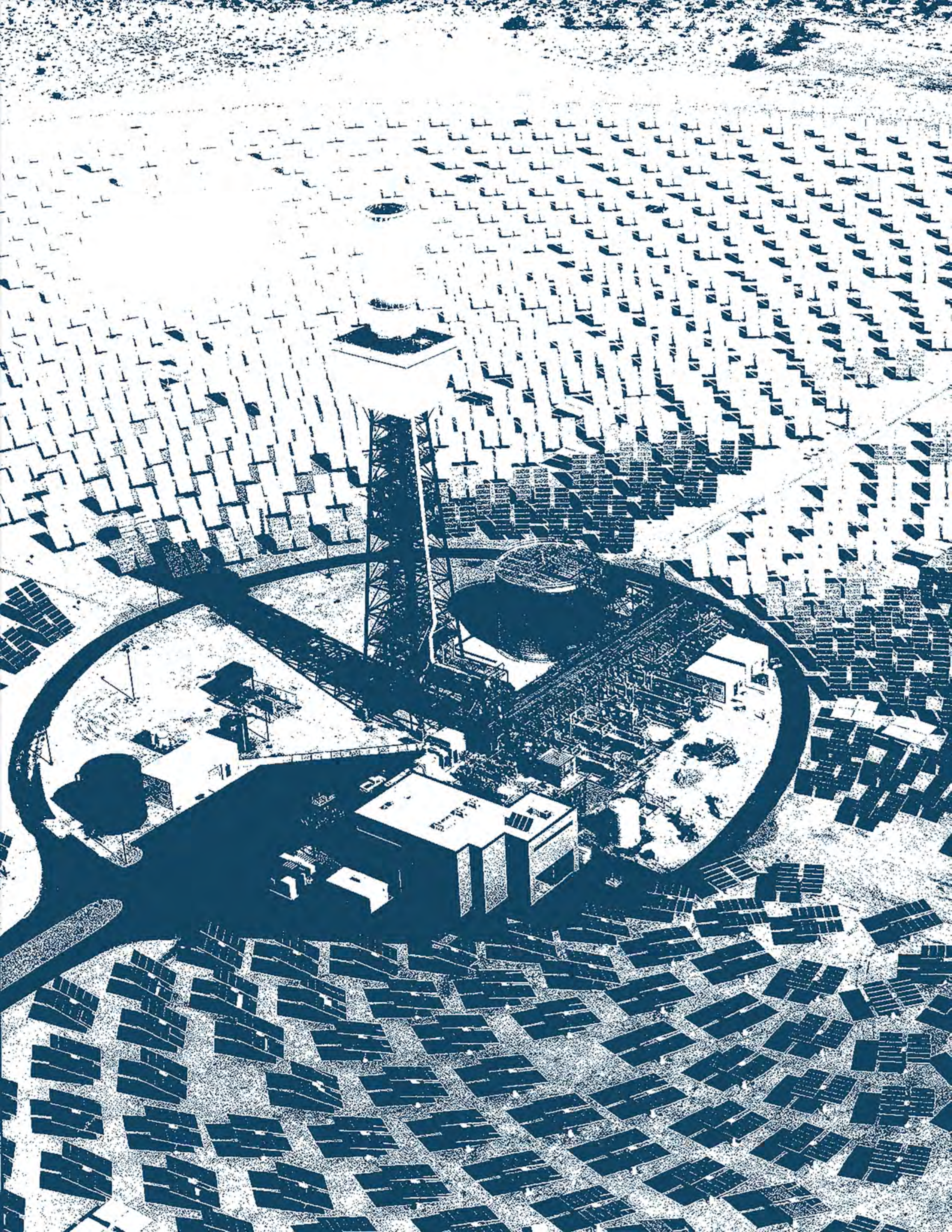


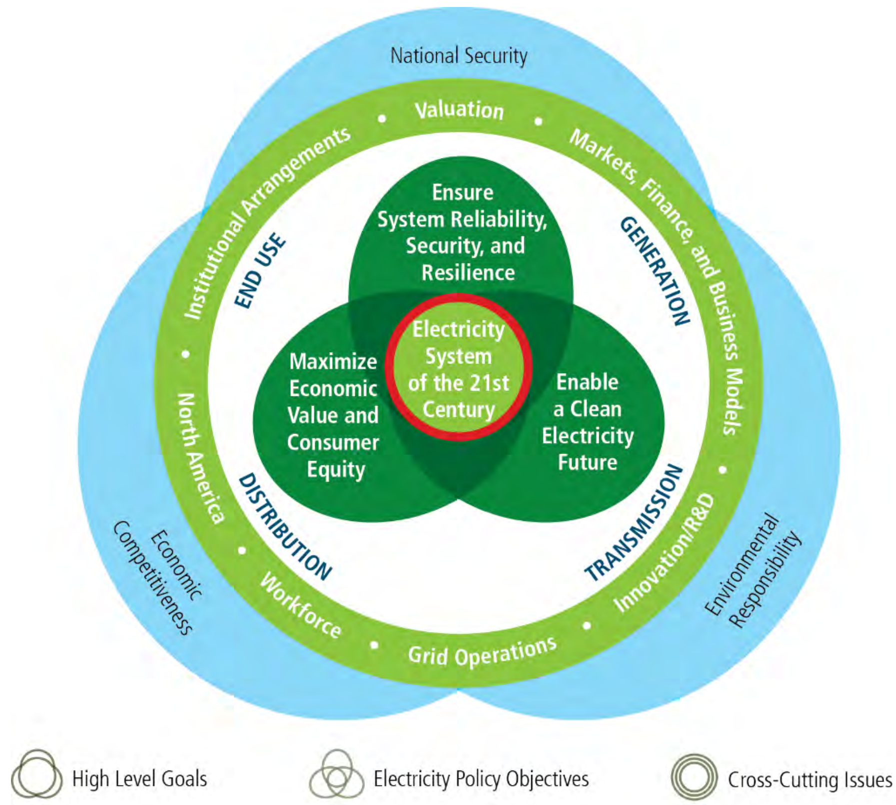
VII A 21st-Century Electricity System: Conclusions and Recommendations

This chapter highlights many recommendations that are enablers of the modernization and transformation necessary. The recommendations build on the analysis and findings in earlier QER 1.2 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, policymakers, industry, and other stakeholders. The policy, research, and investment choices made today will establish critical pathways for decades.

A 21st-Century Electricity System

The central finding in the second installment of the Quadrennial Energy Review (QER 1.2) is as follows: "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."

Figure 7-1. Goals, Objectives, and Organization of QER 1.2



7.1 Key National Security and Reliability Priorities for a 21st-Century Electricity Sector

The electricity sector is a complex system of overlapping interests, investments, and impacts that affect industry, businesses, consumers, and communities served by electricity providers. Accordingly, migration from the present state to a desired outcome for the 21st-century electricity sector requires recognition of critical crosscutting factors that should be addressed as superordinate to the perspectives discussed in preceding chapters. These high-level, crosscutting issues and recommendations address national security, reliability, jurisdictional adjustments, technology investments, streamlined regulatory processes, better gathering and use of data and analysis, and realistic assistance solutions to enable key elements of a 21st-century electricity system.

The Electricity System as a National Security Concern

A set of actions and recommendations in the second installment of the Quadrennial Energy Review (QER 1.2) address the fundamental role of the Federal Government: promoting national security and ensuring the national defense. To this end, it is worth restating a key conclusion from Chapter I (*Transforming the*

Nation's Electricity System: The Second Installment of the QER) to illustrate the essential and growing role electricity now plays in this fundamental function of the Federal Government. The conclusion of a 2015 report from the Center for Naval Analyses notes,

> "Assuring that we have reliable, accessible, sustainable, and affordable electric power is a national security imperative. Our increased reliance on electric power in every sector of our lives, including communications, commerce, transportation, health and emergency services, in addition to homeland and national defense, means that large-scale disruptions of electrical power will have immediate costs to our economy and can place our security at risk. Whether it is the ability of first responders to answer the call to emergencies here in the United States, or the readiness and capability of our military service members to operate effectively in the U.S. or deployed in theater, these missions are directly linked to assured domestic electric power."[1]

The analysis in QER 1.2 reaches a similar conclusion: The reliability of the electric system underpins virtually every sector of the modern U.S. economy, which depends on electricity—including sectors from food production to banking to health care. Electricity is at the center of key infrastructure systems that support these activities—transportation, oil and gas production, water, finance, and information and communications technology. Electricity-dependent critical infrastructures represent the core underlying lifeline framework that supports the American economy and society.

The range of goods and services that involve grid communications and two-way electricity flows, including the Internet of Things (IoT), represents significant value creation and greatly supports and enhances our economy and global competitiveness. At the same time, these goods and services place new demands on the electric grid for high levels of reliability, smarter components, visibility, analytics, and system-wide planning. These features and services also introduce new vulnerabilities to our electricity system (e.g., accelerated time scales sufficient to require significant automation and cybersecurity) that rise to the level of national security concerns.

These vulnerabilities are underscored by the October 21, 2016, hacking incident of simple home devices. Figure 7-2 shows the location of key data centers that support the Internet (discussed in detail in Chapter I, *Transforming the Nation's Electricity System: The Second Installment of the QER*), as well as the global impacts of this event. In this incident, the "Mirai" botnet used the IoT devices, including baby monitors, to create the largest denial-of-service attack in history. The impact of this event was amplified by the U.S. Domain Name System company (called Dyn), infecting 100,000 IoT devices deployed throughout the world (Figure 7-3).[2] The IoT devices in foreign countries worked together to attack a U.S. company. This attack underscores the national security and economic vulnerabilities associated with the growing proliferation of unhardened consumer devices on the distribution network that have the potential to infect bulk power systems.

Figure 7-2. Primary Data Centers for Major Service Providers[3]

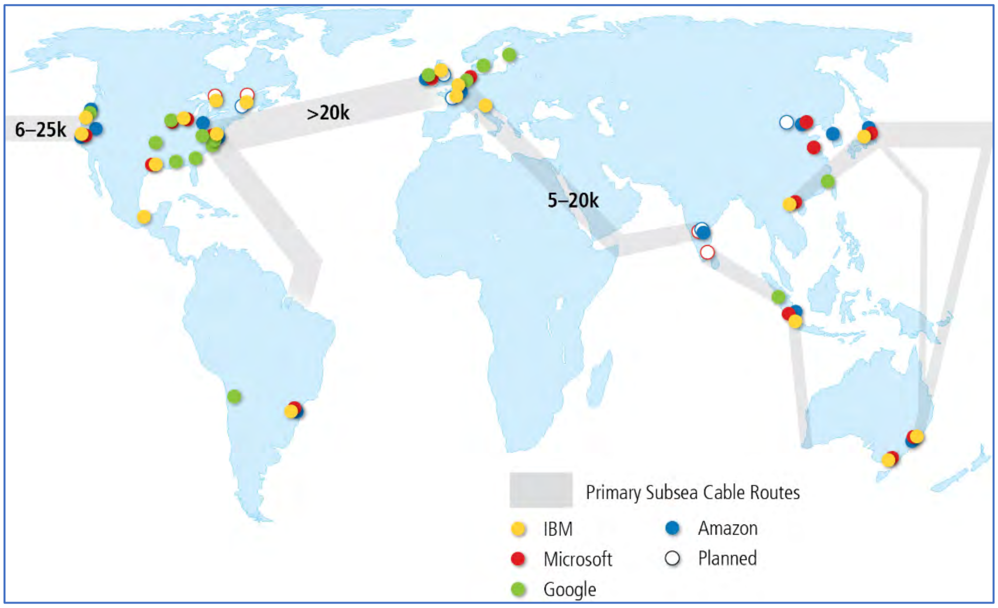


Figure 7-3. October 21, 2016, Hack Had Global Reach[4]

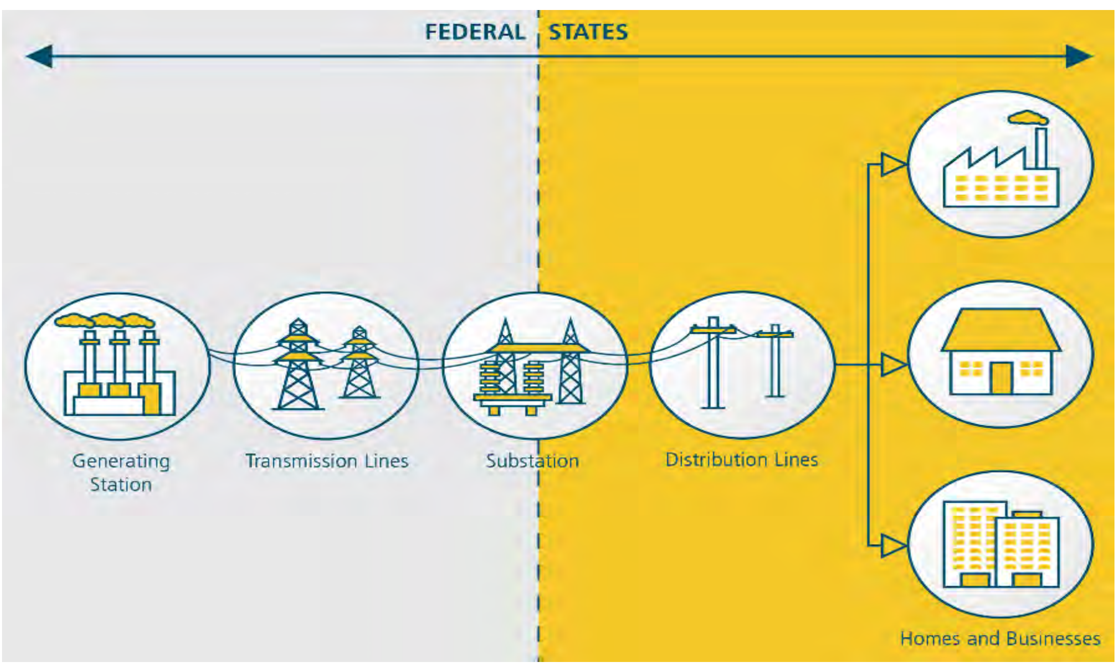
The global Internet is supported by a worldwide network of subsea cables and large-scale data centers operated by firms such as Amazon, Google, IBM, and Microsoft (Figure 7-2). This global reach and interconnectedness, however, also introduces vulnerabilities for U.S. assets and systems that can be affected by connected devices worldwide, as was seen in the October 21, 2016, "Mirai" botnet attack (Figure 7-3, with blue depicting the global impacts of the attack). The global exposure of the "internet of things" merits deliberate risk management activities as the electric power sector becomes increasingly interconnected with global communications networks.

As noted in Chapter I (*Transforming the Nation's Electricity System: The Second Installment of the QER*) and worth repeating here, Congress has recognized the national security implications of the electricity system in the Fixing America's Surface Transportation Act (FAST Act), passed in December 2015. To place the recommendations in QER 1.2 in context, it is important to repeat key language in the Act. The FAST Act gives the Secretary of Energy new emergency authorities for "critical electric infrastructure," where, upon a directive from the President, the Secretary may "with or without notice, hearing or report, issue such orders for emergency measures as are necessary…to protect or restore the reliability of critical electric infrastructure or of defense critical infrastructure during an emergency.” These authorities apply to “the occurrence or *imminent danger of* [italics added]…electronic communication or an electromagnetic pulse, or a geomagnetic storm event that could disrupt the operation of those electronic devices or communications networks, including hardware, software, and data, that are essential to the reliability of critical electric infrastructure or of defense crucial electric infrastructure…the disruption of the operation of such devices or networks, with significant adverse effects on the reliability of critical electric infrastructure or of defense critical electric infrastructure…a direct physical attack on critical electric infrastructure or on defense critical infrastructure; and significant adverse effects on the reliability of critical electric infrastructure or of defense critical electric infrastructure as a result of such physical attack.”[5]

Four essential observations about these provisions should be noted. First, there are, in effect, anticipatory authorities in the law, described in the FAST Act as events that present “imminent danger.” Second, the provisions of the law are all tied to the *reliability* of critical electric infrastructure, directly linking reliability to security: the new security authorities of the President and Secretary of Energy cover security events that affect reliability; to inform imminent threats, they must also encompass cyber, electromagnetic pulses (EMPs), or geomagnetic disturbance events that threaten security. Third, the increasing reliance of the electricity system on natural gas—it is now the number one primary fuel source for power generation for the first time in the Nation’s history—makes security information about related gas infrastructures a critical component for decision making under the FAST Act. Finally, cyber threats do not respect jurisdictional boundaries.

Figure 7-4 clearly illustrates the interconnectedness of the electricity system; the national security responsibilities included in the FAST Act must be addressed without regard to jurisdictional boundaries.

Figure 7-4. Current Jurisdictional Boundaries and the Security of the Electricity System[6]



The U.S. electricity sector regulatory authorities are generally split between the Federal Government for generation and transmission assets and states for distribution networks. The recently passed FAST Act specifies federal authorities to address critical electric infrastructure emergencies.

In addition, the interconnectedness of our modern grid was underscored by the Supreme Court's decision on Federal Energy Regulatory Commission (FERC) Order No. 745. While the Court's majority opinion on Order No. 745 acknowledged that FERC, in this order, only addressed wholesale markets, it also noted, "It is a fact of economic life that the wholesale and retail markets in electricity, as in every other known product, are not hermetically sealed from each other…To the contrary, transactions that occur on the wholesale market have natural consequences at the retail level. And so too, of necessity, will FERC's regulation of those wholesale matters…When FERC regulates what takes place on the wholesale market, as part of carrying out its charge to improve how that market runs, then no matter the effect on retail rates, [the Federal Power Act] imposes no bar."[7]

Recent FERC actions are designed to address and clarify key security issues, as well as issues raised by two-way flows and a modern electricity system. FERC has issued an order pursuant to the FAST Act to control the availability of sensitive critical energy infrastructure information on "production, generation, transmission and distribution of energy," noting that a single critical energy infrastructure information process is "…the most efficient way to fulfill the statutory mandate of the FAST Act and to avoid any confusion that could result from different processes for different types of critical infrastructure information."[8] FERC has also taken steps to enable the aggregation of storage, including at customer facilities, examining the need to develop participation models consisting of market rules.[9]

Integrated Planning Needed to Address National Security Imperatives of the Electricity System

National security investments, regardless of scale, are costs that should be born, in part, by the Federal Government acting on behalf of all Americans. Sorting out how costs should be allocated will be a critical success factor in achieving and sustaining a secure grid throughout this century. New authorities must come with appropriate budgets for Federal responsibilities, and costs to be carried by ratepayers must be made explicit as well. Managing investment requirements while keeping affordability in mind must be a key concern of the Federal Government. While most analysts do not think that these costs will cause rate shocks, having mechanisms for clearly articulating the associated Federal and ratepayer costs will be important for security and public acceptance.

QER 1.2 discusses the limits of existing reliability and resilience planning methodologies and processes in Chapter IV (*Ensuring Electricity System Reliability, Security, and Resilience*). There are many planning methods currently used by utilities, ranging from integrated resource planning to more-focused procurement planning. Despite the breadth and depth of current and emerging planning methods, there are gaps in standards, operational definitions, and geographic scope. There are also several levels of planning as well, such as state-level regulatory planning; state energy office planning; independent system operator/regional transmission organization regional planning; North American Electric Reliability Corporation (NERC) region planning; and FERC planning requirements, which affect all entities regulated by FERC. Still, when aligned with a map of the Nation, there are no adopted common demarcations that enable consistent and seamless planning related to grid security that can serve the need for a national security overlay.

7.1.1 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.

1. **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.

2. **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.

3. **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.

4. **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.[1011] 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 (discussed further in Chapter III, *Building a Clean Electricity Future*), as well as Federal credit assistance to facilitate early deployment of innovative technologies.

5. **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.

6. **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.

7. **Provide funding assistance to enhance analytical capabilities in state public utility commissions and improve access to training and expertise for small rural electric cooperative and public power 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.

8. **Create a Center for Advanced Electric Power System Economics**. DOE should provide 2 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

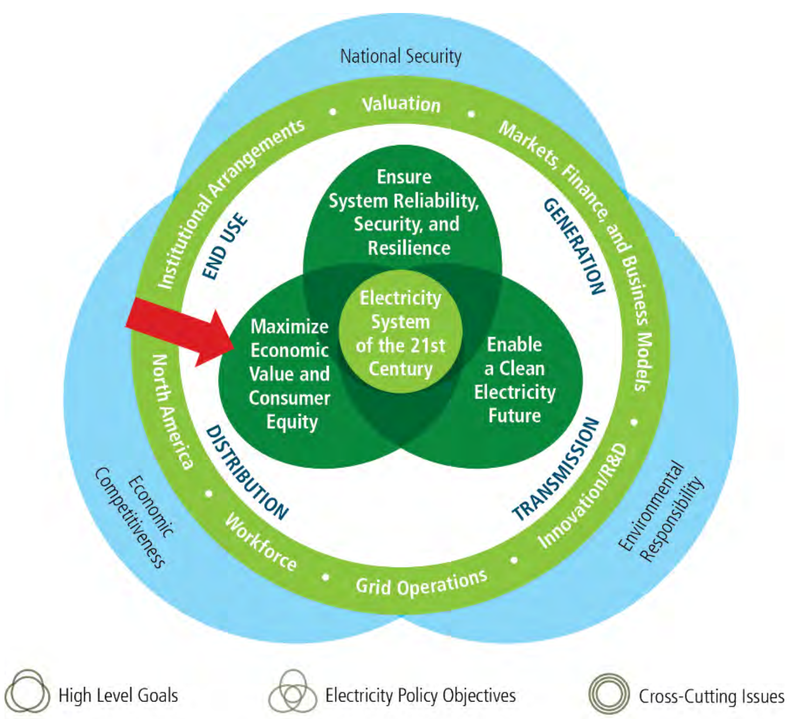
in these disciplines. The focus of the center will include power systems evaluation (e.g., valuation, benefit-cost, and competition analysis).

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.

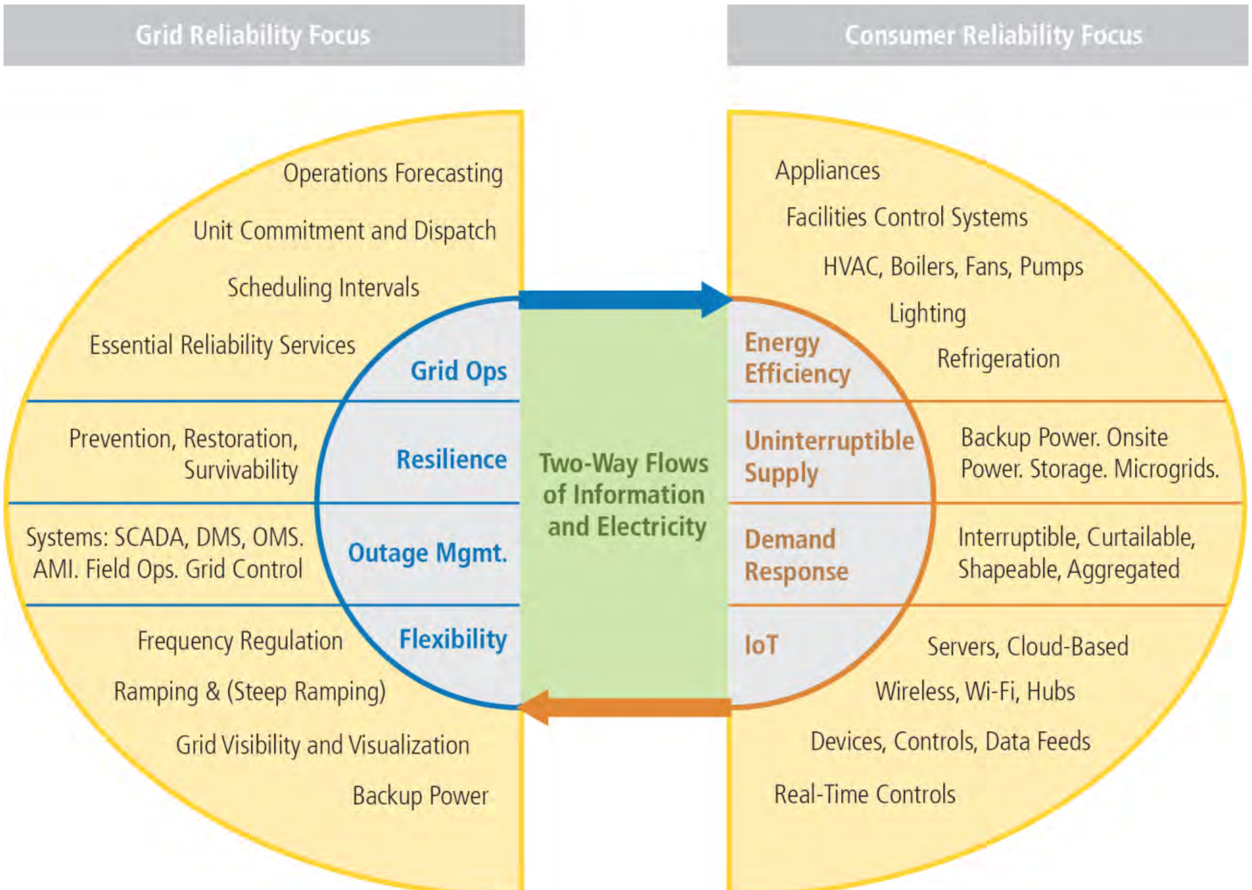
9. **Establish a Federal advisory committee on alignment of responsibilities for rates and resource adequacy**. DOE, in collaboration with the National Association of Regulatory Utility Commissioners, should convene a Federal advisory committee that reports to the Secretary or the Secretary's designee 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.

7.2 Maximizing Economic Value and Consumer Equity



Consumer options for electricity services have grown dramatically, enabled in part by the smart grid and the IoT, and supported by significant consumer demand. New consumer options range from building efficiency technologies that reduce consumer costs for high-quality electricity services, to distributed generation (DG) technologies, to technologies for dynamic energy management. In addition to technology options, different utility business models also have a significant impact on consumer value and compensation. Utilities still provide a majority (84 percent) of the electricity supplied nationwide;[12] however, in the 16 states and the District of Columbia where retail competition is allowed, 58 percent of industrial load, 44 percent of commercial load, and 7 percent of residential load have switched to competitive energy suppliers.[13] These technologies can create value for both grid operators and consumers; adequate and accurate valuation of these new services is essential for maximizing their value. As noted in Chapter IV (*Ensuring Electricity System Reliability, Security, and Resilience*), these two-way flows are affecting both consumer demands for reliability as well as reliability requirements for grid operations. The key components of both consumer and grid reliability are highlighted in Figure 7-6.

Figure 7-5. Electric Service Reliability Increasingly Interactive between Grid and Consumer



The development and adoption of new consumer technologies and services have dramatically outpaced those of the grid. The electricity sector is adapting to the demands placed on the grid by the two-way flows with new market structures, technological solutions, interconnection and reliability standards, and complex grid controls enabled by wide-spread operational data. The evolution of technologies and services on both sides of the grid will likely continue at the same or an accelerated pace. Maintaining—or increasing—grid reliability in the midst of these changes will require new approaches in both the public and private sectors. Acronyms: supervisory control and data acquisition (SCADA); distribution management system (DMS); outage management system (OMS); advanced metering infrastructure (AMI); heating, ventilation, and air conditioning (HVAC).

The two-way flows and different expectations about reliability between consumers and grid operators can benefit both grid operators and consumers if flows are transactional and collaborative. In the alternative, two-way flows can significantly complicate grid operations. Grid operators must adapt to increased consumer options that can both positively and negatively affect grid reliability by changing their systems, processes and technologies. Only when the depth of grid and consumer interdependencies are understood equally by each group can the 21st-century electricity sector be fully realized.

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.

10. **Improve energy management and DR in buildings and industry**. Communication-capable and programmable energy management systems that monitor and control energy using appliances and equipment have demonstrated substantial potential to reduce both volumetric (kilowatt-hours) and peak (kilowatt) electricity demand, delivering significant economic value and service benefits to both consumers and utilities. This joint DOE–Environmental Protection Agency (EPA) initiative could further accelerate the deployment of communications-capable control systems that can deliver improved energy management and DR for residential buildings, small to medium commercial buildings, and comparable industrial facilities.
11. **Create a multi-sector initiative to improve efficiency of miscellaneous electric loads through research and development (R&D), testing, labeling, targeted incentives, and minimum standards**. Miscellaneous electric loads are a broad, rapidly growing, and poorly understood group of end users, which can be addressed by building on existing DOE and EPA efforts. Working with utilities, states, manufacturers, and other key stakeholders, this DOE, Energy Information Administration (EIA), and EPA initiative could gather data, set priorities and take action to increase R&D, improve testing and labeling, and implement targeted incentives and minimum standards to improve the efficiency and management of miscellaneous electric loads in the residential, commercial, and industrial sectors.
12. **Increase Federal support for state efforts to quantitatively value and incorporate energy efficiency, DR, distributed storage, and DG into resource planning**. DOE and EPA should leverage existing programs to provide targeted capacity building and related analytical support to states on the merits of incorporating the value of energy efficiency, DR, distributed storage, and DG in resource planning, meeting environmental goals, and to extract additional value from advanced metering infrastructure networks and resulting data and digital services.
13. **Conduct an analysis of the potential for deployment of demand side (energy efficiency, DR, DG, storage) technologies**. While numerous studies have indicated significant cost-effective potential from energy efficiency investments, there is an incomplete patchwork of different energy efficiency potential studies and other distributed resources at the utility or state level that use a variety of different methodologies. These studies, which typically consider only energy efficiency, do not take into account the potential to integrate energy efficiency investments with other consumer options, such as DR, DG, and onsite storage—technologies to which consumers have growing access. DOE, with input from EPA, should conduct a national demand-side resources potential study with sufficient geographic resolution to more effectively value and integrate DERs into state and national electricity policy, while meeting environmental goals.
14. **Increase state-level clean energy financing**. DOE and the Department of the Treasury, in coordination with other Federal agencies, will identify promising practices in the types of state-level policies, mechanisms, and incentives that support system evolution to a cleaner grid, e.g., Property Assessed Clean Energy (PACE) financing. These efforts will provide states with the tools

and potential solutions to better leverage state resources and deploy clean energy. As part of sharing promising practices, DOE and the Department of the Treasury would help standardize contracts/financing structures for nontraditional project structures.

15. **Evaluate the potential to further increase energy savings and reduce costs to consumers and manufacturers through appliance efficiency standards**. DOE's minimum appliance efficiency standards have resulted in significant energy savings for consumers and businesses across a wide range of products. DOE, working with the Department of the Treasury and EPA, will evaluate approaches for further increasing or optimizing energy savings to consumers, while reducing costs for manufacturers and consumers.

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.

16. **Increase Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP) funding**. Low-income Americans in areas across the country face disproportionate burdens from electricity costs. Congress should increase Federal support for low-income home weatherization, through DOE's WAP, over the next 5 years to weatherize 100,000 homes per year, including support for training and improving auditing tools. Congress should also create a mandatory contingency funding mechanism for LIHEAP, as described in the President's FY 2017 budget.

17. **Evaluate incentives to cut electricity bills for low- and moderate-income households**. The Federal Government should improve the coordination between WAP and LIHEAP to ensure optimal use of resources and increased benefits to households served. The Federal Government should encourage state and local governments to (1) take full advantage of the use of LIHEAP funds for weatherization, (2) use the National Renewable Energy Laboratory's solar savings-to-investment ratio calculator to identify cost-effective areas for solar projects, and (3) find other ways to make it easier for low-income households to access the long-term savings possible from energy efficiency and renewable energy. In particular, DOE should evaluate the impacts of utilizing WAP and LIHEAP to decrease energy bills (i.e., from energy efficiency retrofits and installing renewable energy projects). In addition, state and local governments should ensure human services providers educate low-income clients receiving bill assistance about opportunities to save on their electricity bills through energy efficiency and renewable energy programs and should actively encourage participation in those programs.

18. **Strengthen incentives for public housing authorities to invest in renewable energy and energy efficiency**. Small- and medium-sized housing authorities are often unable to participate in existing energy performance contracting (EPC) options because of a lack of capital or interest from energy services companies. This project would incentivize such public housing authorities to use existing resources to make energy upgrades by allowing them to retain energy cost savings outside of an EPC contract. Congress should authorize a pilot program to allow public housing authorities to retain a greater portion of the savings realized from investments in energy efficiency and renewable energy. The Office of Public and Indian Housing at the Department of Housing and Urban Development (HUD) would focus the pilot on strengthening incentives for housing

authorities, especially smaller and medium-sized housing authorities, to invest their Capital Fund dollars in energy efficiency or renewable energy. The pilot would provide an alternative to the long-standing EPC program, which has primarily served larger housing authorities.

19. **Improve HUD data and utility benchmarking**. In order to reduce taxpayer costs on tenant utility bill allowances, Congress should enact legislation allowing HUD and property owners to access whole-building, aggregated energy consumption and expenditure data for HUD-assisted properties (i.e., whole-building utility data) and appropriate funding for HUD to implement its utility benchmarking strategy, including building out the information technology (IT) systems needed to link current systems with benchmarking software.

20. **Encourage public-private partnerships to underwrite and support clean energy access for low- and moderate-income households**. The Federal Government should align public funding programs and encourage private-sector investment to help make energy efficiency and renewable energy accessible to households that do not qualify or are unlikely to be served by WAP. The bank regulatory agencies are encouraged to publicize recently-issued Community Reinvestment Act guidance concerning loans financing renewable energy or energy efficiency improvements, which help reduce operational costs and maintain the affordability of single-family or multifamily housing.

21. **Provide assistance to address rural, islanded, and tribal community electricity needs**. The Tribal Indian Energy Loan Guarantee Program provides loan guarantees for renewable energy on Indian land and is authorized under the Energy Policy Act of 2005. Indian lands have over 9,000,000 megawatts (MW) of renewable energy potential. Because of the lack of capital, only 125–130 MW have been built. Most tribes do not meet eligibility requirements for existing loan guarantee programs. Existing rural and islanded electricity systems generally rely on imported (nonlocal) diesel fuel oil and, consequently, are high cost and produce significant emissions. Renewable electricity generation and other electricity technologies have the potential to lower cost and reduce emissions on such systems, yet may require new technology capabilities or significant technical expertise to successfully integrate into such systems. The Federal Government should increase support for grants and technical assistance to allow isolated communities that rely on expensive diesel-generated electricity to install more renewable energy, such as wind, small-scale hydro, or solar energy.

Increase Electricity Access and Improve Electricity-Related Economic Development for 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 are limited, there are still areas that lack adequate access to electricity despite the Nation's commitment to full electrification, which dates 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.

22. **Support the achievement of full tribal land electrification**. Over 10 years and building on existing programs, DOE, the Department of the Interior (DOI), and the Department of Agriculture (USDA) will provide technical assistance for distribution infrastructure with the goal of supporting tribal

communities' efforts to achieve complete electrification (Indian tribes, including Alaskan Natives, on Indian lands), while respecting the sovereignty and culture of tribal and Alaska Native communities. DOE, DOI, and USDA should support development of distribution infrastructure to provide access to household electricity and electricity distribution that enables productive economic activity and public services.

23. **Support advanced technology acceleration and economic development opportunities for tribal lands**. While wind energy and solar energy have grown exponentially in recent years, tribes have not been able to fully take advantage of their wind or solar resources. DOE and DOI could accelerate renewable energy development on tribal lands and economic development in tribal communities through new incentives and financing support, workforce development resources, and enhanced consultation with tribes.

Strengthen Rural Electricity and Broadband Infrastructure

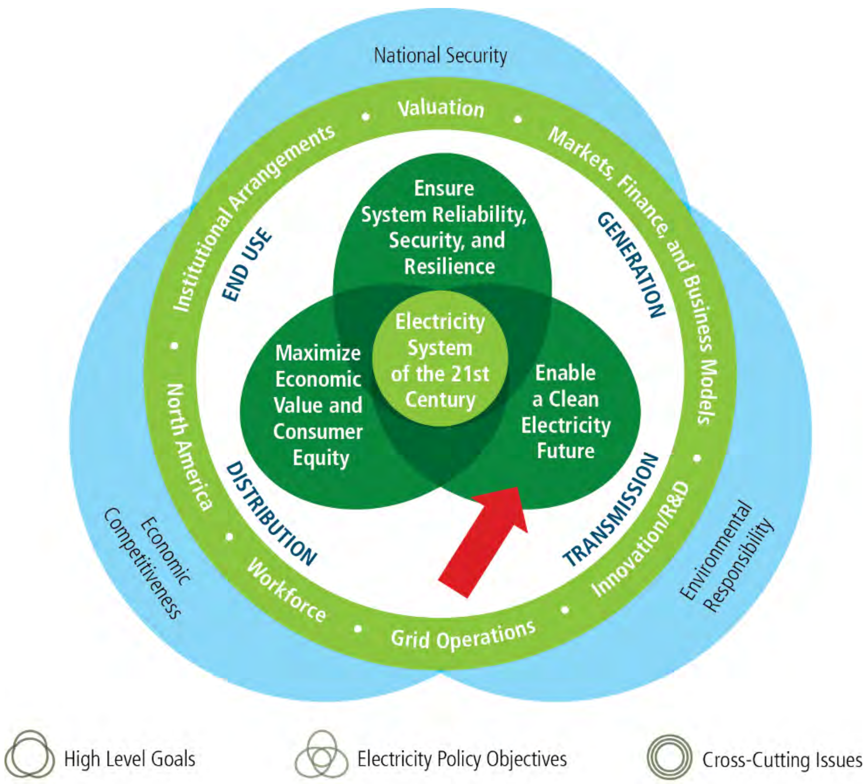
The Federal Government has historically supported the expansion of access to affordable electricity and communications service in rural America, with major initiatives continuing today mainly through USDA. The lack of access to broadband in rural areas means that these consumers lack access to DR technologies, such as smart meters, smart thermostats, and other technologies, which 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 areas, is not, however, profitable for the private sector. Federal support would help enhance security, environmental, and economic development goals.

24. **Leverage utility broadband build-out to expand public broadband access in rural areas**. Many rural areas presently lack access to public broadband service required to take advantage of these consumer smart grid technologies. The Federal Government should continue to modernize Federal programs to expand support for rural broadband, smart grid, and smart home technologies. USDA should update guidance for the Rural Development Community Facility Program to make broadband projects eligible, revise regulations to expand eligibility for the Rural Utilities Service (RUS) Telecommunications Program, and expand financing for smart grid and communications improvements for energy management in the RUS Electric Program.

25. **Increase opportunities for small and rural utilities to utilize USDA's electricity financing programs**. USDA should develop and implement a strategy to remove barriers to participation in its RUS financing program for energy efficiency and renewable energy investments, which would support Congress' intent to provide Federal financial support for ratepayers served by small and rural utilities. DOE and USDA should strengthen collaboration on strategic priorities, including developing a strategy to increase the use of USDA's financing programs by borrowers and supporting the technical needs of small and rural utilities, in part through their industry stakeholders.

26. **Improve the competitiveness of USDA's financing for small and rural utilities**. Congress should give USDA's RUS the authority to refinance its loans to small and rural utilities to keep their competitiveness and reflect economic changes in the broader economy. Congress should undertake legislative action to unlock USDA's renewable energy financing under Section 317(c) of the Rural Electrification Act.

7.3 Enable a Clean Electricity Future



Achieving a clean, affordable, and reliable electricity sector for the 21st century is a key national objective. The transition for accomplishing this objective is complicated and will require major changes in the generation resource mix; in the valuation of key services; and in the way the grid is operated. Managing this complex set of changes while ensuring affordability, reliability, and security for electricity consumers, will require focused investments, incentives and policies in key areas, including the following: optimizing the management of many different types of generation; enhancing the visibility, integration, and valuation of load-shaping and consumer technologies; enabling the development and diffusion of distributed and utility-scale storage technologies; managing the large-scale integration of variable energy resources and DERs into grid operations; and supporting the ongoing need for dispatchable baseload generation. This transition will also require a core investment in operational and predictive analytics, including control algorithms and granular grid visualization tools. Clean electricity options from generation to end use need to be advanced through a combination of additional research, development, and demonstration (RD&D) across the portfolio of solutions and additional policy that encourages the most cost-effective options.

Transform the Electricity System through Leadership in National Clean Electricity Technology Innovation

Private-sector investment in clean energy technology faces many barriers; for example, 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 lengthy time horizons for R&D and capital stock turnover in comparison to many other sectors (e.g., IT). Increased investments in electricity technology innovation are essential for the 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 photovoltaic power, among many other electricity-related technologies, demonstrate the instrumental role of Federal investment in early-stage R&D.

27. **Significantly Increase Federal investment in clean electricity RD&D**. The current scale and speed of clean electricity innovation is well short of what is needed for meeting the Nation's clean energy and climate goals, yet there are a series of barriers to the private sector investing adequate

amounts on its own. The American Energy Innovation Council in 2010 identified specific needs for government involvement in accelerating energy innovation and recommended that Federal clean energy funding be more than tripled, as the minimum level required to maintain America's competitive edge. Pursuant to the Mission Innovation initiative, the Federal Government should double clean energy R&D funding across all relevant Federal agencies from $6.4 billion to $12.8 billion between FY 16 and FY 21.

28. **Implement regional clean energy innovation partnerships**. Create cost-shared, technology-neutral innovation partnerships based in multi-state regions intended to accelerate clean energy R&D, including electricity, by tailoring project portfolios to the needs, opportunities, innovative capabilities, and intellectual and economic infrastructure of those regions. The FY 17 DOE Mission Innovation request includes initial funding of $110 million for regional partnerships.

29. **Expand clean electricity innovation analysis and tools**. Improve the data, metrics, analysis, and tools used to plan DOE's investments in clean energy innovation. Although there is substantial research on the value and impact of innovation for individual technologies, there are few robust measures and quantitative assessments of energy innovation. Enhanced energy innovation frameworks and models that include policy interactions are needed to characterize the relationship between inputs and outputs of energy innovation, help inform investment, and deploy scarce innovation dollars.

30. **Continue reducing barriers to deploy clean energy technologies**. Since 2008, the cost of solar, wind, storage, and electric vehicle technologies has decreased more than 50 percent. DOE should continue working to cut the costs of solar, wind, storage, and electric vehicle technologies through their world class programs, continuing to reduce the cost of solar more than 50 percent by 2030; making electric vehicles cost competitive with gasoline-powered cars by 2022; decreasing the price of energy storage; and developing the next-generation wind technologies, including offshore technologies and tall turbines, to expand the geographic reach of cost-competitive wind.

31. **By 2030, reduce the electricity intensity of newly constructed residential and commercial buildings by at least 50 percent relative to typical new building construction today**. Buildings, which last for decades, account for significant portions of electricity demand and greenhouse gas emissions in the United States. Ensuring highly efficient new construction will capture decades of energy savings for American families and businesses. DOE, in consultation with EPA, should set a goal, establish baselines, and scale up activities to deploy energy efficient technologies and DERs in newly-constructed residential and commercial buildings.

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 United States 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 United States in 2015. Each of these technologies faces 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, these deployments can take 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.

32. **Analyze financing for advanced large-scale generation**. Alternative financing and organizational structures should be explored for advanced large-scale generation, including small modular reactors, advanced reactors, enhanced geothermal, concentrated solar power, offshore wind, and advanced carbon capture and storage projects. Many of these new, larger systems require sponsors to make significant upfront capital investments, and several also contain technology risk, which creates barriers for lenders and regulators. For example, it is currently challenging for state public utility commissions to allow a regulated utility to begin construction on an advanced new nuclear or carbon capture and storage plant with guaranteed rate base recovery. DOE should analyze potential opportunities to support the financing options for advanced large-scale generation by utilities and others, building upon existing programs where applicable.

33. **Increase funding for the life-extension R&D program to ensure maximum benefits from existing nuclear generation**. The existing DOE research program to resolve technical issues with regard to subsequent license renewals for existing nuclear plants should be significantly expanded to accommodate the expected increase in renewal applications and to enable the continued operation of existing plants through technology development, as well as to improve performance and reduce costs and the use of high-performance computing to simulate reactor processes.

34. **Increase support for advanced nuclear technology licensing at the Nuclear Regulatory Commission**. Congress should provide funding to the Nuclear Regulatory Commission for the certification and licensing of advanced reactors, including the development of advanced reactor certification and licensing criteria, and processes and for general public outreach, as reflected in the President's FY 17 budget proposal. In addition, Congress should authorize and fund a program at DOE to support advanced reactor license applicants, especially in the development and submission of pre-applications.

35. **Develop environmental mitigation technologies for hydropower**. Increase funding for RD&D to better understand and mitigate the environmental impacts of new and existing hydropower projects. Continued operation of some existing facilities and deployment of new facilities depends upon demonstration and acceptance of environmental mitigation technologies and strategies for facilities of all sizes.

36. **Promote responsible operation, optimization, and development of non-Federal hydropower**. Organize a national dialogue to address potential licensing and re-licensing processes that would encourage the responsible operation, optimization, and development of non-Federal hydropower in a manner that maximizes opportunities for low-cost, low-carbon renewable energy production, economic stimulation, and environmental stewardship to provide long-term benefits for the Nation.

Address Significant Energy-Water Nexus Issues Affecting—and Affected by—the Electricity System

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, 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; research, development, demonstration, and deployment (RDD&D); and engagement with stakeholders.

37. **Launch an electricity-related energy-water nexus policy partnership with Federal, state, and local partners**. DOE should create an electricity-related energy-water nexus policy partnership with states, related organizations, local governments, and other Federal agencies, where appropriate; this policy partnership would discuss ways to improve and better integrate existing energy and water policies with respect to goals, data, metrics, and compliance dates. Many energy and water policies are designed to address only energy or water, but not both, potentially leading to conflicting incentives and unintended consequences that could be avoided through more integrated policy design. In support of the partnership, DOE should develop an Integration Analysis Framework to map out broad, system-wide benefits and potential vulnerabilities of energy-water systems integration (at multiple temporal and spatial scales) to inform relevant decision makers. This analysis framework would serve to enable valuation of costs and benefits associated with energy-water systems.

38. **Support additional RDD&D to reduce water requirements for carbon capture technologies**. Provide additional funding to complement existing efforts in technology RDD&D to reduce water requirements of carbon capture systems, including capture systems themselves (solvents, membranes, materials), as well as integration of the capture system with the generation plant or industrial facility. Reduced water use at power plants and other industrial facilities outfitted with CCUS would lower water withdrawal and consumption out of natural water bodies and could make CCUS technology more attractive in water-scarce areas.

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.

39. **Expand tax incentives for renewable electricity, electric vehicles, and energy efficiency**. Consistent with the current Administration's Green Book proposal, expand the list of technologies eligible for Federal tax incentives to include other sources of low-carbon generation beyond wind and solar; extend the timeframe for the Production Tax Credit (PTC) and Investment Tax Credit (ITC); and make the PTC refundable, available to otherwise eligible renewable electricity consumed directly by the producer, and also available to individuals who install solar electric or solar water heating property on a dwelling. In addition, implement the proposed reform to the electric vehicle tax credits and extension of commercial building energy efficiency tax credits included in the President's FY 17 budget.

40. **Extend the time frame and the total capacity allowed under the PTC for nuclear generation**. Current law provides a $0.018/kilowatt-hour production tax credit for new nuclear plants placed in service by 2020 and places a capacity cap of 6,000 MW. Extend the eligibility date so that reactors placed in service after 2020 could qualify and increase the capacity cap.

41. **Provide tax credits for CCUS**. Provide a tax credit, such as the proposal to create $2 billion in refundable ITCs for 30 percent of eligible CCUS equipment and infrastructure in the President's FY 17 budget; create a refundable sequestration tax credit ($10 per metric ton for carbon dioxide that is stored and reused, and $50 per metric ton for carbon dioxide that is stored and not reused);

index to inflation; or implement reforms to the existing 45Q tax credit that would achieve similar goals. Expand eligibility to include industrial-sector applications of CCUS.

42. **Assess business model inequities associated with Federal electricity financial incentives and public-private partnerships**. DOE should assess the current utilization of energy tax credits by ownership type, including the impact of proposed changes to the tax code on the ability of entities to utilize incentives. DOE should also identify options to increase the impact of tax credits on the deployment of clean energy assets. Relevant topics could include the usage of tax credits by tax-exempt entities, the exclusion of ITCs from normalization, Federal financing for public power and rural electric cooperative utilities, and the possibility for expanded use of public-private partnerships.

43. **Increase power purchasing authorities for the Federal Government from 10 to 20 years**. The Federal Government is currently subject to goals and mandates for the purchase of clean energy which, if achieved, can help to catalyze action in the private, state, and local sectors. However, widespread Federal Government clean energy purchases are constrained by generally applicable procurement rules that prohibit entering long-term contracts. Congress should authorize all Federal agencies to negotiate 20-year power purchasing authorities for clean energy.

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.

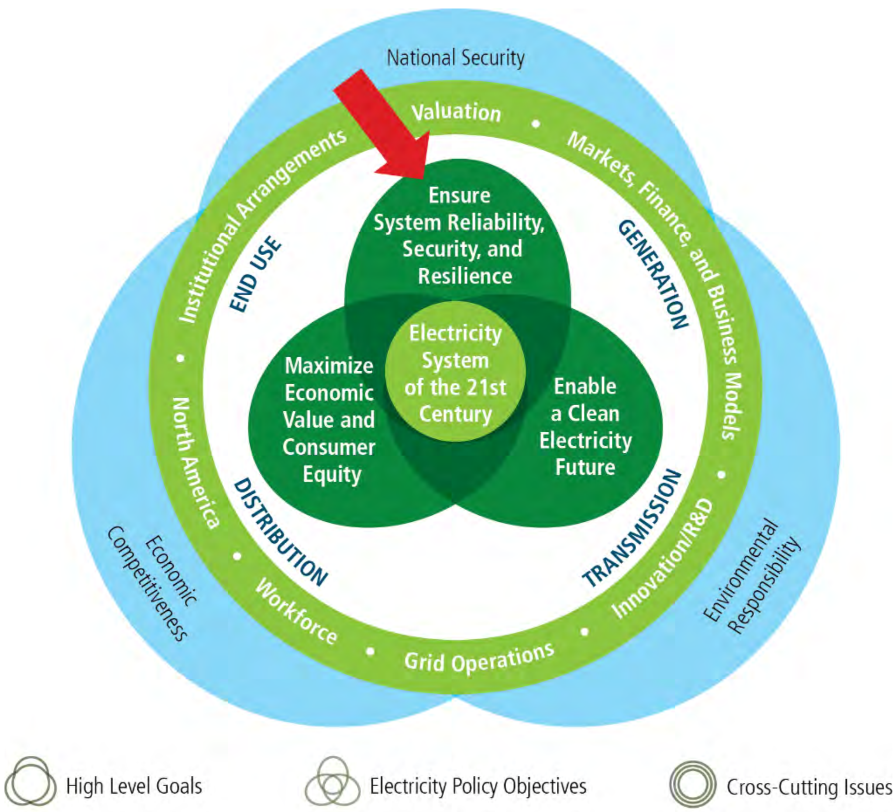
44. **Evaluate and develop generation-siting best practices**. DOE and DOI should initiate a 2-year series of technical workshops to evaluate generation-siting best practices, environmental impacts, mitigation options, and risk to inform decision making by developers and regulators. The workshops will draw upon state and local permitting expertise and experience and will issue reports to provide developers and regulators tools and best practices for streamlining and potentially standardizing underlying requirements for environmental impact studies and siting analysis. Permitting of projects should continue expeditiously during this process.

45. **Support improved regional and interregional transmission planning processes**. DOE should fund the development of a systematic monitoring program to enable valuation of new transmission facilities, measure the outcomes of FERC Order Nos. 890 and 1000, and develop methodologies to improve their effectiveness. The objective of FERC Order No. 1000 is to identify methods and approaches that enable the selection of the "best" set of transmission facilities (i.e., the more efficient or cost-effective transmission facilities selected in a regional transmission plan for purposes of cost allocation); it aims to accomplish this by (1) establishing requirements for regional transmission planning and interregional transmission coordination processes, and (2) opening transmission investment to non-incumbent owners. However, because implementation of FERC Order No. 1000 is in early stages and no systematic monitoring system is in place, it is not possible to assess whether its requirements are having their intended effects. Success would mean that transmission planning and cost allocation would be effectively supporting transmission, while also reducing costs, sustaining or improving reliability, reducing congestion, and/or meeting transmission needs driven by public policy requirements.

46. **Modernize electricity transmission permitting procedures**. DOE should expand the domestic coverage of its Regulatory and Permitting Information Desktop (RAPID) Toolkit, which contains information relating to critical state requirements to include the 36 states that currently have no transmission-related information in the Toolkit. This would provide support for the Federal Permitting Improvement Steering Council, which was tasked with modernizing Federal

infrastructure permitting to create efficient project delivery and improve outcomes. One step in reducing complexity is providing developers, government agencies, tribes, and other affected entities ready access to information relating to Federal and state policies and requirements that would expedite their involvement

7.4 Ensure Electricity System Reliability, Security, and Resilience



System reliability has been an essential expectation of electricity consumers since the development of the modern electricity system. Reliability is formally defined through metrics describing power availability or outage duration, frequency, and extent of the outage. The utility industry is primarily responsible for ensuring system reliability through risk-management strategies to prevent disruptions from reasonably expected hazards. Risk-management practices need to keep pace with the emerging threat environment, particularly cybersecurity and severe weather associated with climate change. The grid's growing interconnectedness and incorporation of new energy resources also create new risks and vulnerabilities, even as they create significant new value to all users of the electricity system.

For these reasons, the traditional definitions of reliability alone may be insufficient to ensure future system integrity and available electricity services. U.S. policies, markets, and institutional arrangements must evolve to reflect this new reality. Actions and approaches are needed to integrate resilience concerns into system planning and reliability standards, prioritize investments in reliability and resilience, quantify the benefits of investments that address emerging or low-probability hazards, broaden the range of risk-reduction options, improve flexibility through activities both pre- and post-disruption, and ultimately, focus on maintaining and improving energy delivery outcomes for the customer under all conditions.

A focus on evolving hazards, new metrics, better analysis, finer data granularity, and strong interdependencies between grid operators and consumers frames the scale and scope of necessary sector transformation. These challenges could be mitigated through a combination of standards, risk-management methods and processes, and collaboration across industry, state, local, and Federal stakeholders.

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. Cyber threats to the electricity system are increasing in sophistication, magnitude, and frequency. Physical threats remain a concern. These challenges could be addressed through a combination of cost-benefit analyses, standards, and collaboration across industry, state, local, and Federal stakeholders. The following recommendations build upon and extend current initiatives, such as DOE's Grid Modernization Initiative and Partnership for Energy Sector Climate Resilience.

47. **Develop uniform methods for cost-benefit analysis of security and resilience investments for the electricity system**. DOE should develop methods for calculating the costs and benefits of investments in resilience solutions, as well as methods for managing the risks associated with many types of high-impact, low-frequency events or emerging and rapidly evolving threats related to climate change, cyber or physical attacks, or combined threats. This could be implemented in part through the establishment of a "community of practice" for valuation of electricity-sector reliability and resilience, providing a stakeholder forum for sharing current practices and developing uniform valuation methods.

48. **Provide incentives for energy storage**. Provide a financial incentive to reduce the cost and support deployment of non-emitting energy storage. Qualified storage includes equipment that receives, stores, and delivers energy using batteries, compressed air, hydrogen storage (including hydrolysis), thermal energy storage, regenerative fuel cells, flywheels, capacitors, superconducting magnets, technologies and systems that provide the verified services and benefits or technologies and systems.

49. **Improve and upgrade existing Federal hydropower operations**. Fifty percent of U.S. hydropower is federally owned. DOE, the Army Corps of Engineers, and the Bureau of Reclamation should convene relevant stakeholders to identify and discuss opportunities to improve existing Federal hydropower. Relevant topics to address include technology upgrades; increasing generation, capacity, and essential reliability service capabilities; operations and maintenance efficiency; acquisition improvements; funding flexibility; and mitigating impacts from hydropower.

50. **Account for emerging threats in reliability planning**. Reliability standards and planning requirements should be updated to increase electricity-sector resilience to emerging and rapidly evolving hazards, like climate change and cyber and physical threats. The Federal Government should take formal steps to update reliability planning standards for the bulk power system. States, cooperatives, and public power should update or establish new requirements for resource planning and other planning processes for distribution systems. States should also update design standards for critical infrastructure and annually update Energy Assurance Plans accordingly. Similarly, standard making organizations (e.g., the American National Standards Institute and the Institute of Electrical and Electronics Engineers [IEEE]) should take steps to evaluate whether new performance standards and testing procedures are needed to ensure electrical equipment resilience to rapidly evolving hazards.

51. **Support grants for small utilities facing cyber, physical, and climate threats**. Small utilities cover over 75 percent of the Nation's landmass, including sensitive and military installations.[a] The combination of large service territories, minimal staffing, limited budgets, lack of access to tax incentives, and low customer density presents challenges to small utilities addressing such new and evolving threats. DOE and USDA's RUS should work together to develop risk-management tools, provide grants for shared staff to implement solutions (such as through joint action and/or generation and transmission programs), and host workshops to facilitate knowledge transfer to support small utilities as they address these challenges.

52. **Support mutual assistance for recovering from disruptions caused by cyber threats**. Utilities have a long history of providing mutual assistance in the event of traditional disruptions, but as the grid becomes more reliant on digital technology, cyber and cyber-physical threats present new and distinct challenges to system restoration. DOE, in coordination with interagency partners and industry, should increase support for private-sector efforts to respond to significant cyber incidents on the electric system.

53. **Support the timely development of standards for grid-connected devices**. Common interoperability standards are critical to enabling the distribution system to accommodate the growth of grid-connected technologies at large scale and to potentially improve grid cybersecurity. DOE should work with the National Institute of Standards and Technology to increase the pace of standards development so that it aligns with the rapid development and deployment of grid-connected devices.

54. **Support development of an enhanced reliability service class for commercial customers**. When there is a power failure, a new and growing class of commercial customers loses significant economic value immediately. The electricity demand of individual commercial customers is of insufficient scale, however, to support options similar to those of large industrial customers, who can pay their utilities to install additional feeders to enhance service reliability. This lack of scale and rate options has led some commercial customers to pursue third-party options (e.g., storage, back-up generators, onsite generation) to improve their electricity reliability. Associated grid defections could affect the overall customer and rate base. Analysis is needed to inform new rates for this class of customers. DOE should encourage states to consider having utilities offer enhanced reliability through commercial service packages that provide reduced outages, higher reliability, and quicker recovery for interested customers.

55. **Improve system reliability through analysis of back-up generation best practices**. Many industrial, commercial and residential customers utilize onsite back-up power generation during electricity disruptions. There have however been several high-profile failures of back-up generation had significant impacts on consumers and businesses. Also, as load management grows in importance, so too does the visibility of the level and reliability of back-up generation. Finally, key lifeline infrastructures and defense facilities depend on back-up generation. DOE should conduct a nationwide study of back-up generation; it should specifically identify related gaps and critical needs for consumers, critical infrastructure, and sensitive facilities. This analysis should further consider interconnection approaches for back-up generation to improve overall system resilience and reliability through the update and adoption of IEEE 1547 interconnection standards. This analysis should also take into account cost effectiveness and environmental performance. DOE should consider the outcomes of this analysis and provide recommendations

[a] Although such facilities frequently have back-up power capabilities, the durability of such backups is typically limited to fuel supplies on hand.

on best practices for back-up generation and how to maximize is value for grid operations, lifeline networks, and consumers.

56. **Develop guidance, best practices, and protocols for select categories of distribution equipment and consumer grid-interactive devices**. Distribution system-wide outages could be induced by disrupting interconnected DERs and their associated data feeds to the distribution grid, especially during critical peak demand or by causing lasting damage to a distribution transformer. DOE will do this in coordination with the National Institute of Standards and Technology and industry.

57. **Require states to consider the value of DERs, funding for public purpose programs, energy and efficiency resource standards, and emerging risks in integrated resource or reliability planning under the Public Utility Regulatory Policies Act (PURPA)**. PURPA section 111(d) establishes Federal standards for regulated electric utilities that State public utility commissioners "must consider." Because rates of distribution utilities are not directly regulated by the Federal Government, PURPA amendments serve to preserve the legal authority of the states to amend or establish new standards. Without statutorily dictating any final state decisions, Congress should amend PURPA to require state public utility commissions and nonregulated utilities to consider the following: (1) the costs and benefits of DERs and alternatives in rate design and integrated resource planning, (2) stable funding for public purpose programs, (3) energy efficiency resource standards, and (4) emerging risks in integrated resource or reliability planning.

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 United States 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.

58. **Establish Federal standards for maintaining and sharing common data on Presidentially-declared natural disasters and physical attacks affecting the electricity system.** DOE and DHS should improve the collection, curation, and accessibility of data related to the impacts of disasters along with detailed characterizations of the nature and cause of each disaster. By improving the availability and quality of historical disaster impact data, the government and its partners can develop improved risk models, as well as gain the ability to more effectively locate and more clearly understand points of vulnerability within existing systems. Defining data standards would increase the ability of Federal agencies to manage and share disaster impact data by making it possible to merge and query disparate data sets by common feature, such as Presidential disaster declaration number. Types of data that would be more readily available as a result of this effort include detailed characterization of the nature and cause of each disaster as well as the extent and degree of associated impacts, such as power outages, fatalities, injuries, property losses, as well as other data to inform decision making that will help communities better prepare for and respond to future disasters.

59. **Enhance coordination between energy-sector information sharing and analysis centers and the intelligence communities to synthesize threat analysis and disseminate it to industry in a timely and useful manner**. The nature of cyberspace and its associated threats requires individuals, organizations, and the government to actively participate in incident response activities. Increased coordination would provide deeper analysis of threats based on both classified and unclassified data available from the operational and enterprise environments.

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, as well as other planning priorities.

60. **Promote deployment of advanced technologies for new and existing transmission**. DOE should work with stakeholders to identify, analyze, and develop recommendations for removing barriers to the valuation and deployment of advanced technologies for new and existing transmission, such as those that enhance reliability, security, and affordability through visibility and control. DOE should explore a range of legislative and regulatory options and analytically test their potential effectiveness on both a stand-alone basis and a collective basis to enable deployment of technologies that cost-effectively increase existing transmission capacity utilization (i.e., remove barriers to technology solutions that enable greater transmission utilization of existing transmission capacity). In addition, DOE should identify and mitigate barriers to technologies that can increase transmission capacity utilization and create a framework for future work based on the experiences of work in capacity utilization, synchrophasors, and storage.

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 on 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.

61. **Expand economic modeling capability for electricity**. EIA should be able to more accurately reflect the role of energy efficiency, DR, electricity storage, and a variety of DG technologies in current and future energy consumption to better inform investments and modeled policy scenarios.

62. **Expand EIA data collection on energy end uses**. EIA should expand the scope and frequency of its data collection on energy end uses and services in the residential, commercial, and industrial sectors, including the use of new data collection methods and tools, in order to enable a more detailed representation by region, income, and other characteristics.

63. **Expand EIA hourly data collection on power system operations**. EIA should expand the scope of the current grid operations data collection to require (1) net generation by energy source (e.g., coal, solar, wind, natural gas, nuclear) and (2) sub-regional detail for large balancing authorities in order to inform investment decisions and provide higher-resolution and more quickly delivered data on how system operations are changing. EIA should continue to evaluate new definitions for National Energy Modeling Systems Electricity Market Module.

64. **Expand EIA data collection on electricity transmission**. EIA should improve the scope, frequency, and resolution of transmission data collection by (1) developing an regional transmission organization/independent system operator dashboard on the operation of centrally organized, wholesale power markets; (2) collecting and maintaining information on the utilization of the bulk transmission system that complements current data collection; and (3) improving reporting on transmission investment and on the functioning and outcomes of transmission planning activities,

to enable analysis on whether transmission policies and regulations are achieving their intended effects. All proposed activities should be undertaken through processes that comply with existing data-collection protections.

65. **Support EIA's collection of additional data on Electricity and water flow for water and wastewater utilities**. Electricity usage in delivering water services represents a significant portion of U.S. electricity consumption (estimated at 3 to 4 percent of total electricity consumption) and may present major opportunities for both efficiency and renewable generation; however, EIA does not currently collect this data in its surveys. EIA should expand its data collection to include annual electricity and annual water flow (millions of gallons) by water and wastewater utilities, in order to enable identification of new opportunities for electricity use and savings.

7.5 The Electricity Workforce: Changing Needs, New Opportunities

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 an interest in the development of this workforce.

66. **Support cyber-physical systems (CPS) curriculum, training, and education for grid modernization and cybersecurity**. The December 2010 report of the President's Council of Advisors on Science and Technology, titled "Designing a Digital Future," highlighted the unique importance and challenges of CPS, such as the power grid. One of the challenges with such systems is the lack of a dedicated and trained cross-disciplinary workforce skilled at comprehending, designing, and managing CPS. This presents an acute challenge in the realm of power-sector cybersecurity, where cyber and cyber-physical threats are presenting new and distinct challenges. Prevention, mitigation, and response and recovery efforts require a workforce that understands the unique electric sector IT and operational technology systems and challenges; however, the industry currently faces a shortage of such workers. The Federal Government—through the Department of Education, DOE, National Science Foundation, and others—should sponsor development and deployment of CPS and cybersecurity educational curricula with community colleges, universities, and institutions of higher education to meet the grid-modernization needs of the 21st-century electricity system; they can do this by offering grants and supporting programs for educational institutions to develop and deploy CPS and power-sector cybersecurity educational curricula.

67. **Enhance and align skills-based training and electricity-sector workforce development**. The Federal Government has multiple resources that help address the difficulty employers are experiencing in hiring skilled workers in the electricity sector. To facilitate access to these Federal programs, the following steps should be taken:
    - DOE should, with other Federal agencies (e.g., the Department of Labor [DOL], National Science Foundation, Department of Commerce, Department of Education, and Department of Defense), coordinate Federal initiatives on electricity-sector education and training, including programs to facilitate national training credentials in new electricity technologies.
    - DOL should expand its pre-apprenticeship programs.

- DOE should expand its existing programs to increase the number of internships, fellowships, traineeships, and apprenticeships.
- DOE, DOL, and the Department of Defense should work together to create workforce opportunities for veterans, to build a more inclusive workforce, and to bring clean energy job training to low- and moderate-income communities.
- DOL and DOE should develop a single resource web portal to inform industry and potential employees about the multiple Federal agency workforce development initiatives and resources.

68. **Support Federal and regional approaches to electricity workforce development and transition assistance**. Changes in the electricity sector are increasing the need for a diverse and specialized workforce. To ensure electricity-sector workers maintain the capabilities required to provide for reliable and affordable electricity in a rapidly changing environment, DOE (in partnership with other agencies) should facilitate programs and regional approaches for workforce development. Federal funding and technical support should enhance existing programs on workforce diversity; apprenticeship and apprenticeship-readiness programs; skills-based training and education; transition assistance; and curriculum development. Workforce assessment tools should be developed to complement training programs. Federal agencies should coordinate their efforts through the interagency Energy and Advanced Manufacturing Workforce Initiative, staffed by DOE. Unemployed workers nearing but not yet eligible for retirement may have difficulty retraining after careers built on specialized skills that are no longer in demand in the modern electricity industry. Retirement transition assistance should be provided to these workers. Where possible, Federal agencies should leverage existing government, nongovernment, labor, and industry workforce consortia.

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.

69. **Fulfill Federal commitment to fund coal miner retiree benefits**. Over the last 50 years, coal miners have repeatedly foregone increases in wages in exchange for pension and healthcare benefits. These benefits are now imperiled by (1) the recent bankruptcy of three of the largest public coal companies in America—allowing those companies to avoid fully funding their employees' benefit funds—and (2) the declining ratio of active contributing workers relative to beneficiaries in the health and pension funds. Recognizing the commitments to support coal miner retirement benefits made by the Federal Government in the 1946 Krug-Lewis Agreement, the 1992 Coal Industry Retiree Health Benefit Act, and the 2006 amendments to that act, and also recognizing the contribution that coal miners have made to the U.S. economy, the Administration strongly supports legislation that would transfer funds to the largest multi-employer health and pension fund serving retired coal miners and their families, thereby ensuring that it can continue paying benefits.

70. **Meet the Federal commitment to appropriate sufficient funding to accomplish the mission of the Abandoned Mine Lands (AML) Fund**. DOI's Office of Surface Mining Reclamation and Enforcement estimates that there are more than $4 billion worth of high-priority, health- and safety-related abandoned coal mine lands in the United States. At the same time, the AML Fund has an unspent balance of $2.5 billion dedicated to reclaiming these sites. The AML fees should be returned to their original 1977 levels to raise additional reclamation funds, and disbursements from the AML Fund should be accelerated over the next 5 years, enhancing economic development in distressed coal communities through reclamation employment.

7.6 Targeted Opportunities to Enhance Electricity Integration in North America

Increase North American Cooperation on Electric Grid and Clean Energy Issues

Cooperation on electricity is needed to strengthen the security and resilience of an integrated, cross-border electricity grid, as well as to provide increasing amounts of clean energy and improve economic competitiveness across North America. A clear understanding of the regulatory requirements at the Federal and state levels for the permitting of cross-border transmission facilities, a sharing of best practices, and an exploration of potential future cooperation on grid management issues will limit uncertainties and improve policy coordination at the multilateral and international levels. This includes implementing the target established in the 2016 North American Leaders Summit to increase clean power to 50 percent of the electricity generated in North America by 2025.

71. **Increase U.S. and Mexican cooperation on reliability**. In 2005, the United States and Canada codified an international reliability framework based on an electricity reliability organization. As Mexico moves ahead with electricity reform and looks to expand their electricity system (including planning for international transmission), an international commitment to reliability would signal good progress towards improved electricity system management across North America. A commitment to working jointly on reliability was also included in the statement from the North American Leaders Summit in June 2016, where these leaders "committed to deepened electric reliability cooperation to strengthen the security and resilience of an increasingly integrated North American electricity grid."[14] The U.S. Government should increase cooperation on reliability between the United States and Mexico by establishing bilateral reliability principles between the United States and Mexico.

72. **Advance North American grid security**. In December 2016, the United States and Canada released a Joint United States–Canada Grid Security Strategy framing how these two countries plan to work together to strengthen the security and resilience of the electric grid, including against the growing threat from cyber attacks and climate change impacts. This recommendation aims to complete that objective through sharing of best practices and exploration of potential future cooperation on grid security issues with Mexico, in parallel with implementation of the Joint United States–Canada Grid Security Strategy and domestic Action Plans.

73. **Promote North America clean energy infrastructure development by sharing best practices for community engagement**. Lessons learned from sharing across regional entities can be a challenge, but the Federal Government can provide a forum for that engagement. This recommendation proposes that the U.S. Government initiate a series of high-level meetings with Canada and Mexico to share best practices relating to community engagement for clean energy infrastructure development throughout North America.

74. **Promote permitting of cross-border transmission facilities**. The "Regulatory Side-by-Side Governing Permitting of Cross-Border Electricity Transmission Facilities between the United States and Canada" summarizes existing regulations as of the time of publication. The document has proved incredibly useful as a resource for other analytical efforts and in informing discussion about simplifying or harmonizing regulations. Expanding this work to Mexico as the energy reforms move ahead would be very helpful to developers and governments. In addition, high-level meetings to improve community engagement for infrastructure can be supported by an effort at the U.S. Department of Energy with partners in Canada and Mexico to complete and update the Regulatory Side-by-Side and expand the Regulatory and Permitting Information Desktop (RAPID) Toolkit to the North America cross-border context. Consistent with the "North American Climate, Clean Energy, and Environment Partnership Action Plan," DOE should promote permitting of cross-border transmission facilities by expanding the Regulatory and Permitting Information Desktop (RAPID) Toolkit. Expansion of this toolkit will enable a clear understanding of the regulatory requirements at the Federal and state levels for the permitting of cross-border transmission facilities, in addition to those for bulk transmission.

75. **Modernize international cross-border transmission permitting processes**. Building upon Executive Order 13604, "Improving Performance of Federal Permitting and Review of Infrastructure Projects," a 2013 Presidential Memorandum titled "Transforming our Nation's Electric Grid through Improved Siting, Permitting, and Review" aims to modernize transmission permitting processes. The Presidential Memorandum directed Federal agencies to create the integrated interagency pre-application process (IIP) across the Federal Government (1) to help identify and address issues before the formal permitting process begins and (2) to improve coordination of permitting across Federal, state, and tribal governments. On September 21, 2016, DOE's Office of Electricity Delivery and Energy Reliability announced a final rule for the IIP. The IIP process encourages robust early coordination prior to the submission of a formal transmission permit application. That includes increased engagement with DOE as a coordinating agency, as well as relevant state, local, and tribal stakeholders. The principles of the IIP have already been successfully applied to two existing and recent Presidential permit applications for clean energy transmission. Building on these activities, DOE should modernize international cross-border transmission permitting processes by implementing a pre-application process and update the Presidential Permitting rules.

76. **Increase North American clean energy and technical coordination**. **T**echnical discussions have the potential to support better coordination on clean energy and climate goals, primarily through the creation of more robust North American modeling capabilities and wider accounting of clean energy and carbon emissions associated with cross-border trade. Technical discussions can also continue and enhance cooperation on energy information exchange across North America. In addition, technical discussions should focus on increasing North America wholesale electricity markets cooperation by sharing best practices for market development. As North America moves towards greater integration, there should be continued engagement on the cross-border impacts of climate and clean energy policies in order to limit uncertainties and improve policy coordination at the multilateral and international levels. There is a need for analytical tools and models that can estimate the value of technology deployment and summarize the impacts of policies in the clean energy and climate policy space. Specifically, models and studies are needed to examine (1) policy levers and incentives for clean energy and technologies to achieve climate goals; (2) the emissions impacts of jointly planning climate action and policies for climate and clean energy; (3) the impacts of cross-border trading on clean energy development, emissions, and the electricity system; and (4) the impacts of market policies, including cross-border trading schemes for carbon

and emissions. With new modeling capabilities and through technical discussions, DOE should explore the impact of enhanced cross-border trade on greenhouse gas emissions, economic development (in all countries, and collectively), as well as system reliability. Specific analysis could model market structures and examine the interplay between short-term operational flexibility and long-term financial certainty; examine the impact of enhanced U.S. imports of Canadian hydropower on carbon emissions and U.S. renewable energy development; examine best practices for the development of wholesale electricity markets; study Mexico's integration into the Western Climate Initiative; and explore impacts on the U.S. renewable energy industry, end-use costs for consumers, and the impacts of adjustments in sub-national policies on clean energy consumption across the continent.

7.7 Endnotes

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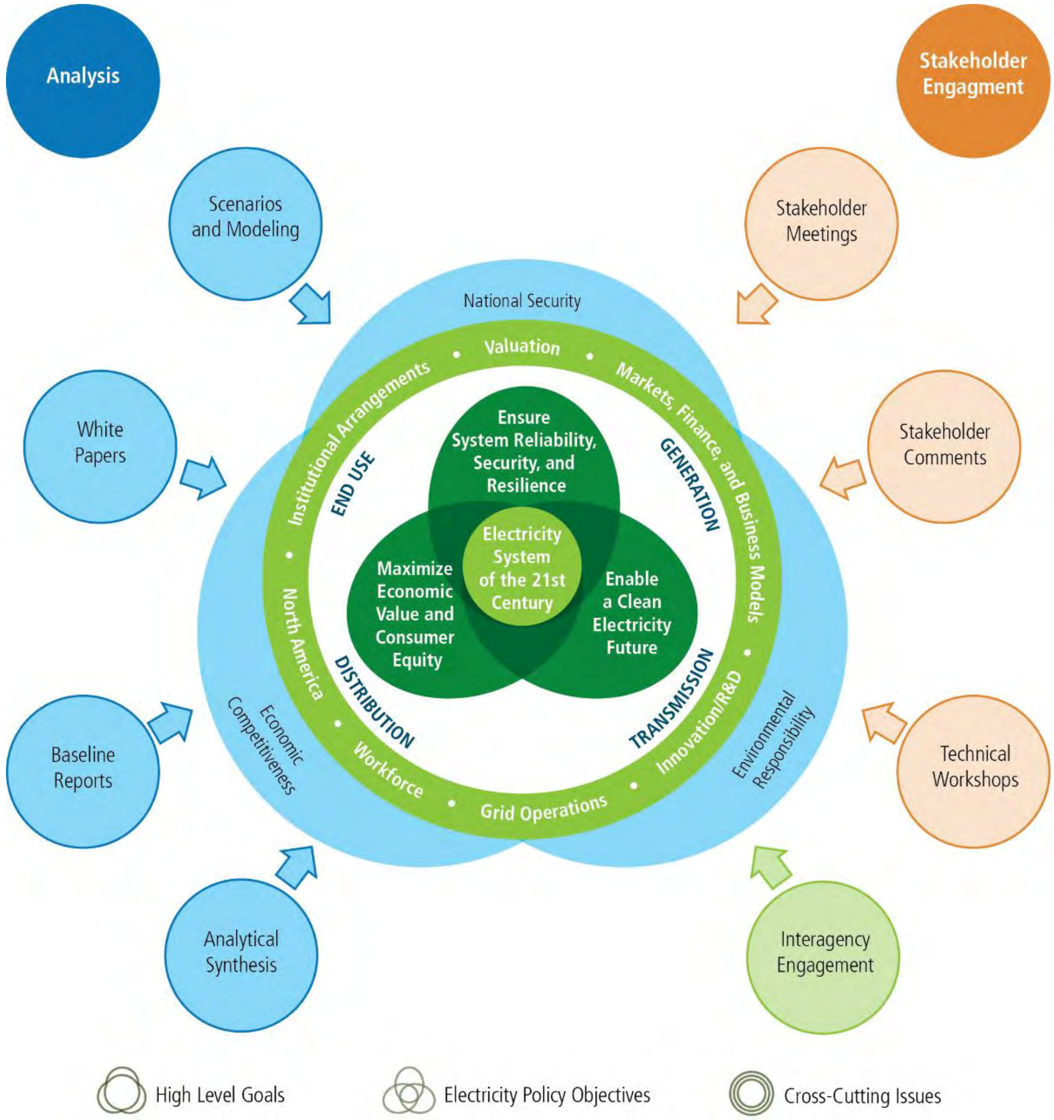
VIII Analytical and Stakeholder Process

This chapter describes the analyses and stakeholder engagement process that provided the substantive basis for this second installment of the Quadrennial Energy Review (QER 1.2). The first section describes the analytical work carried out for the QER 1.2, including baselines, models, topical reports, and white papers. The second section describes how the QER 1.2 process included engagement with a broad range of stakeholders across the Nation, through technical workshops, seven formal public stakeholder meetings, and the collection and consideration of public comments. This chapter is intended to document the process of developing the QER 1.2 and to provide transparency on the methods used to develop the material in the report.

Figure 8-1. Inputs to QER 1.2



This figure shows the analytical, stakeholder, and interagency efforts underpinning the QER 1.2.

8.1 Systems Analysis

The Administration-wide Quadrennial Energy Review (QER) is intended to enable the Federal Government to translate policy goals into a set of analytically based, integrated actions over a 4-year planning horizon. The White House Domestic Policy Council and Office of Science and Technology Policy jointly chair the interagency QER Task Force, while the Secretary of Energy provides an Executive Secretariat in the Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA). The QER involves a multi-agency review process, and more than 20 executive departments and agencies[a] play key roles in

[a] The members of the Task Force include: (1) the Department of State; (2) the Department of the Treasury; (3) the Department of Defense; (4) the Department of the Interior; (5) the Department of Agriculture; (6) the Department of Commerce; (7) the Department of Labor; (8) the Department of Health and Human Services; (9) the Department of Housing and Urban Development; (10) the Department of Transportation; (11) the Department of Energy; (12) the Department of Veterans Affairs; (13) the Department of Homeland Security; (14) the Office of Management and Budget; (15) the National Economic Council; (16) the

developing and implementing policies proposed in the QER. Unlike other Federal quadrennial review processes where analysis is done every 4 years, the QER is conducted through installments to allow for granular analysis of key energy subsectors. Serving as Secretariat, EPSA is responsible for coordinating activities related to the preparation of the report, including commissioning an extensive suite of policy analysis focused on the electricity system (see Figure 8-1).

QER 1.2's analysis was completed over many months through the following methods:

- Commissioning five baseline reports to provide an overview of the current state of the electricity system
- Commissioning analyses, modeling, synthesis, and white papers from U.S. National Laboratories, energy consultants, and analytics firms
- Convening technical workshops with relevant stakeholders and producing write-ups of findings and stakeholder viewpoints
- Performing analysis and modeling within EPSA, in collaboration with partners across DOE and other Federal agencies, to generate analysis, policy working papers, and reports
- Meeting with EPSA and staff-level agency representatives and experts on the findings and recommendations proposed in QER 1.2.

8.2 Crosscutting Analysis

This section provides examples of major external analyses commissioned by EPSA that support the findings and recommendations within QER 1.2. The descriptions below categorize the analyses (with the caveat that most QER 1.2 analyses are crosscutting in nature and apply to more than one energy objective or sector).

8.2.1 Baselines

A series of EPSA baselines were developed to provide an overview of elements of the electricity system. These baselines helped inform QER 1.2 and focused on the following issue areas: generation, distribution, end use, markets, and climate and environment.[b] These baseline analyses identify major historical trends in the electricity sector and reflect the workings, characteristics, and issues of the current electricity system. These baselines provide a foundation for the analysis of systems and policy recommendations that form QER 1.2.

8.2.2 Key Reports and Studies

QER 1.2 drew from multiple studies of the electricity system, including but not limited to the following:

National Security Staff; (17) the Council on Environmental Quality; (18) the Council of Economic Advisers; (19) the Environmental Protection Agency; (20) the Small Business Administration; (21) the Army Corps of Engineers; (22) the National Science Foundation; and (23) such agencies and offices as the President may designate.

[b] The environmental baseline was divided into four volumes in the following categories: Greenhouse Gas Emissions, Solid Waste and Decommissioning, Energy-Water Nexus, and Environmental Quality.

Table 8-1.[c] List of Chapter Specific Analyses for QER 1.2

Title	Performer
Transforming the Nation's Electricity Sector: The Second Installment of the QER	
Accelerate Energy Productivity 2030	NREL
Principles for Creating and Evaluating Electric System Reliability Plans in the 21st Century	NREL, PNNL, ORNL
Cyber Threat and Vulnerability Analysis of the U.S. Electric Sector	INL
Energy Supply Chain Vulnerabilities: Framework and Case Study	ANL, ORNL, INL
Modernizing the Electric Distribution Utility to Support the Clean Energy Economy	EPSA
Harmonizing the Electricity Sectors across North America	RFF
Electricity Distribution System Baseline Report	PNNL
Electricity Generation Baseline Report	NREL, INL, NETL
Residential Electricity Bill Savings Opportunities from Distributed Electric Storage	EPSA
Establishing the Playing Field: Surveying Clean Energy-Related Economic Development Policy across the States	NREL
Ensuring Electricity System Reliability, Security, and Resilience	
Assessing Cost and Benefits of Investments in Climate Resilience	ORNL
Utility Risk-Mitigation Strategies	Deloitte
Scoping Analytical Tools and Methods for Vulnerability Analysis of Linked Electricity Generation and River Basin Systems	ORNL
Guide to Cybersecurity, Resilience, and Reliability for Small and Under-Resourced Utilities	NREL
Resilience of the U.S. Electricity System: A Multi-Hazard Perspective	ORNL, LANL, ANL, SNL, PNNL, BNL
Front-Line Resilience Perspectives: The Electric Grid	ANL
State Energy Resilience Framework	ANL
Building a Clean Electricity Future	
Energy Efficiency under Alternative Carbon Policies: Incentives, Measurement, and Interregional Effects	NREL
Evaluating the CO_2 Emissions-Reduction Potential and Cost of Power Sector Re-Dispatch	NREL
Literature Review of Studies That Includes an 80% Reduction in GHGs by 2050	Energetics
Characterizing Energy Efficiency in Low-Income Communities	LBNL
Environment Baseline Vol. 4: Energy-Water Nexus	EPSA
Advanced Water Metering Infrastructure	NREL, INL, NETL
The Electricity Sector: Maximizing Economic Value and Consumer Equity	
Energy Efficiency Financing Programs	LBNL
Characterization of Regional Electric Markets	Pace Global
Review of the Economics Literature on U.S. Electricity Restructuring	University of California, Davis
Distributed Energy Resources and Rate Financial Analysis	EPSA
Recovery of Utility Fixed Costs: Utility, Consumer, Environmental and Economist Perspectives	LBNL
Fixed Cost Allocations and Rate-Making Instruments to Address Distributed Energy Resources	EPSA

The QER commissioned multiple studies across the electricity system, including but not limited to these reports for specific chapters.

[c] NREL – National Renewable Energy Laboratory; PNNL – Pacific Northwest National Laboratory; ORNL – Oak Ridge National Laboratory; INL – Idaho National Laboratory; ANL – Argonne National Laboratory; RFF – Resources for the Future; NETL – National Energy Technology Laboratory; LANL – Los Alamos National Laboratory; SNL – Sandia National Laboratories; BNL – Brookhaven National Laboratory; GHGs – greenhouse gases; LBNL – Lawrence Berkeley National Laboratory.

8.2.3 Technical Workshops

As part of the crosscutting analysis conducted for QER 1.2, the QER Task Force flagged some topics deemed particularly complex for technical workshops to discuss further with stakeholders and industry experts. Technical workshops convened subject matter experts and relevant stakeholders to provide expert insights on various elements of the electricity system through the intensive analytical approach of these 1-day and 2-day symposia. Each technical workshop featured a roster of subject matter experts from industry, academia, the National Laboratories, and other relevant organizations.

Below are details about the topics, dates, and locations of the technical workshops that DOE held to inform QER 1.2:

Technical Workshop on Electricity and Information and Communication Technologies Convergence
June 15, 2015 – Washington, D.C.
DOE hosted a technical workshop to understand stakeholder issues on electricity and information and communications technology (ICT). The workshop sought to inform the completion of the Pacific Northwest National Laboratory white paper commissioned by DOE: *The Emerging Interdependence of the Electric Power Grid and Information and Communication Technology*. The second focus of the workshop was to elicit additional electricity and ICT research and policy-analysis topics for potential examination within DOE. The workshop included participants from utilities, industry stakeholders, energy associations, and regulators.

The goal of this meeting was to leverage the inherent synergies between DOE's research and policy functions and gather expert input. Specifically, this workshop concerned the current status of deployment of electricity and ICT infrastructure, as well as trends and developments in market places, technologies, and regulations.

Electric Power in the United States and Canada: Opportunities for Regulatory Harmonization
October 20, 2015 – Boise, Idaho
October 27, 2015 – Albuquerque, New Mexico
DOE sponsored a workshop hosted by Resources for the Future—in concert with the International Institute for Sustainable Development and Boise State University—looking at the electricity sectors in the United States and Canada. The workshop had several purposes: (1) to identify gaps, best practices, and inconsistencies with regulations and electricity-system planning across the United States, Canada, and Mexico; (2) to inform the creation of legal, regulatory, and policy roadmaps for harmonizing regulations and planning; and (3) to bring together individuals who can help implement greater harmonization. The two workshops examined policies, regulations, and planning associated with the electricity sector, and within that sector, environmental regulations (for air pollution, greenhouse gases [GHGs], and renewables). They also examined the regulations and processes associated with the operation and planning of the electricity system—including generation and transmission. DOE and Resources for the Future published a final paper summarizing the recommendations and observations of workshop participants in early 2016.

Low-Carbon Futures of the U.S. Energy System
January 14, 2016 – Washington, D.C.
In 2009, and subsequently in 2014, the Administration set GHG-emissions reduction targets in the range of 17 percent below 2005 levels by 2020 and 26 to 28 percent below 2005 levels by 2025. Both of these goals are intended to put the United States on a path toward 80 percent decarbonization by 2050. DOE hosted a 1-day workshop to better understand possible pathways to achieving substantial economy-wide GHG-emissions reductions by 2050.

Participants from academia, DOE, the National Laboratories, and other interested stakeholder groups met to discuss two main topics: (1) potential pathways for substantial GHG reductions in electricity generation and (2) how future end-use demand for electricity might shape the scale of required GHG-emissions reductions in the electric-power sector. There were two primary goals for the workshop. The first goal was to identify a set of representative pathways (and elements of such pathways) toward substantial economy-wide reductions in GHG emissions by 2050. The second goal was to identify the key characteristics, challenges, opportunities, and requirements of different pathways. The workshop informed analysis of the transition to a cleaner, low-carbon electricity system for QER 1.2.

Electricity Use in Rural and Islanded Communities
February 8–9, 2016, *Washington, D.C.*
The objective of this workshop was to help EPSA's public outreach efforts by focusing on communities with unique electricity challenges. The workshop explored challenges and opportunities for reducing electricity use and associated GHG emissions while improving electricity system reliability and resilience in rural and islanded communities. Although the statement of task mentioned design of microgrids for hospitals, universities, military bases, and other unified load centers, presenters covering microgrids were encouraged to describe potential applications serving isolated communities and towns in keeping with the theme of the workshop. The workshop assembled speakers from diverse locations that have rural or islanded energy issues, including Hawaii, Alaska, North Carolina, and Vermont, and they held expertise in many facets of electricity-system design and operation. Speakers were encouraged to do the following: (1) identify and share best practices between rural and islanded electricity-system users and operators and (2) provide suggestions for Federal policies and research and development investments that could be implemented in both the near and long term.

The Future of Energy Efficiency
February 10, 2016 – Washington, D.C.
This session, held at a meeting of the National Association of State Energy Offices, provided a discussion of the role of energy efficiency in response to the emerging electric-system challenges and opportunities that DOE intends to address in QER 1.2. The purposes of this workshop were to focus on issues related to electricity end use and to explore the potential for energy efficiency moving forward; barriers and opportunities to overcome; system benefits and the costs of increased energy efficiency deployment; and what policies or methods can be deployed to meet evolving consumer needs, and how these needs can be met while creating a more efficient system. Key themes and areas of interest from the discussion included evolving trends in electricity demand; in benefits and costs for energy efficiency in a more integrated grid; options for increasing consumer value/equity/access to services; the potential for greater electrification and decarbonization of the economy; data access and security issues; improving methods for valuing energy efficiency; and opportunities for new services and business models.

The Future of U.S. Bulk Power Markets
March 4, 2016 – Washington, D.C.
DOE, in coordination with Boston University's Institute for Sustainable Energy, hosted a technical workshop to gather input from current industry stakeholders on the future of the Nation's bulk power markets. The workshop also included distinct discussions on the state of transmission-planning efforts, essential reliability services (also known as ancillary services), and the potential for markets at the distribution-system level.

Participants from academia, industry associations, individual companies, public power, and state/Federal regulatory agencies were encouraged to discuss these topics and outline the major issues in their respective areas of expertise. The participants provided recommendations and feedback for ways in which DOE and the QER process could help alleviate those issues. The workshop ultimately informed the direction of subsequent analyses in support of QER 1.2, specifically with regard to transmission systems and resource adequacy constructs.

Workshop on Siting and Regulating Carbon Capture, Utilization, and Storage Infrastructure

April 8, 2016 – Washington, D.C.

DOE sponsored a workshop to identify and promote best practices for siting and regulating carbon dioxide (CO_2) infrastructure—including pipelines, enhanced oil recovery, and saline CO_2 storage sites. The purposes of this workshop were to foster communication and coordination, as well as to share lessons learned and best practices among states that are already involved in siting and regulating CO_2 infrastructure or that may have proposed future CO_2 infrastructure projects.

The workshop convened subject matter experts, industry representatives, Federal officials, and state agencies with jurisdiction over energy-infrastructure planning, siting, and economic development. The aim of the workshop was to facilitate a knowledge exchange regarding CO_2 pipeline and storage-site infrastructure needs. The workshop also informed issues being addressed in QER 1.2, including discussions around CO_2-enhanced oil recovery and other storage sites, which serve as infrastructure for entities capturing CO_2.

Technical Workshop on Electricity Valuation

May 2–3, 2016 – Washington, D.C.

DOE hosted a technical workshop to understand stakeholder issues relevant to the valuation of electricity system technologies, products, and services. The workshop sought to examine four major topics: (1) valuing electricity system components and attributes; (2) valuing technologies for contributions to power quality and reliability; (3) managing electricity risks; and (4) valuation within the distribution system.

The workshop included stakeholders from state and Federal regulatory agencies, electric utilities, technology developers and manufacturers, universities, the National Laboratories, industry associations for consumers, and electricity-system operators. The opening session began with a presentation on a proposed valuation methodology. During the workshop, participants provided their views on issues that must be adequately resolved to support higher penetration levels for advanced or distributed energy technologies. Participants also discussed the challenges associated with methods to value and plan for their integration. The workshop informed and improved analysis commissioned on valuation for QER 1.2.

QER 1.2 Finance Workshop

June 1, 2016 – New York, New York

As input to the QER 1.2, EPSA hosted a technical workshop to gather stakeholder views on power-sector finance in the context of national energy objectives, a changing resource mix, and new technologies and business models. The discussion focused on financing required to deploy proven or advanced clean electricity technologies. Workshop participants included senior leaders from industry and investor communities, who were encouraged to provide examples of existing barriers and ideas on effective public policies and programs for U.S. electricity-system modernization.

Participants emphasized that there is sufficient capital available for proven clean electricity projects with an identified revenue stream, but there is a revenue model problem for many projects and technologies. Some of the topics discussed included the potential role of grid-scale storage; challenges with large-scale nuclear; and the need for policy stability. Participants also encouraged a systems approach to modernization. They emphasized the need to provide assets with revenue streams (via price signals) for all services they provide to the grid so that asset valuations reflect their overall value to the system. The discussion included near-term, incremental changes to facilitate asset financing and deployment such as changes to the tax code, as well as longer-term policy and market changes such as incentive-based regulation, a clean capacity incentive, or pricing local reliability to provide an economic signal for customers to behave in ways that benefit the grid.

Technical Workshop on the Implications of Increasing Electric-Sector Natural Gas Demand
June 7, 2016 – Washington, D.C.
This workshop explored how medium- and long-term planning is evolving given the trend of increased use of natural gas in the electric-power sector. While there are favorable economic and environmental benefits to increased use of natural gas in electricity, potential challenges in infrastructure compatibility and reliability arise, as well. Stakeholders from both the natural gas and electric sectors from different regions of the country convened at this workshop. Participants then shared the practices, tools, and metrics that they employ in order to understand the interdependency between the electric and natural gas industries, as well as the approaches that stakeholders have implemented to resolve challenges and leverage opportunities.

Accelerate Energy Productivity 2030 Executive Review and Dialogue Session
June 28, 2016 – Washington, D.C.
The purpose of this session was not only to provide input to DOE from key industry representatives but also to build upon the work done under the Accelerate Energy Productivity 2030 partnership between DOE, the Alliance to Save Energy, and the Council on Competitiveness. Through the partnership, energy productivity has become an increasingly influential way to drive meaningful policy deployment in the United States and abroad. This session followed the 2014 announcement of the initiative at the 2014 American Energy and Manufacturing Competitiveness (AEMC) Summit by Secretary of Energy Ernest Moniz and the release of *Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth* at the 2015 AEMC. Representatives at the session provided input on several issues relevant to the QER 1.2, including increased deployment of electric vehicles; electric utility rate design that supports deployment of new technologies; regulatory consistency and certainty; improving electric consumer equity; ensuring a strong electric-sector workforce; the role of states in driving energy productivity; the role of incentives and consumer awareness in promoting clean energy technology; the importance of public-private partnerships; and improving access to financing for energy efficiency.

8.3 QER Stakeholder Engagement

In the Presidential Memorandum establishing the QER, President Obama directed the QER Task Force to "gather ideas and advice from state and local governments, tribes, large and small businesses, universities, National Laboratories, nongovernmental and labor organizations, consumers, and other stakeholders and interested parties." The President also ordered the QER Task Force to "develop an integrated outreach strategy that relies on both traditional meetings and the use of information technology."

In its role as Secretariat for the QER Task Force, EPSA undertook an open, transparent process for informing stakeholders of the purposes and scope of the QER 1.2.

This outreach process included the following:

- Informal meetings at DOE headquarters involving EPSA staff members and dozens of stakeholder groups from the electricity sector, such as academic researchers; local, state and Federal governments; and regulatory agencies
- Briefings on the QER process at meetings with industry associations; groups of state officials; the offices of environmental groups; and with Members of Congress, their staffs, and the staffs of multiple relevant congressional committees

- A series of seven formal public stakeholder meetings, beginning in Washington, D.C. and extending to Boston, Massachusetts; Salt Lake City, Utah; Des Moines, Iowa; Austin, Texas; Los Angeles, California; and Atlanta, Georgia
- Special dialogues with officials in Canada and Mexico to discuss cross-border integration and international collaboration, given the extensive electricity integration that exists between the United States and Canada and opportunities present to increase integration between the United States and Mexico
- Speeches and briefings to interested groups in Washington, D.C., and across the country by the Secretary of Energy, the Director of the President's Office of Science and Technology Policy, other White House officials, and various members of DOE leadership
- The creation of a public comments portal to allow interested stakeholders and the general public to provide comments on individual stakeholder meetings, as well as outside experts to submit studies, reports, and data sets related to topics within the scope of the QER 1.2.

8.3.1 Formal Public Stakeholder Meetings

Some of the most visible effort to engage stakeholders during the QER 1.2 process was the series of seven public meetings held around the country from February 2016 to May 2016. These meetings provided opportunities for the Administration to fully consider the unique challenges and opportunities facing each of the many geographically diverse segments of our Nation's electricity system. The regions selected for QER 1.2 stakeholder meetings were based on wholesale market footprints as a convenient approach to capturing the Nation's regional electricity diversity, which is also characterized by differing resource mixes, state policies, and a host of other factors.

The mixture of panel discussions and a public comment period framed multi-stakeholder discourse around deliberative analytical questions in QER 1.2 relating to the intersection of electricity and its role in promoting economic competitiveness, energy security, and environmental responsibility. The Administration sought public input on key questions relating to possible Federal actions that would address the challenges and take full advantage of the opportunities of this changing system to meet the Nation's objectives of reliable, affordable, and clean electricity.

Each meeting began with opening statements by the hosting Administration representatives, along with local, state, and national political leaders who participated at events in their parts of the country. Each meeting, with the exception of the kickoff meeting in Washington, D.C., had three panel discussions. The first two topics were the same for all regions (*Bulk Power Generation and Transmission Opportunities: How Can We Plan, Build, and Operate the Appropriate Amount for Future Needs?* and *Electricity Distribution and End-Use: How Do We Manage Challenges and Opportunities?*)—although content varied as there are significant regional differences. The third panel's topics were different for each session to highlight issues of regional importance, and these discussions are described in more detail below. Each meeting concluded with an "open microphone" segment, during which members of the general public could make statements for the QER 1.2 record and had the opportunity to offer prepared presentations, studies, reports, and more for review by EPSA analysts and inclusion in the QER Library.

Federal Register notices announcing each formal public stakeholder meeting were published; these notices also were made available via the DOE QER website (http://energy.gov/epsa/quadrennial-energy-review-qer). DOE publicized the meetings by sending advisories to local media; using social media; and emailing state, local, and tribal governments, as well as representatives of energy stakeholders—both in the region of each meeting and in Washington, D.C.

In the interests of transparency and open government, court reporters produced a transcript for each meeting, and EPSA produced a summary of each meeting's presentations and discussions. The transcripts and summaries, along with links to the live-streamed recordings and panelists' prepared remarks and presentations, are available on the QER website.

Following are details about the dates, topics, locations, and focus areas of the formal public stakeholder meetings organized by EPSA to inform QER 1.2 (Table 8-2).

Table 8-2. List of QER 1.2 Formal Public Stakeholder Meetings (with Topic, Location, Date, and Administration Officials)

Location	Topic (Third Panel)	Date	Administration Chair(s) and Local/State/Congressional Officials
Washington, D.C.	Not Applicable	2/4/16	Secretary of Energy Ernest Moniz; Assistant to the President for Science and Technology Dr. John Holdren; Deputy Assistant to the President for Energy and Climate Change Dan Utech; and Representative Earl Blumenauer (D-OR)
Boston, Massachusetts	Resource adequacy	4/15/16	Secretary of Energy Ernest Moniz; Assistant to the President for Science and Technology Dr. John Holdren; and Governor Charlie Baker
Salt Lake City, Utah	Cyber- and physical security and resilience	4/25/16	Deputy Assistant to the President for Energy and Climate Change Dan Utech; and Department of Agriculture Rural Utilities Service Deputy Administrator Joshua Cohen
Des Moines, Iowa	Transmission development	5/6/16	Secretary of Energy Ernest Moniz; Governor Terry Branstad; Lieutenant Governor Kim Reynolds; Mayor T.M. Franklin Cownie; and Department of Agriculture, Rural Development Rural Business-Cooperative Service Administrator Sam Rikkers
Austin, Texas	New technologies and actors in the grid edge space	5/9/16	Secretary of Energy Ernest Moniz; Department of Agriculture Deputy Under Secretary for Rural Development Lillian Salerno; and Mayor Steve Adler (Austin)
Los Angeles, California	Generating and delivering electricity to meet GHG targets	5/10/16	Deputy Secretary of Energy Elizabeth Sherwood-Randall; Department of Agriculture, Rural Development Rural Business-Cooperative Service Administrator Sam Rikkers; and Deputy Mayor for City Services Barbara Romero (Los Angeles)
Atlanta, Georgia	Financing new electricity infrastructure	5/24/16	Secretary of Energy Ernest Moniz; and Department of Agriculture, Rural Utilities Service Deputy Administrator Joshua Cohen

Dates, topics, locations, and focus areas for the formal QER 1.2 Stakeholder Meetings.

1. **Washington, D.C., Kickoff Meeting**
   February 4, 2016

   The Washington, D.C., public stakeholder meeting served as the formal kickoff meeting for QER 1.2, an integrated study of the U.S. electricity system from generation through end use. The meeting included two main panel discussions and a public comment period focused on the challenges and opportunities facing the electricity sector and its key role in promoting economic competitiveness, energy security, and environmental responsibility.

2. **Boston, Massachusetts**
   April 15, 2016

   The QER 1.2 public stakeholder meeting in Boston covered the footprint of the 21 states and the District of Columbia which are, all or in part, in the Regional Transmission Operator (RTO) PJM Interconnection, Independent System Operator (ISO)-New England, or New York ISO. The third panel for the Boston public stakeholder meeting covered "*Ensuring Resource Adequacy*," highlighting the proper design and operation of the eastern RTO/ISO markets, with Federal and state policies and consumer demand creating momentum for low-carbon options, as crucial.

3. **Salt Lake City, Utah**
   April 25, 2016

   The Salt Lake City meeting covered the footprint of 13 of the 14 states (excluding California) which are, all or in part, in the Western Interconnection, and are represented by the Western Electricity Coordinating Council. The third panel in the Salt Lake City public stakeholder meeting covered "*Cyber/Physical Security and Resilience.*"

4. **Des Moines, Iowa**
   May 6, 2016

   The Des Moines meeting covered the footprint of the 20 states which are, all or in part, in the Southwest Power Pool and the Midcontinent ISO. The third panel in the Des Moines public stakeholder meeting covered "*Transmission Development with an Evolving Generation Mix.*"

5. **Austin, Texas**
   May 9, 2016

   The Austin meeting covered the footprint of the state of Texas, grid operations, and the flow of energy—most of which is managed by the Electric Reliability Council of Texas. The third panel in the Austin public stakeholder meeting covered "*New Technologies and Actors in the Grid Edge Space.*"

6. **Los Angeles, California**
   May 10, 2016

   The Los Angeles meeting covered the footprint of the State of California, grid operations, and the flow of energy—most of which is managed by the California ISO. The third panel for the Los Angeles public stakeholder meeting covered "*Generating and Delivering Electricity in a High GHG-Reduction Environment.*"

7. **Atlanta, Georgia**
   May 24, 2016

   The Atlanta meeting covered the footprint of the 10 southeastern states that, all or in part, have bilateral wholesale electricity markets. The third panel for the Atlanta public stakeholder meeting covered "*Financing New Electricity Infrastructure*."

8.3.2 Comments Portal and QER Library

From the beginning of the QER 1.2 process, stakeholders and the general public were encouraged to offer suggestions, comments, insights, and criticisms on issues surrounding the electricity system. Public comments were collected through a web-based portal, which allowed stakeholders to share comments as well as studies, reports, data sets, and any additional materials from stakeholder organizations to help inform QER 1.2. All comments submitted to the portal will be made publically available at http://energy.gov/epsa/quadrennial-energy-review-stakeholder-engagement.

EPSA received 295 total comments—including 215 total attachments comprising detailed reports and studies on behalf of trade associations, utilities, and energy companies; state and local governments; nonprofit organizations; and other stakeholders (totaling over 2,600 pages). EPSA reviewed each of the comments received. Insights and recommendations extracted from these comments and materials have been included in QER 1.2. Stakeholder comments were grouped into multiple themes, namely issues with evolving generation mix; increased attention to cyber and physical security; reliability needs during transformation; problems with organized wholesale markets; evolving transmission planning and investment; activity at distribution and end-use sector; valuation and rate reform; business models; evolving state and Federal regulations; and the Federal role.

8.4 QER Interagency Engagement

As outlined by the QER Presidential Memorandum, the President identified more than 20 executive departments and agencies that play key roles in developing and implementing policies governing energy resources and consumption, as well as associated environmental impacts. The President directed the QER Secretariat (1) to develop a comprehensive and integrated review of energy policy, based on interagency dialogue and active engagement of external stakeholders, and (2) to make recommendations on what additional actions it believes would be appropriate. The findings and recommendations in QER 1.2 are based on Task Force deliberations, meetings with staff-level agency representatives and experts, and information provided to the Secretariat and the Task Force by external stakeholders.

Throughout the development of QER 1.2, the White House has convened regular interagency meetings and worked closely with the agencies' leadership and staff. Member agencies have collaborated to develop QER 1.2 by providing information on topics within their statutory and regulatory jurisdiction or areas of particular expertise related to energy infrastructure transmission, storage, and distribution. Agencies have delivered studies, data, and other information to be considered in policy analysis and modeling; reviewed analysis and findings; leveraged the work of other relevant Administration initiatives and led by the Office of Science and Technology Policy and the Domestic Policy Council, collaboratively developed policy recommendations. A series of roundtable discussions was held with representatives from key departments and agencies to ensure a transparent and inclusive process in the development of policy recommendations.

Interagency members also partnered with the Secretariat on the seven formal public stakeholder meetings and opened the events and set the focus for the expert panels that followed.

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A QER 1.2 Appendix A: Electricity System Overview

A.1. Elements of the Electricity System

The U.S. electric power system is an immensely complex system-of-systems, comprising generation, transmission, and distribution subsystems and myriad institutions involved in its planning, operation, and oversight (Figure A-1). End use and distributed energy resources (DERs) are also important parts of the electric power system.

A.1.1 Generation

Electricity generation accounts for the largest portion of U.S. primary energy use, using 80 percent of the Nation's domestically produced coal,[1] one-third of its natural gas, and nearly all of its nuclear and non-biomass renewable resource production. In 2014, 39 percent of the Nation's primary energy use was devoted to electricity generation, and electricity accounted for 18 percent of U.S. delivered energy.[2]

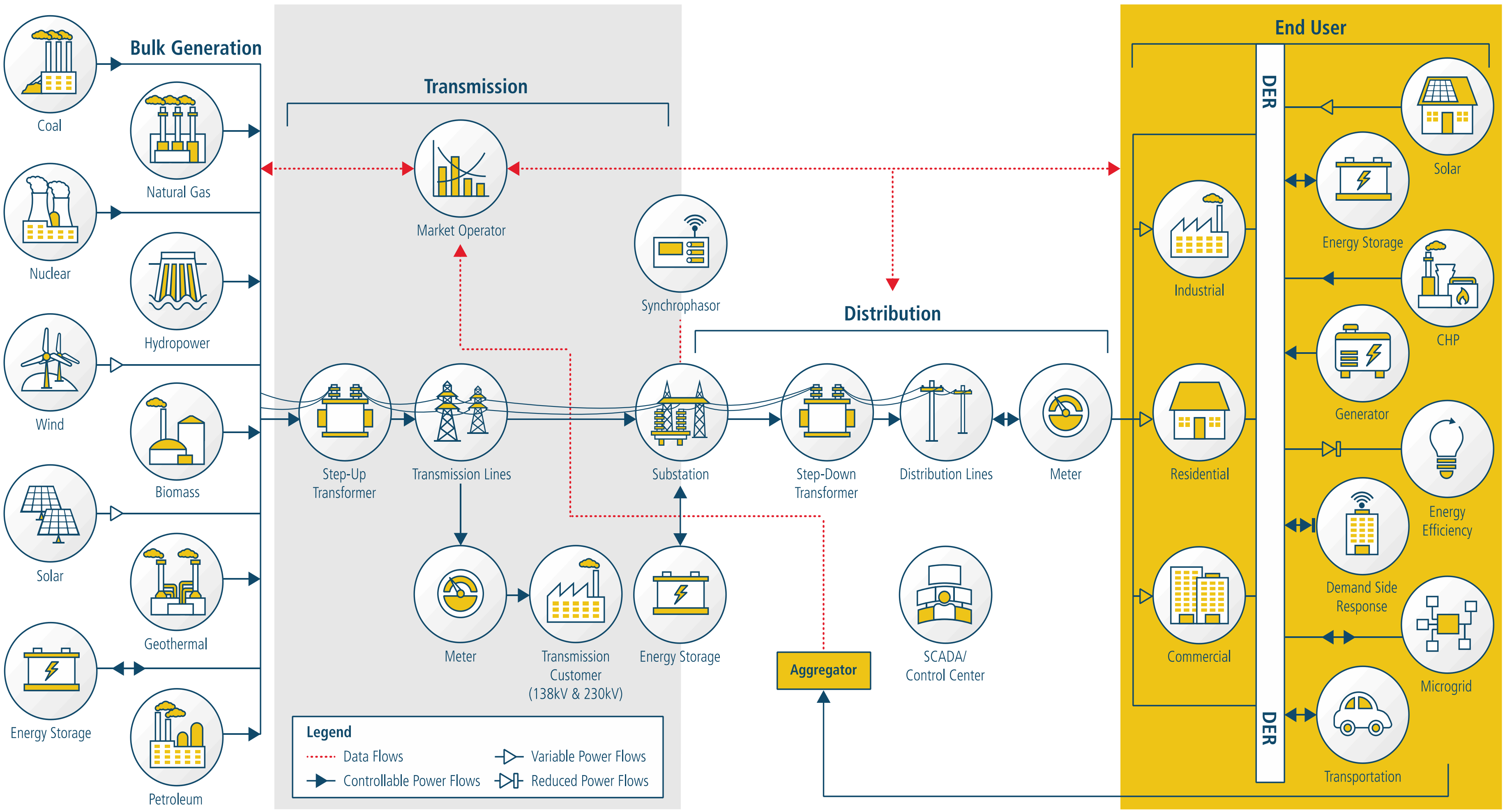
In 2014, there were over 6,500 operational power plants of at least 1 megawatt in the U.S. electric power system.[a, 3, 4] These power plants delivered nearly 3,764 billion kilowatt-hours (kWh) of power in 2014, supplying electricity to over 147 million residential, commercial, and industrial customers at an average price of $0.104/kWh for a total revenue from electricity sales of more than $393 billion.[5, 6, 7, 8]

The U.S. electricity generation portfolio is diverse and changes over time through the commercial market growth of specific generation technologies—often due to a confluence of policies, historic events, fuel cost, and technology advancement. Today, coal and natural gas each provide roughly one-third of total U.S. generation; nuclear provides 20 percent; hydroelectric and wind provide roughly 5 percent each; and other resources, including solar and biomass, contribute less than 2 percent each.[9] However, there are major generation mix differences between regions (Figure A-2**Error! Reference source not found.**).[10]

The availability of primary energy resources, like coal and natural gas, and renewable energy resources, like wind and solar, differs widely across the country (Figure A-3). This dispersed resource availability influences the regional generation mixes.

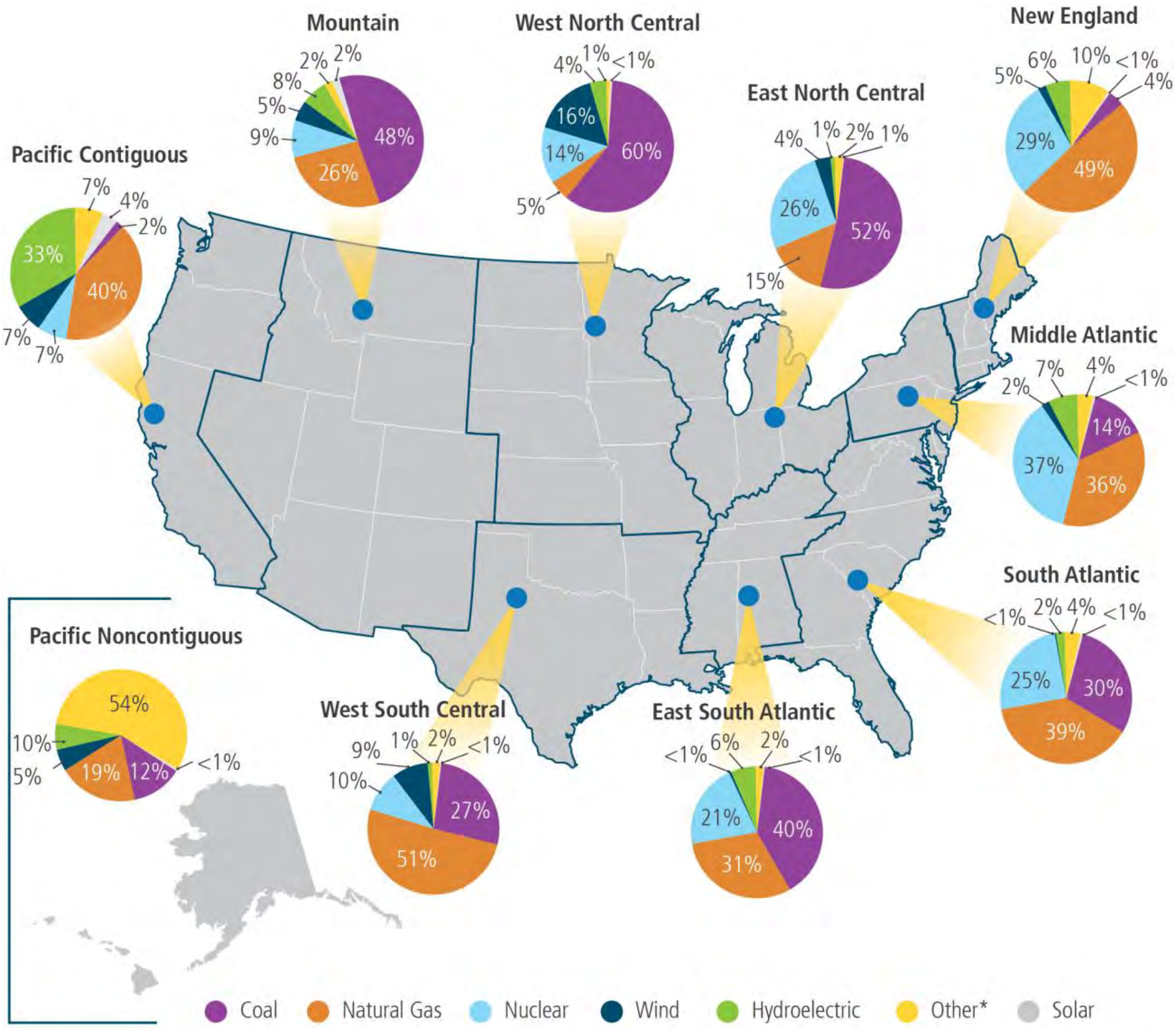
[a] A megawatt is a thousand kilowatts. A kilowatt is a unit of power output commonly used in the electricity industry. A kilowatt-hour (kWh) is a related unit of energy (the amount of power provided times the number of hours that it is provided). Electricity is usually billed by the kWh. An average American home uses roughly 11,000 kWh per year. Source: "How Much Electricity Does an American Home Use?" Energy Information Administration, Frequently Asked Questions, last updated October 18, 2016, https://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3.

Figure A-1. Schematic Representation of the U.S. Electric Power System



The electric power system comprises the following broad sets of systems: bulk generation, transmission, distribution, and end use (including DERs).

Figure A-2. Electric Power Regional Fuel Mixes, 2015[11, 12]

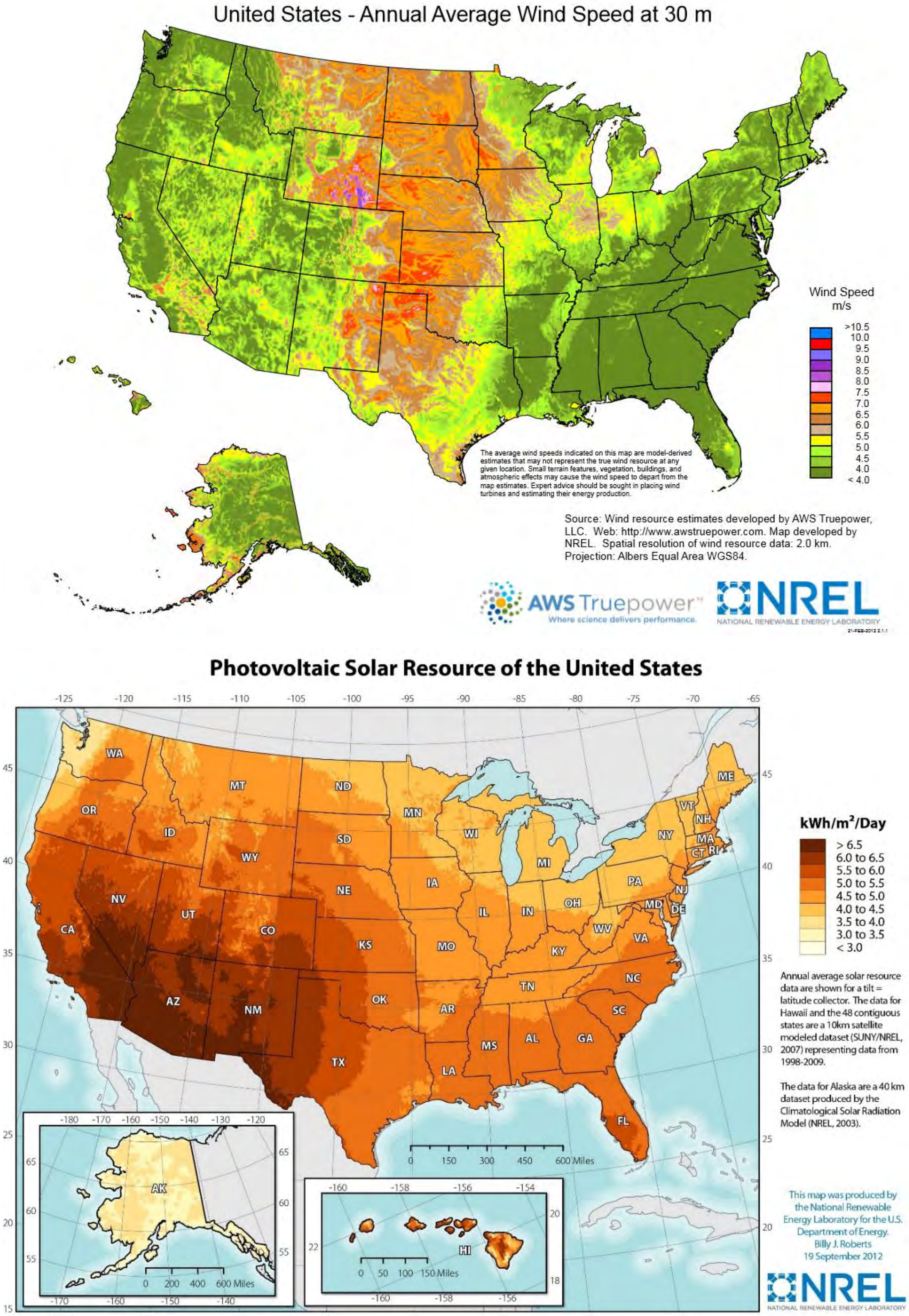


*Includes the following EIA fuel type designations: Distillate Petroleum, Geothermal, Biogenic Municipal Solid Waste and Landfill Gas, Other Gases, Other Renewables, Other (including nonbiogenic MSW), Petroleum Coke, Residual Petroleum, Waste Coal, Waste Oil, and Wood and Wood Waste.

Note: Sum of components may not add to 100% due to independent rounding.

The U.S. electricity industry relies on a diverse set of generation resources with strong regional variations. As of 2015, coal fuels the majority of electricity generation in the Mountain, West North Central, East North Central, and East South Central regions. Coal is also a significant resource for the South Atlantic and West South Central regions, though both have sizable natural gas generation as well, and the South Atlantic region includes substantial shares of nuclear. The Pacific Contiguous and New England regions are predominately natural gas, with significant contributions of hydroelectric and nuclear, respectively. The Middle Atlantic is the only region that is predominately nuclear, and the Pacific Noncontiguous region is the only region in which fuel oil represents more than a few percentage points of total generation, where it constitutes nearly half of all generation.

Figure A-3. Wind and Solar Energy Resource Maps for the United States[13, 14]



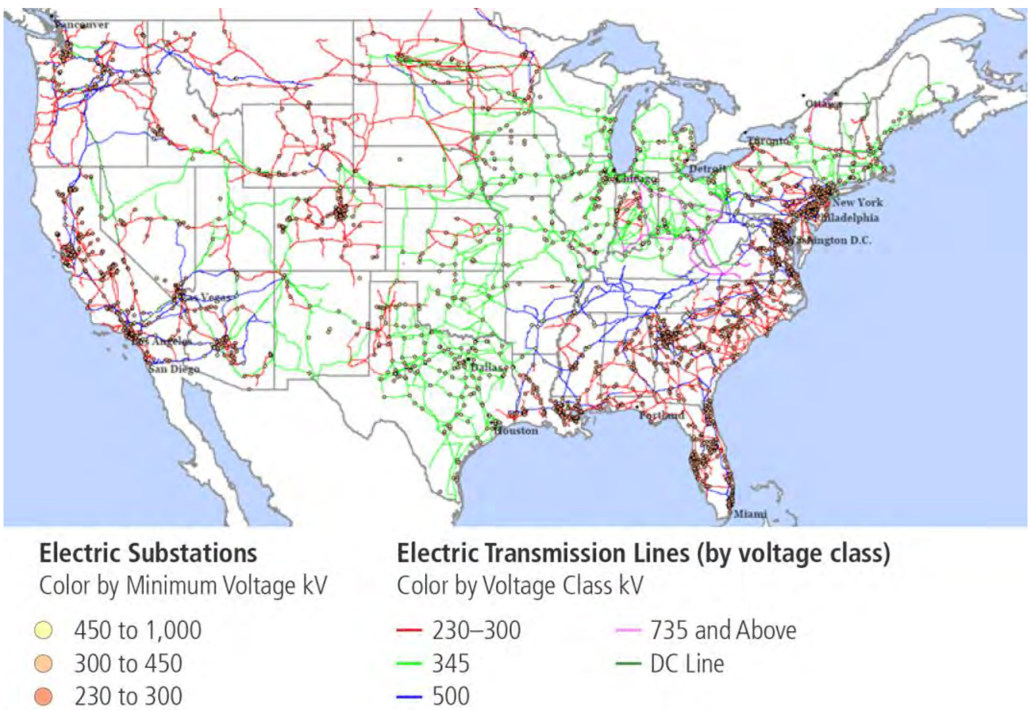
Energy resource availability varies widely across the United States. Wind and solar energy resources are concentrated in the Midwest and Southwest regions of the United States.

A.1.2 Transmission

The U.S. transmission network includes the power lines that link electric power generators to each other and to local electric companies. The transmission network in the 48 contiguous states is composed of approximately 697,000 circuit-miles[b] of power lines and 21,500 substations operating at voltages of 100 kilovolts (kV)[c] and above.[15] Of this, 240,000 circuit-miles are considered high voltage, operating at or above 230 kV (Figure A-4**Error! Reference source not found.**).[16] A substation is a critical node within the electric power system and is composed of transformers, circuit breakers, and other control equipment. Distribution substations are located at the intersection of the bulk electric system and local distribution systems.

The vast majority of transmission lines operate with alternating current (AC). With commonly used technology, system operators cannot specifically control the flow of electricity over the AC grid; electricity flows from generation to demand through many paths simultaneously, following the path of least electrical resistance. A limited number of transmission lines are operated using direct current (DC). Unlike AC transmission lines, the power flows on DC lines are controllable. However, their physical characteristics make them cost effective only for special purposes, such as moving large amounts of power over very long distances.[17]

Figure A-4. High-Voltage Transmission Network and Substations of the 48 Contiguous States, 2015[18]



The transmission network comprises approximately 697,000 circuit-miles—of which roughly 240,000 miles operate at or above 230 kV—and 21,500 substations operating at voltages of 100 kV and above. [19, 20, 21]

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[b] A circuit-mile is 1 mile of one circuit of transmission line. Two individual 20-mile lines would be equivalent to 40 circuit-miles. One 20-mile double-circuit section would also be equivalent to 40 circuit-miles.

[c] A kilovolt (kV) is a commonly used unit of electrical "force" in the electricity industry. Electricity at higher voltages moves with less loss; however, system components able to manage high voltage are costly, and high voltages can be dangerous. Lower voltage is used in distribution systems to manage costs on system equipment and for safety.

Electricity moved through transmission and distribution systems faces electrical resistance and other conversion losses. Losses from resistance and conversion amount to 5 to 6 percent of the total electricity that enters the system at the power plant.[22]

Each transmission line has a physical limit to the amount of power that can be moved at any time, which depends on the conditions of the power system. Within one market or utility control area, physical limits of system assets are the primary drivers of power price differences in different parts of the system.

A.1.3 Distribution System

The role of the large generators and transmission lines that comprise the bulk electric system is to reliably provide sufficient power to distribution substations. In turn, the distribution system is responsible for delivering power when and where customers need it while meeting minimum standards for reliability and power quality.[23] Power quality refers to the absence of perturbations in the voltage and flow of electricity that could damage end-use equipment or reduce the quality of end-use services.[24]

Before delivery to a customer, electric power travels over the high-voltage transmission network (at hundreds of kilovolts) to a distribution substation where a transformer reduces the voltage before the electricity moves along the distribution system (at tens of kilovolts). Several primary distribution feeder circuits, connected by an array of switches at the distribution bus, emanate from the substation and pass through one or more additional transformers before reaching the secondary circuit that ultimately serves the customer. One or more additional transformers reduce the voltage further to an appropriate level before arriving at the end-use customer's meter.[d, 25]

An emerging role of the distribution system is to host a wide array of distributed energy generation, storage, and demand-management technologies. Though some distributed energy technologies—like campus-sized combined heat and power—have existed for decades, rapid cost declines in solar, energy storage, and power electronic technologies, coupled with supportive policies, have led to a rapid proliferation of new devices and, at times, new challenges and opportunities for the planning and operation of distribution systems.

A.1.4 Distributed Energy Resources (DERs)

DERs constitute a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid. Though definitions of DERs vary widely, the term is used in the Quadrennial Energy Review (QER) to refer to technologies including distributed generation, distributed storage, and demand-side management resources, including energy efficiency. Given the multiple definitions and understandings of the term DER, the QER will use DER to refer to the full range of these technologies and will delineate specific technologies where only some are relevant. Current and projected market penetration of distributed generation is shown in Table A-1.

DER technologies can be located on a utility's distribution system or at the premises of an end-use customer. They differ with respect to several attributes, though a key differentiator is their level of controllability from a grid management perspective. Certain DERs, such as energy efficiency or rooftop solar photovoltaic, impact total load but may not be directly controlled by grid operators. Other DERs, such as demand response or controllable distributed energy storage, can be more directly managed and called upon by grid operators when needed.

[d] Most residential and commercial customers in the United States receive two 120-volt (V) connections. Most household plugs provide 120 V, while large appliances like dryers and ovens often combine the two 120-V connections into a single 240-V supply.

Table A-1. Current and Projected Distributed Generation Market Penetration, 2015 and 2040[26]

Resource	Total Generation (GWh)		% of Total Utility Generation	
	2015	2040	2015	2040
Combined Heat and Power (CHP)	166,946	246,896	4.2%	5.2%
Rooftop Solar PV	13,453	64,485	0.3%	1.4%
Distributed Wind	637	1,643	0.0%	0.0%
Other DG	4,298	4,298	0.1%	0.1%
Total Distributed Generation	185,334	317,323	4.7%	6.7%
Total Utility-Scale Generation	**3,947,520**	**4,745,441**		

Other distributed generation includes small-scale hydropower; biomass combustion or co-firing in combustion systems; solid waste incineration or waste-to-energy; and fuel cells fired by natural gas, biogas, or biomass. Backup generators (for emergency power) are not included here because generation data are limited, and these generators are not used in normal grid operation. Acronyms: distributed generation (DG); gigawatt-hours (GWh); photovoltaic (PV).

A.1.5 End Use

Electricity end-use infrastructure includes physical components that use, require, or convert electricity to provide products or services to consumers. Since the first time the electric light bulb lit up New York City, nearly all parts of the United States have gained access to electricity.[e] In that time, the proliferation of novel and unanticipated uses of electricity has placed electricity at the center of everyday life and established it as the engine for the modern economy.

Today, the residential and commercial sectors each consume about the same share of total electricity—38 percent and 36 percent, respectively—with the industrial sector accounting for an additional 26 percent of electricity demand.[27, 28] Cumulatively, electricity sales to end-use customers in the United States generated approximately $393 billion in 2014.[29, 30] Moving forward, new technologies, from automated thermostats to electric vehicles, are changing the way consumers use electricity.

Electricity is a high-quality energy source available at a relatively low price. However, many low-income Americans struggle to afford their monthly electricity bills.[31] Nationally, average monthly residential bills in 2015 were $114.[32]

A.2. Brief History of the U.S. Electricity Industry

The U.S. electricity system represents one of the greatest technological achievements in the modern era. The complexity of the modern electricity industry is the result of a complicated history.

A.2.1 The Beginning of the Electricity Industry

The U.S. electricity industry began in 1882 when Thomas Edison developed the first electricity distribution system. Edison designed Pearl Street Station to produce and distribute electricity to multiple customers in the New York Financial District and to sell lighting services provided by his newly invented light bulbs.[33]

[e] There are thousands of households in Indian lands that still do not have access to electricity.

Early utilities distributed power over low-voltage DC lines. These lines could not move electricity far from where it was produced, which limited utility service to areas only about a mile from the generator. Multiple generators and dedicated distribution lines were required to serve a larger area. The limited reach of distribution lines and the lack of regulation of utilities resulted in the co-location of multiple independent utilities and competition for customers where multiple distribution lines overlapped.[34, 35]

In 1896, AC generation emerged as a competitor to DC when Westinghouse Electric developed a hydropower generation station at Niagara Falls, New York, and transmitted power 20 miles to Buffalo, New York.[36] At the voltage levels used at that time, AC has better electrical characteristics for moving power over long distances. This technological development—and related business models—allowed a single utility to broaden the geographic extent of its customers and sources of revenue. A wave of consolidation followed, where small, isolated DC systems were converted to AC and interconnected with larger systems. Interconnecting with other systems and serving more customers allowed operators to take advantage of the diversity of customer demand, deliver better economies of scale, and provide lower prices than competitors.[37]

A move toward today's system of regulatory oversight occurred around the turn of the century. With the industry consolidation of the late 1890s came public concern over lack of competition and the potential for large utilities to exert a monopoly power over prices.[38] In 1898, a prominent electricity industry leader and Thomas Edison's former chief financial strategist, Samuel Insull, called for utility regulation that granted exclusive franchises in exchange for regulated rates and profits in order to create a stable financial environment that would foster increased investments and electricity access.[39] Insull claimed that such regulation was needed because utilities are natural monopolies, meaning that a single firm can deliver a service at a lower total cost than multiple firms through economies of scale and avoidance of wasteful duplication (e.g., multiple distribution substations and circuits belonging to different companies serving a single area).

In 1907, Wisconsin became the first state to regulate electric utilities, and by 1914, 43 states had followed.[40, 41] The general form of utility regulation that was established by the Wisconsin legislature in 1907 endures today and is called the "state regulatory compact."

This compact allowed electric utilities to operate as distribution monopolies with the sole right to provide retail service to all customers within a given franchise area—as well as an obligation to do so. Those monopolies were allowed an opportunity to earn a fair rate of return on their investments. Some municipal governments across the country created their own utilities, owned and governed by the local government, as an alternative to investor-owned, regulated utilities.[42, f]

[f] Since municipal utilities were first formed, they have been owned by several types of political subdivisions. These include states, public utility districts, and irrigation districts. The term "public power" is often used to refer to electricity utilities operated by any of these political subdivisions.

The State Regulatory Compact

The "state regulatory compact" evolved as a concept "to characterize the set of mutual rights, obligations, and benefits that exist between the utility and society."[43] It is not a binding agreement. Under this "compact," a utility typically is given exclusive access to a designated—or franchised—service territory and is allowed to recover its prudent costs (as determined by the regulator) plus a reasonable rate of return on its investments. In return, the utility must fulfill its service obligation of providing universal access within its territory. The "regulatory compact" applies to for-profit, monopoly investor-owned utilities that are regulated by the government. The compact is less relevant to public power and cooperative utilities, which are nonprofit entities governed by a locally elected or appointed governing body and are assumed to inherently have their customers' best interests in mind. Regulators strive to set rates such that the utility has the opportunity to be fully compensated for fulfilling its service obligation. While not technically part of the "compact," customers also have a role to play in this arrangement: they give up their freedom of choice over service providers and agree to pay a rate that, at times, may be higher than the market rate in exchange for government protection from monopoly pricing. In effect, utilities have the opportunity to recover their costs, and, if successful, their investors are provided a level of earnings; customers are provided non-discriminatory, affordable service; and the regulator ensures that rates are adequately set such that the aforementioned benefits materialize.

In the early 1900s, states regulated nearly all of the activities of electric utilities—generation, transmission, and distribution.[44] However, a 1927 Supreme Court case[45] held that state regulation of wholesale power sales by a utility in one state to a utility in a neighboring state was precluded by the commerce clause of the U.S. Constitution.[46] These transactions were left unregulated as Congress had the authority to regulate, but no Federal agency existed to do so.[47]

The 1935 Federal Power Act (FPA) addressed the regulatory gap by providing the Federal Power Commission (FPC, eventually renamed the Federal Energy Regulatory Commission, or FERC)[g] with authority to regulate "the transmission of electric energy in interstate commerce" and "the sale of electric energy at wholesale in interstate commerce."[48, 49] The FPA left regulation of generation, distribution, and intrastate commerce to states and localities.[50] Federal regulation was to extend "only to those matters which are not subject to regulation by the States."[51] FERC was given jurisdiction over all facilities used for the transmission or wholesale trade of electricity in interstate commerce and was charged with ensuring that corresponding rates are "just and reasonable, and not unduly discriminatory or preferential."[52, 53]

A.2.2 Federal Investments in Rural Electrification

Urban areas were the first areas to attract utility investment. The higher density of potential customers in urban areas made these areas more cost effective to serve. By the 1930s, most urban areas were electrified, while sparsely populated rural areas generally lagged far behind. The Great Depression and widespread floods and drought in the Great Plains during the 1930s led to a wave of significant Federal initiatives to develop the power potential of the Nation's water resources.

One example of Federal efforts to capture the benefits of the Nation's water resources is the Tennessee Valley Authority (TVA). TVA was created in 1933 as a Federally owned corporation to provide economic development through provision of electricity, flood control, and other programs to the rural Tennessee Valley area. To this day, TVA maintains a portfolio of generation and transmission assets to sell wholesale electricity to public power and cooperatives within its territory. Federal law grants first preference for this electricity to public power and cooperative utilities.

Congress passed the Rural Electrification Act in 1936, which encouraged electrification of areas unserved by investor-owned utilities (IOUs) and public power utilities. The act authorized rural electric cooperatives

[g] The Federal Power Commission was created in 1920 by the Federal Water Power Act to encourage the development of hydroelectric generation facilities.

to receive Federal financing support and preferential sales from Federally owned generation. The Bonneville Power Administration was created in 1937 to deliver and sell electric power from Federally owned dams in the Pacific Northwest.[54] Increased Federal investment in hydropower followed through the 1940s, and by the 1960s, rural electrification was largely complete.[55]

Federally Owned Utilities

There are five Federal electric utilities: Tennessee Valley Authority (TVA), Bonneville Power Administration (BPA), Southeastern Power Administration (SEPA), Southwestern Power Administration (SWPA), and Western Area Power Administration (WAPA). TVA is an independent government corporation, while BPA, SEPA, SWPA, and WAPA are separate and distinct entities within the Department of Energy. Starting with BPA in 1937, followed by SEPA, SWPA, and WAPA, Congress established the Power Marketing Administrations (PMAs) to distribute and sell electricity from a network of more than 130 Federally built hydroelectric dams.

The PMAs don't own or manage the power they sell but, in many cases, maintain the transmission infrastructure to distribute the low-cost electricity to public power and rural cooperative utilities, in addition to some direct sales to large industrial customers. The electricity-generating facilities are primarily owned and operated by the Department of the Interior's Bureau of Reclamation, the Army Corps of Engineers, and the International Boundary and Water Commission.

BPA, WAPA, and SWPA collectively own and operate 33,700 miles of transmission lines, which are integrally linked with the transmission and distribution systems of utilities in 20 states. Millions of consumers get electricity from the PMAs (usually indirectly, via their local utility), but a much larger number of consumers benefit from—and have a stake in—the continued efficient, effective operation of the PMAs and the transmission infrastructure they are building and maintaining.

TVA is a corporate agency of the United States that provides electricity for business customers and local power distributors, serving 9 million people in parts of seven southeastern states. TVA receives no taxpayer funding, deriving virtually all of its revenues from sales of electricity. In addition to operating and investing its revenues in its electric system, TVA provides flood control, navigation, and land management for the Tennessee River system and assists local power companies and state and local governments with economic development and job creation.

A.2.3 Electricity Industry Restructuring and Markets

As early as the 1920s, utilities sought operational efficiencies by coordinating generation dispatch and transmission planning across multiple utility territories. Coordination through cooperative power pools provided economies of scale and scope that ultimately lowered costs for all participant utilities. The principles of coordination pioneered in power pools later became the basis for the centrally organized electricity markets that exist today.[56]

Over time, economists and industry observers came to believe that the natural monopoly status that was the basis of so much of electricity industry regulation no longer applied to generation and instead only applied to the "wires" part of the system. While it would be economically wasteful for multiple companies to install overlapping and competing distribution and transmission lines, the generation and sale of electricity to retail customers could be organized as competitive activities.[57] To encourage fair and open competition, several states eventually restructured individual IOUs into separate companies that invested in either regulated or competitive parts of the industry.

Restructuring actions vary by region and by state, but they are typically characterized by the "unbundling" of ownership and regulation of electricity generation, transmission, distribution, and sales, with large variations in how restructuring is implemented across regions and states.

Congress took an early step toward reintroducing market competition in the generation sector in 1978 when it enacted the Public Utilities Regulatory Policies Act (PURPA).[58] PURPA required utilities to purchase power from qualifying non-utility generators at the utility's avoided cost. This led to a wave of investment in generation by non-utility companies.

A major step toward creating electric markets was Congress' enactment of the Energy Policy Act of 1992 (EPAct 1992), which provided FERC with limited authority to order transmission access for wholesale buyers in procuring wholesale electric supplies.[59, 60, 61] Subsequent FERC actions, including Order No. 888 and Order No. 889, created greater transmission access and facilitated the creation of competitive wholesale electricity markets. These FERC orders increased access to electricity supplies from other utilities for wholesale buyers, including public power and rural cooperative utilities.

Also in the 1990s, several states made regulatory changes introducing retail electric choice programs to allow some customers to choose an electricity provider other than their local utility, and to have electricity delivered over the wires of their local utility.[62] States that allow customer choice are sometimes called "deregulated states," a misnomer, as retail electricity providers and other parts of the industry remain highly regulated. By 1996, at least 41 states, including California, New York, and Texas, had or were considering ending utility monopolies and providing electricity service through retail competition.[63] Some states, notably in the Southeast and in western states besides California, did not embrace this wave of restructuring. In 2000 and 2001, California and the Pacific Northwest experienced severe electricity shortages and price spikes. This California electricity crisis left many states that had not yet implemented restructuring wary of pursuing such reforms. Today, 15 states allow retail electric choice for some or all customers, while eight states have suspended it, including California, which suspended retail choice for residential customers after the energy crisis.[64]

The net result of these changes to jurisdictions, industry structure, and competitive markets is that the United States today has a patchwork of mechanisms governing the electricity industry and a diverse set of industry participants. Regulation of the industry continues to evolve as new technologies, policies, and business realities emerge.

A.3. Laws and Jurisdictions

Government oversight and regulation of the electricity industry centers on the concurrent needs to

- Ensure that safe and adequate electricity service is provided at just and reasonable rates
- Protect the public interest
- Enable the financial health of the system, such as ensuring that service providers can attract the investments needed to continue providing this essential public service
- Play a beneficial role in diminishing the impact of negative externalities, such as ensuring that industry activities are not inadvertently causing hardship to neighboring communities or the environment.

A.3.1 Governmental Actors

The responsibility for regulating and overseeing the numerous actors that encompass the electricity industry and the activities they carry out is vested in multiple government officials. These authorities span Federal, state, local, and tribal governments. The jurisdictional relationship between the actors is shown in Figure A-5 and is explained further below.

Figure A-5. Broad Overview of Jurisdictional Roles in the Electricity Industry[65]

Jurisdictional responsibility of the electricity industry is divided between Federal, state, local, and tribal jurisdictions. Several issues, such as generation siting, transmission siting, and environmental planning, span all of the four jurisdictions. Federal and state jurisdictions overlap in planning, resource adequacy, and mergers and acquisitions for regulated utilities. Other areas, such as interstate transmission commerce and retail sale to end users, are regulated by the Federal Government (FERC) or the states (public utility commissions), respectively. Acronyms: Department of Agriculture (USDA); Department of Energy (DOE); Department of the Interior (DOI); Department of Justice (DOJ); Environmental Protection Agency (EPA); Federal Trade Commission (FTC); independent system operator (ISO); North American Electric Reliability Corporation (NERC); Nuclear Regulatory Commission (NRC); Occupational Safety and Health Administration (OSHA); public utility commission (PUC); regional transmission organization (RTO); Securities and Exchange Commission (SEC).

A.3.2 Federal Actors

At the Federal level, FERC carries out the vast majority of the economic Federal regulatory responsibilities pertaining to the electricity industry, primarily regulating transmission and wholesale sales in interstate commerce. In addition, other Federal authorities are involved with various aspects of regulation or oversight; their responsibilities are wide ranging and relate to environmental protection, land use, anti-trust protection, and transmission siting.

Federal Ratemaking

The Federal Energy Regulatory Commission (FERC) is the Federal Government agency responsible for overseeing rates for wholesale sales of electricity and transmission in interstate commerce. Sections 205 and 206 of the Federal Power Act (FPA) require FERC to assure that the rates charged for transmission and wholesale sales are "just and reasonable" and do not unduly discriminate against any customers or provide preferential treatment. Initially, all FERC rate regulation was based on the cost of service, but that policy has evolved. FERC continues to employ the cost-of-service approach for transmission service. For wholesale power sales, the primary means for setting "just and reasonable" wholesale electricity rates are through competitive mechanisms, subject to market rules to address market power.

A.3.3 State, Local, and Tribal Actors

At the state level, the electricity industry is regulated by state public utility commissions (PUCs), state environmental agencies, and other parts of state government, such as governors, legislatures, and state energy offices.

State governors and legislatures establish laws or standards that impact the electricity industry, such as Renewable Portfolio Standards, and state environmental agencies implement state and some Federal environmental laws and regulations and thus have jurisdiction on electricity.

PUCs in the states, territories, and the District of Columbia regulate IOUs. State laws in a handful of states also give PUCs jurisdiction over public power and cooperatives.[66] PUCs regulate all matters of IOU distribution (rates, capital expenditures, cyber security, reliability, demand-side resources, and the wholesale purchase process) and usually site transmission and generation projects; they also oversee generation choices in non–regional transmission organization (RTO)/independent system operator (ISO) states and oversee retail competition in those states that allow it.

State Retail Rate Setting

State public utility commissions (PUCs) review and set retail rates for investor-owned utilities (IOUs). In states with retail competition, rates only include the costs of the distribution of electricity, while prices for electricity generation are determined competitively. In states that have not restructured their utility industry, retail rates set by PUCs include the recovery of generation, transmission, and distribution costs that utilities incurred to serve their ratepayers.

The underlying mandate of the PUC rate-setting process is to provide affordable and reliable electricity to consumers while ensuring that IOUs are given the opportunity to recoup their costs and earn a reasonable return on their investment. Under cost-of-service regulation, PUCs calculate utility revenue requirements as the sum of (1) rate base times allowed rate of return plus (2) utility operating expenses. The rate base consists of the depreciated cost of a utility's assets. Based on the revenue requirement, rates for each consumer class are determined.[h]

A few states also grant PUCs the authority to regulate rates for public power utilities, but in most cases rates for public power utilities are set by the utility's governing body, for example, a city council or other local authority. Rates for members of rural cooperatives are set by the cooperative's governing board.[67]

A.3.4 Federal and State Jurisdictional Responsibilities

The current jurisdictional division of regulatory authority in the electricity sector between the Federal Government and the states, codified in the FPA and interpreted by subsequent Supreme Court and lower court decisions, is the result of the evolution of a regulatory scheme that was originally governed predominantly by state and local agencies. The FPA established an affirmative grant of authority to the Federal Government to regulate wholesale sales and transmissions of electricity in interstate commerce, but the FPA also attempts to draw a "bright line" where that exclusive authority ends and the state's authority to regulate other matters (principally facilities used in the generation and distribution of electric power, as well as retail sales of electricity) begins.

The "bright line" in the FPA uses factors such as transaction and customer type (wholesale v. retail), facility type (generation v. transmission v. distribution), geography (interstate commerce v. intrastate commerce), and regulatory action (e.g., rate regulation v. facility permitting) to divide exclusive regulatory responsibilities between Federal and state regulators. Congress has chosen different approaches for defining Federal regulatory responsibilities and the role of the states in other energy and energy-related statutes, however. The principal differences in approach include the following: (1) while the FPA contemplates exclusive authority for each regulator, with implicit opportunities for cooperative federalism, other Federal statutes explicitly provide for shared authority (sometimes called "cooperative federalism"); and (2) while the FPA provides the Federal Government with limited authority over energy facility siting or generation facilities in general (FERC has jurisdiction over siting hydro), leaving such matters mostly to the states, other Federal statutes, such as the Natural Gas Act, provide for Federal authority over facility siting.[68]

However, new and emerging technologies that are gaining an increasing presence throughout the electricity system today have significantly different operational characteristics and attributes than those that existed when the FPA and its jurisdictional "bright line" were written, and different characteristics than those that existed as that jurisdictional line developed over the ensuing decades. For distributed generation, no clear delineation exists between wholesale and retail jurisdiction as power flows from generation through delivery to ultimate consumption. Instead, new DERs (including energy storage) can be interconnected to either the FERC-jurisdictional, high-voltage transmission grid or the state-

[h] A more detailed discussion on different charges for consumers is included in Chapter II (The Electricity Sector: Maximizing Economic Value and Consumer Equity).

jurisdictional, low-voltage local distribution system (or behind the customer's meter). In addition, these resources, along with the other new and advanced technologies noted above, can provide (or enable demand response that can provide) several kinds of wholesale and retail grid services, with benefits that extend across the traditional generation, transmission, and distribution classifications.

Tensions between Federal and state regulatory jurisdiction over the electricity system have played out in the courts recently. From the October Term of 2014 to the October Term of 2015, the Supreme Court heard three cases involving FERC jurisdictional issues, an atypical number for a single year. The Court's decisions to hear these cases reflect, in part, the growing complexity of regulating the electricity industry, but also point to uncertainty about statutes that regulate services that are increasingly converging with the electricity industry, like natural gas and telecommunications. Two of these cases, the recent *FERC v. Electric Power Supply Association*[69] and *Hughes v. Talen Energy Marketing*[70] decisions, provide examples of the courts applying the FPA's jurisdictional division to new sets of technology and market challenges. In both of those cases, the Court decided generally in favor of the broader view of the Federal role. *FERC v. Electric Power Supply Association*—relating to FERC's Order No. 745—confirmed FERC's authority under the FPA to determine compensation for demand response that is bid into the organized wholesale market.

A.3.5 Major Federal Laws Pertaining to the Electricity Industry

While the FPA is the enabling legislation providing the FPC (and now FERC) its authority over portions of the electricity industry, additional laws and rules have further defined the legal landscape governing the electricity system. Overall, these laws and regulations can be broken into two separate categories: electricity industry–related and environmental.

The Federal Water Power Act, enacted in 1920, created the FPC (now FERC) to encourage the development of hydroelectric generation facilities by non-Federal entities. The 1935 FPA expanded the Commission's regulatory jurisdiction to include rates, terms, and conditions of service for interstate electricity transmission and wholesale electricity sales, but left regulation of generation, distribution, and intrastate commerce to state and local governments.[71] This set up the "bright line"[i] between Federal authority over wholesale rates and state and local authority over retail rates.

The utility industry of the early 1900s often relied on holding companies—a financial structure where a parent company would hold the financial stocks and bonds of subsidiary utilities—to improve financial performance and seek economies of scale. Though these companies provided cost savings that contributed to the growth of the utility industry, their complex financial structures enabled companies to subsidize their unregulated business activities with earnings from regulated activities. In response, Congress passed the Public Utility Holding Company Act in 1935, which reduced the role of holding companies in the industry and allowed closer regulatory scrutiny of utilities.[72]

PURPA (1978), passed as part of the National Energy Act, was one of the major reformations of the governance of the electricity industry. Utilities were required to purchase power from qualifying facilities at the utilities' incremental cost of producing or purchasing alternative electricity, which is now known as "avoided cost."[73] The right to sell the power at avoided cost, combined with the exemption from several state and Federal regulations, "created a new and rapidly expanding nonutility generation sector of the electric power industry."[74] Qualifying facilities fall into two categories: (1) cogeneration facilities without any size limitations and (2) small power production facilities, which use biomass, waste, or renewable resources and which have a generating capacity of no more than 80 megawatts. PURPA also required states (and utilities not regulated by states, such as public power and rural cooperative utilities) to conduct proceedings to consider charging cost-of-service rates for different customer classes; eliminating declining

[i] The term "bright line" was coined by the Supreme Court in *Federal Power Commission v. Southern California Edison Co*. in 1964.

block pricing;[j] using time-of-day, seasonal, or interruptible rates; and implementing other retail utility policies.

The Energy Policy Act of 1992 (EPAct 1992) implements many of the provisions of the National Energy Strategy proposed by DOE in February 1991.[75] EPAct 1992 authorized FERC to order transmission-owning utilities to provide transmission services to third parties on a case-by-case basis and adopted reforms to the Public Utility Holding Company Act of 1935, both of which supported increased competition in wholesale electricity markets. EPAct 1992 also included a wide variety of energy efficiency measures, such as requiring states to establish minimum commercial building energy codes and consider voluntary minimum residential codes and equipment standards for commercial heating and air-conditioning equipment, electric motors, and lamps. As a result of the incentives offered through EPAct 1992, several Native Nations developed alternative energy projects on their lands. The Renewable Electricity Production Tax Credit for wind, biomass, landfill gas, and other renewable sources was also first passed in EPAct 1992, and has been renewed several times since then.[76] As of May 2016, the Production Tax Credit provided an inflation-adjusted tax credit worth $0.023/kWh to qualifying electricity production from wind, closed-loop biomass, and geothermal, as well as a $0.012/kWh credit for open-loop biomass, landfill gas, municipal solid waste, qualified hydro, and marine and hydrokinetic.[77]

The Energy Policy Act of 2005 (EPAct 2005) addressed several major areas of the electricity industry.[78] EPAct 2005 pared back the must-purchase clause contained in PURPA by giving FERC the authority to allow utilities in regions with competition not to use the avoided-cost principle. The legislation also gave FERC responsibility for mandatory reliability standards and allowed the agency to certify an electric reliability organization to develop and enforce those standards. The North American Electric Reliability Corporation (NERC) is the designated electric reliability organization for North America and oversees eight regional reliability entities in the United States, Canada, and Baja California (Mexico). NERC is a not-for-profit corporation that, through a stakeholder process, develops and enforces mandatory electric reliability standards under FERC oversight in the United States.

EPAct 2005 also tasked DOE with issuing periodic studies of transmission congestion, and following the appropriate evaluation of transmission congestion and alternatives, authorizes DOE to designate National Interest Electric Transmission Corridors where there are electricity transmission capacity constraints or congestion. For projects located in these corridors, FERC has “backstop authority” to authorize transmission siting.[79] FERC was also given responsibility to provide rate incentives to promote transmission investment.

EPAct 2005 also increased the Investment Tax Credit, which has been renewed several times, including in the Omnibus Appropriations Act of 2015.[80] Currently, the Investment Tax Credit is 30 percent for solar, fuel cells, and small wind and 10 percent for geothermal, microturbines, and combined heat and power.[81] Additionally, EPAct 2005 provided grants for nuclear energy research and development and also implemented a $0.018/kWh production credit for modern nuclear energy plants (1) whose design was approved by the Nuclear Regulatory Commission after December 1, 1993, (2) that started construction by January 2014, and (3) that are placed in commercial operation by 2021. EPAct 2005 also created the Title XVII Loan Program, which allows DOE to provide “guarantee loans that support early commercial use of advanced technologies, if there is reasonable prospect of repayment by the borrower.”[82]

Other key laws and orders in the electricity industry are included in Table A-2, and key electricity industry-related environmental laws and regulations are included in Table A-3.

[j] Effectively a bulk-purchase discount for large electricity consumers, making marginal increments of electricity cheaper as consumption rises.

Table A-2. Additional Key Electricity Industry Laws and Orders

Name	Year	Major Provisions
Atomic Energy Act	1954	• Established Federal regulatory authority over civilian uses of nuclear materials and facilities exercised through the Nuclear Regulatory Commission. • Delineated Federal/state jurisdiction for nuclear material and facilities: licensing of nuclear plant construction and operation as well as waste disposal are exclusively in the Federal domain. States retain oversight of generation planning by vertically integrated utilities (e.g., questions of whether or not to construct nuclear facilities in the first place).
Price-Anderson Act	1957	• Facilitated the development of nuclear-powered generating capacity by establishing a program for covering claims of members of the public if a major accident occurred at a nuclear power plant and providing a ceiling on the total amount of liability for nuclear accidents.
National Energy Act	1978	• Passed in response to oil shortages in the 1970s and the increased reliance on imported oil, which was seen as a threat to national security.[83] • Included the Natural Gas Policy Act of 1978, Public Utilities Regulatory Policies Act, the Energy Tax Act, the Powerplant and Industrial Fuel Use Act, and the National Energy Conservation Policy Act.[84]
Energy Independence and Security Act	2007	• Strengthened lighting energy-efficiency standards. • Added Section 1705 to the loan guarantee program, allowing subsidized loans to commercial facilities. • Called for coordination to develop a framework for smart grid interoperability standards (National Institute of Standards and Technology).
American Recovery and Reinvestment Act	2009	• Funded $31 billion in energy efficiency, renewable energy, and energy infrastructure and made other major investments in energy research and development programs administered by the Department of Energy.[85]
FERC Order 1000	2011	• Requires regional transmission planning and interregional coordination; mandates that the planning process consider transmission needs driven by public policy requirements. • Requires regional and interregional cost allocation methods that satisfy six allocation principles. • Eliminated the Federal right of first refusal in Federal Energy Regulatory Commission (FERC) jurisdictional tariffs and agreements.[86]

In addition to the FPA, the Federal Water Power Act, the Public Utility Holding Company Act of 1935, PURPA, EPAct 1992, and EPAct 2005, which are discussed in the above section, these laws and orders have played key roles in shaping the electricity industry.

Table A-3. Key Electricity Industry-Related Environmental Laws and Regulations

Name	Year	Major Provisions
Clean Air Act	1970	• Authorized comprehensive Federal and state regulation of stationary pollution sources, including power plants.[87] • Provided for National Ambient Air Quality Standards, State Implementation Plans, New Source Performance Standards, and National Emission Standards for Hazardous Air Pollutants.[88] • Requires states to decide what pollution reductions will be required from particular sources to address National Ambient Air Quality Standards, and requires states to submit State Implementation Plans.[89]
National Environmental Policy Act	1970	• Requires Federal agencies to review the environmental consequences of a proposed project before granting approval.[90] Agencies prepare statements on the environmental impact of a proposed project (Environmental Impact Statement or Environmental Assessment), considering the views of the public and of other Federal, state, and local agencies, and make the report publicly available.[91]
Clean Water Act	1972	• Established regulations for discharging pollutants into water,[92] which includes wastewater discharges from the power sector (such as cooling water, wastewater from coal ash handling, and wastewater from pollution control equipment). • The Steam Electric Effluent Limitations Guidelines—promulgated under the Clean Water Act—were updated in 2015.
Resource Conservation and Recovery Act	1976	• Provides EPA with the authority to regulate hazardous waste,[93] including management of power sector waste, such as coal ash. • The Coal Combustion Residuals rule—promulgated under the Resource Conservation and Recovery Act—was finalized in 2015.
New Source Performance Standards	1979	• EPA rule governing sulfur dioxide emissions from coal power plants.[94] • Effectively required flue gas desulfurization on all new coal plants.
Clean Air Act Amendments	1990	• Encouraged market-based principles to pollution control, such as emissions trading.[95] • Requires EPA to regulate more than 180 specified hazardous air pollutants[96] and set up specific procedures to determine whether the air pollution regulations would apply to power plants that run on fossil fuels.[97] • Established the U.S. Acid Rain Program, the world's first large-scale emissions cap-and-trade system to reduce air pollution. The program set a permanent cap on annual sulfur dioxide emissions from the power sector.
Cross-State Air Pollution Rule	2011	• Replaced the Clean Air Interstate Rule starting on January 1, 2015 • Requires states to reduce power plant emissions that contribute to ozone and fine particle pollution in downwind states.[98]
Mercury and Air Toxics Standard	2011	• EPA rule limiting mercury and other toxic pollution from power plants.[99]
Carbon Pollution Standards and Clean Power Plan	2015	• In 2015, EPA finalized the Carbon Pollution Standards rule establishing carbon dioxide emission standards for new fossil fuel-fired generators under Clean Air Act section 111(b). • Also in 2015, EPA finalized the Clean Power Plan, a rule to reduce carbon dioxide emissions from existing fossil fuel-fired generators under Clean Air Act section 111(d).[100] The rule establishes final emission

Name	Year	Major Provisions
		guidelines for states to follow in developing plans to reduce greenhouse gas emissions from existing fossil fuel–fired electric generating units, leaving states with considerable discretion to choose the approach.[101] • As of January 2016, implementation of the Clean Power Plan has been stayed by the Supreme Court pending the outcome of litigation.[102] • EPA regulation of greenhouse gas emissions followed from the 2007 Supreme Court decision in Massachusetts v. EPA that greenhouse gases are air pollutants under the Clean Air Act, and the 2009 EPA finding that the current and projected concentrations of six key greenhouse gases in the atmosphere endanger the public health and welfare, a prerequisite for implementing greenhouse gas emissions standards.[103]

Beginning with the Clean Air Act in 1970, major environmental laws and regulations have impacted the electric industry in key ways.

A.4. Federal Authorities, Policies, and Frameworks for Electric Grid Resilience and Security

The Federal Government plays a key role in enhancing the resilience and security of the grid through diverse efforts, including research and development, information sharing, the establishment and enforcement of utility performance standards, and the coordination of response resources. Presidential policy directives and congressional legislation have outlined specific authorities for the Federal Government in recognition of the importance of the electricity sector—and supporting energy sectors—for national and economic security. This section describes select Federal policies and frameworks guiding national resilience and security efforts, as well as selected challenges in fulfilling Federal roles to protect critical electricity infrastructure.

Selected Authorities for the Energy Sector

Defense Production Act: Ensures timely availability of resources for national defense and civil emergency preparedness and response, including energy-related assets. (1950)

Energy Policy and Conservation Act: Directs the Secretary of Energy to establish, operate, and maintain the Strategic Petroleum Reserve (1975), which includes the Northeast Gasoline Supply Reserve, and provides for the Presidentially-directed drawdown of those reserves. Also authorizes the Secretary to establish and manage the Northeast Home Heating Oil Reserve. (2000 as amended)

Federal Energy Administration Act: Grants the Department of Energy (DOE) the authority to collect, evaluate, and analyze energy information from facilities or businesses operating in any phase of energy supply or major energy consumption. (1974)

Federal Power Act: Provides the Secretary of Energy authority in time of emergency to order temporary interconnections of facilities and the generation, delivery, interchange, or transmission of electric energy necessary to meet an emergency. (1935, 2015 as amended by FAST Act, as defined below) The Federal Power Act also gives FERC the authority to order compliance with reliability standards. (1935, 2005 as amended by EPAct) In addition, the **Fixing America's Surface Transportation Act (FAST) Act** amended the Federal Power Act empowering the President to declare a grid security emergency in the face of an electromagnetic pulse, cyber or geomagnetic disturbances, and physical threats and, in doing so, enabling the Secretary of Energy to (1) direct users and operators of electricity assets to undertake such actions as are necessary to ensure the reliability of critical electric infrastructure, and (2) share classified information as necessary to mitigate effects of the grid security emergency. It also allows the

Federal Energy Regulatory Commission to provide a mechanism for any affected entities to recover related costs. (2015)

Natural Gas Policy Act: Authorizes DOE to allocate supplies of natural gas to help alleviate an existing or imminent, Presidentially-declared, severe natural gas shortage that would endanger the supply of gas for high-priority uses. (1978)

Stafford Disaster Relief and Emergency Assistance Act: The Stafford Act[104] gives the Federal Government its authority to provide response and recovery assistance in a major disaster. (1988). The Stafford Act identifies and defines the types of occurrences and conditions under which disaster assistance may be provided. Under the law, the declaration process[k] remains a flexible tool for providing relief where it is needed. Designates the Federal Emergency Management Agency (FEMA) as the lead for Federal emergency response; FEMA may require other Federal agencies to provide resources and personnel to support emergency and disaster assistance efforts. DOE is the sector-specific agency for energy under this framework.

Executive Order 12656—Assignment of Emergency Preparedness Responsibilities: Assigns preparedness responsibilities to Federal agencies and requires agencies to be prepared to respond adequately to all national security emergencies, including developing emergency plans. (1988)

Homeland Security Presidential Directive 5 (HSPD-5): Establishes a single, comprehensive National Incident Management System under the purview of the Department of Homeland Security, under which all other Federal agencies provide their cooperation, resources, and support. The directive also provides direction for Federal assistance to state and local authorities. (2003)

Presidential Policy Directive 8 (PPD-8)—National Preparedness: Replaces prior national planning directives and takes an "all-of-Nation" approach to prepare for a wide range of threats and emergencies. National Planning Frameworks—coordinating structures of key Federal agencies and other stakeholders—have been established around five mission areas: prevention, protection, mitigation, response, and recovery. (2011)

Presidential Policy Directive 21 (PPD-21)—Critical Infrastructure Security and Resilience: Establishes shared responsibility for strengthening critical infrastructure security across the Federal Government. PPD-21 highlights the role of the national physical and cyber coordinating centers in enabling successful critical infrastructure security and resilience outcomes.[105] Designates critical infrastructure sectors and sector-specific agencies, notably DOE as the sector-specific agency for the energy sector. (2013)

A.4.1 Planning and Coordination Frameworks

Federal policy directives and legislation address the evolving threats and institutional vulnerabilities of the Nation's critical infrastructure by defining roles and responsibilities for national grid *resilience* and security. Homeland Security Presidential Directive (HSPD)-7, Presidential Policy Directive (PPD)-8, and PPD-21 laid the groundwork for the key coordinating bodies and a national approach to plan for events.

[k] "The Robert T. Stafford Disaster Relief and Emergency Assistance Act, 42 U.S.C. §§ 5121-5207 (the Stafford Act) §401 states in part that: 'All requests for a declaration by the President that a major disaster exists shall be made by the Governor of the affected State.' A State also includes the District of Columbia, Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. The Republic of Marshall Islands and the Federated States of Micronesia are also eligible to request a declaration and receive assistance through the Compacts of Free Association." See "The Disaster Declaration Process," Federal Emergency Management Agency, accessed September 23, 2016, https://www.fema.gov/disaster-declaration-process.

Joint United States–Canada Electric Grid Security and Resilience Strategy

In December 2016, the Federal Governments of the United States and Canada released the "Joint United States-Canada Electric Grid Security and Resilience Strategy," a collaborative effort between the two nations intended to strengthen the security and resilience of the U.S. and Canadian electric grids from all adversarial, technological, and natural hazards and threats. The Strategy addresses the vulnerabilities of the two countries' respective and shared electric grid infrastructure, not only as an energy security concern, but for reasons of national security. Because the electric grid is complex, vital to the functioning of modern society, and dependent on other infrastructure for its function, the United States and Canada developed the Strategy under the shared principle that security and resilience require increasingly collaborative efforts and shared approaches to risk management.

The Strategy organizes joint approaches to protect today's grid, manage contingencies by enhancing response and recovery capabilities, and cultivate a more secure and resilient future grid. As an expression of shared intent and approach, the Strategy organizes joint efforts to manage current and future security challenges. Three strategic goals underpin the effort to strengthen the security and resilience of the electric grid:

Protect Today's Electric Grid and Enhance Preparedness: A secure and resilient electric grid that protects system assets and critical functions and is able to withstand and recover rapidly from disruptions is a priority for the governments of both the United States and Canada.

Manage Contingencies and Enhance Response and Recovery Efforts: The Strategy sets out a shared approach for enhancing continuity and response capabilities, supporting mutual aid arrangements, such as cyber mutual assistance across a diverse set of stakeholders, understanding interdependencies, and expanding available tools for recovery and rebuilding.

Build a More Secure and Resilient Future Electric Grid: The United States and Canada are working to build a more secure and resilient electric grid that is responsive to a variety of threats, hazards, and vulnerabilities. To achieve this, the electric grid will need to be more flexible and agile, with an architecture into which new technologies may be readily incorporated.[106]

The Strategy will be implemented through the U.S. and Canadian Action Plans, which detail specific steps and milestones for achieving the Strategy's goals within their respective countries.[107] These documents are intended to guide future activity within areas of Federal jurisdiction, with full respect for the different jurisdictional authorities in both countries.

Under HSPD-7 and then PPD-21, the National Infrastructure Protection Plan set out a number of partnership structures for coordination and information sharing within and across sectors, including electricity. Some of the formal coordination and information-sharing councils available to the electricity subsector include the following:

- **Electricity Subsector Coordinating Council**: Represents the interests of the industry and is composed of electric utility industry executives. It is the principal mechanism for private-sector owners and operators to work collaboratively with the government under a structured and protected framework that allows open dialogue. There is a counterpart subsector coordinating council for the oil and natural gas subsector. Numerous task forces and subcommittees have worked on supply-chain concerns, interdependencies, and coordination with other sectors. The Electricity Subsector Coordinating Council is also a critical coordination mechanism for information sharing during and after incidents.
- **Energy Government Coordinating Council**: This government counterpart to the Electricity Subsector Coordinating Council is jointly led by DOE and the Department of Homeland Security (DHS), with membership from all levels of government and international partners.

These structures collectively serve as a means of sharing information, best practices, research needs, and other critical infrastructure security information, such as information about interdependencies, across sectors.

Additionally, PPD-8 calls for the development of a National Planning System to integrate planning across all levels of government and the private sector. The intent is to provide a flexible approach to prevent, protect, mitigate, respond, and recover from an event. The National Planning System includes the following:[108, 109]

- National planning frameworks describing the key roles and responsibilities to deliver the core capabilities required for the key mission areas: prevent, protect, mitigate, respond, and recover.
- Federal Interagency Operational Plans for each mission area to provide further details regarding roles and responsibilities, specify critical tasks, and identify requirements for delivering core capabilities.
- Federal department and agency operational plans to implement the Federal Interagency Operational Plans.
- Comprehensive planning guidance to support planning by local, state, tribal, and territorial governments; the private sector; and others.

PPD-8 also outlines five frameworks to maintain proper support from the Federal Government by working through states to assist affected local jurisdictions or organizations. The five frameworks divide efforts into rational disciplines of competence—prevention, protection, mitigation, response, and recovery. The combined frameworks shape efforts to prepare our Nation for emergencies stemming from all hazards.

The National Response Framework and its Emergency Support Function (ESF)-12 Annex outline much of the joint Federal, state, and private-sector responsibility for response and recovery to energy service disruptions. The ESF-12 Annex characterizes the Federal response as the facilitation of restoration of damaged energy systems and components. For example, DOE may exercise its emergency powers depending on the conditions of certain respective declarations and findings to facilitate restoration and to meet the needs of industry. After an incident, the National Disaster Recovery Framework[110] provides guidance for an expeditious return to a normal way of life. Like the National Response Framework's ESFs, the National Disaster Recovery Framework has Recovery Support Functions. DOE is named as a primary agency in the Recovery Support Function–Infrastructure Systems.

A.4.2 Tools and Technical Assistance

The Federal Government also provides numerous tools and technical assistance to enhance states' and the electric industry's capabilities to operate electricity systems in a secure and resilient manner. Many of these resources help stakeholders understand risks, assess their systems, analyze vulnerabilities, and prioritize mitigation strategies. Below are a few examples:

- DOE's Electricity Subsector Cybersecurity Capability Maturity Model helps entities evaluate, prioritize, and improve their cybersecurity capabilities and allows for a better overall assessment of the cybersecurity posture of the energy sector.[111]
- DHS's Cyber Security Evaluation Tool[112] and the Cyber Resilience Review are complementary and voluntary tools for evaluating industrial control system (ICS) and information technology network practices, and operational resilience and cybersecurity capabilities, respectively.[113]
- DHS's ICS Cyber Emergency Response Team provides resources to critical infrastructure sectors to prevent and recover from cyber attacks. This includes working onsite to help resolve spear phishing campaigns that seem to target ICS/supervisory control and data acquisition (or SCADA) data, including data that could facilitate remote access and control of systems.[114]

- DHS's Regional Resiliency Assessment Program conducts regional assessments of the Nation's critical infrastructure, addressing a range of hazards that could have regionally and nationally significant consequences. Argonne National Laboratory has completed 56 Regional Resiliency Assessment Program projects during 2009–2014, which addressed a variety of postulated hazards, including tornadoes, ice storms, earthquakes, hurricanes, solar storms, and other threats to the electric sector.
- The National Oceanic and Atmospheric Administration supports Regional Climate Centers, which are able to provide technical assistance and climate data to support risk assessment and decision making by utilities and governments.[115]
- DOE's Office of Energy Policy and Systems Analysis convenes the Partnership for Energy Sector Climate Resilience, through which DOE provides technical assistance for 18 electric utilities that are demonstrating leadership in developing vulnerability assessments and pursuing strategies for investing in climate resilience.

Continued support for tools development and expanding technical assistance resources is increasingly important as changing risks from human-induced actions and natural hazards make risk-based planning more challenging. For example, to credibly account for projected changes in climate, utility planners and regulators need technical assistance in accessing and correctly interpreting climate data at the appropriate time and geographic scales.

A.4.3 Standards and Guidance

As previously discussed, FERC has regulatory authority over the reliability of the bulk power system, overseeing the development and approval of standards set by NERC. FERC can also proactively direct NERC to develop a new or modified reliability standard to address reliability issues identified by FERC. While these standards cover the reliability and security of bulk power assets, NERC has typically designed them with the benefit of the system as a whole in mind, balancing the interests of its stakeholders. In addition to standards, the Federal Government works with stakeholders to develop additional guidance to support risk mitigation strategies across the electric sector.

It is worth noting that NERC's planning standards for electric reliability (e.g., TPL-001-4) and facility ratings standards (e.g., FAC-008-3) require consideration of a broad range of risks to the system. However, assumptions within these standards regarding the frequency and intensity of extreme weather events, for example, do not account for projected changes in climate. Furthermore, transmission planning efforts routinely consider system-wide costs associated with average weather-related loads, rather than accounting for extreme conditions.[116] The practice of using historical data and average conditions undercuts efforts to plan and prepare for threats, such as extreme weather, cyber attacks, or hostile actions, that may have different characteristics in the future.

Within the Commerce Department, the National Institute of Standards and Technology (NIST) develops frameworks, voluntary standards, and other guidance documents to assist electric sector efforts in reliability, resiliency, and security.[117] NIST conveys unique technical requirements for authorizing, monitoring, and managing all methods of remote access to the smart grid information system.[118, 119] The NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0, is one example of these resources.[120, 121] In addition, in 2014, the NIST released the Framework for Improving Critical Infrastructure Cybersecurity, which includes a set of standards, methodologies, procedures, and processes that align policy, business, and technological approaches to address cyber risks, and incorporates voluntary consensus standards and industry best practices.[122] In 2015, DOE released guidance to help the energy sector establish or align existing cybersecurity risk management programs to meet the objectives of the Framework released by NIST.

Several organizations are also actively revising interconnection standards—the rules that prescribe capabilities that technologies like distributed generation must possesses as a precondition to connecting to the electricity system—to better support the reliability, safety, and cost effectiveness of the grid. As technologies subject to interconnection standards increase in number and potential impact on the grid, enhanced Federal support is critical to the timely and robust completion of these standards.

A.4.4 Information Sharing and Threat Analysis

Federal agencies have institutions and programs in place to enhance information sharing and the dissemination of threat analysis to government and industry partners. DHS is responsible for several key infrastructure security programs. The National Infrastructure Coordinating Center and the National Cybersecurity and Communications Integration Center are the national focal points for industry partners to obtain 24/7 situational awareness and integrated actionable information to secure the Nation's physical and cyber critical infrastructure, respectively.[123] During major incidents, the National Infrastructure Coordinating Center and the National Cybersecurity and Communications Integration Center closely coordinate with the Federal Emergency Management Agency (FEMA) to ensure that overall critical infrastructure status and impacts on life and safety are understood throughout the Federal incident response community.[124]

Below are additional examples of government programs available to electric sector participants:

- *DHS Fusion Centers* are information-sharing hubs for Federal, state, local, tribal and territorial agencies and industry to maintain situational awareness at the state and local levels. Fusion centers receive, analyze, and disseminate threat information, providing local perspectives to their partners.[125]
- *DHS Automated Indicator Sharing* is a free program that facilitates the exchange of cyber threat indicators between the Federal Government and parties that opt in to the program through machine-to-machine sharing.[126]
- *DOE's Cybersecurity Risk Information Sharing Program* facilitates the exchange of detailed cybersecurity threat information among electric utilities, the Electricity Information Sharing and Analysis Center, DOE, and several National Laboratories. The program was designed to facilitate the timely bidirectional sharing of unclassified and classified threat information, and to develop situational awareness tools to enhance the sector's ability to identify, prioritize, and coordinate the protection of their critical infrastructure and key resources.
- *Information Sharing and Analysis Organizations* encourage exchange of information to protect critical infrastructure and are supported by sector-specific agencies and DHS in accordance with EO-13691 and PPD-63.

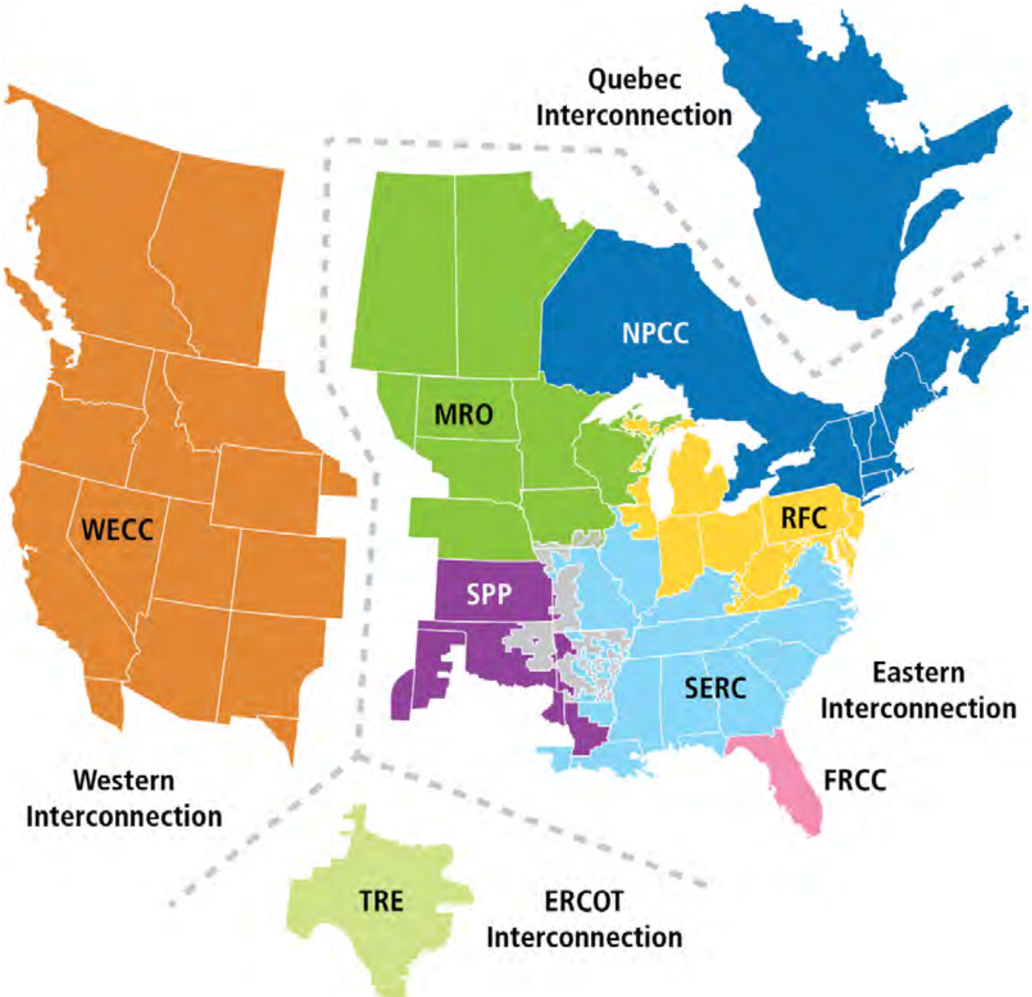
A.5. Electricity System Operations, Business Models, and Markets

A.5.1 System Operation

The electricity system of the continental United States does not function as a single, unified grid, but rather is split into three interconnections that each function as independent power systems with limited power flows between them, enabled by DC interconnections between the regional systems. Hawaii and parts of Alaska also operate as independent systems. The goal in operating each of these power systems is to deliver low-cost and reliable electricity. A complex set of institutions, defined by geographic boundaries, accomplishes this goal.

One of the broadest geographic divisions is the regional reliability entity,[l] which develops and enforces standards on behalf of NERC.[m, 127] Figure A-6 shows the three interconnections of the continental United States and the NERC reliability regions.

Figure A-6. North American Interconnections and Reliability Regions[128, n]



This map shows four North American interconnections, three of which include the United States, and eight NERC reliability regions. The four interconnections include Eastern, Western, Quebec, and the Electric Reliability Council of Texas (ERCOT). The NERC regions include: Florida Reliability Coordinating Council (FRCC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), ReliabilityFirst (RF), SERC Reliability Corporation (SERC), Southwest Power Pool Regional Entity (SPP RE), Texas Reliability Entity (TRE), and Western Electricity Coordinating Council (WECC).

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[l] Instead of *entity*, the terms *council* and *organization* are sometimes used to refer to these entities as a group. Individually, their names include entities (e.g., Texas Reliability Entity), councils (e.g., Florida Reliability Coordinating Council), organizations (e.g., Midwest Reliability Organization), corporations (e.g., SERC Reliability Corporation), and pools (e.g., Southwest Power Pool, Inc.).

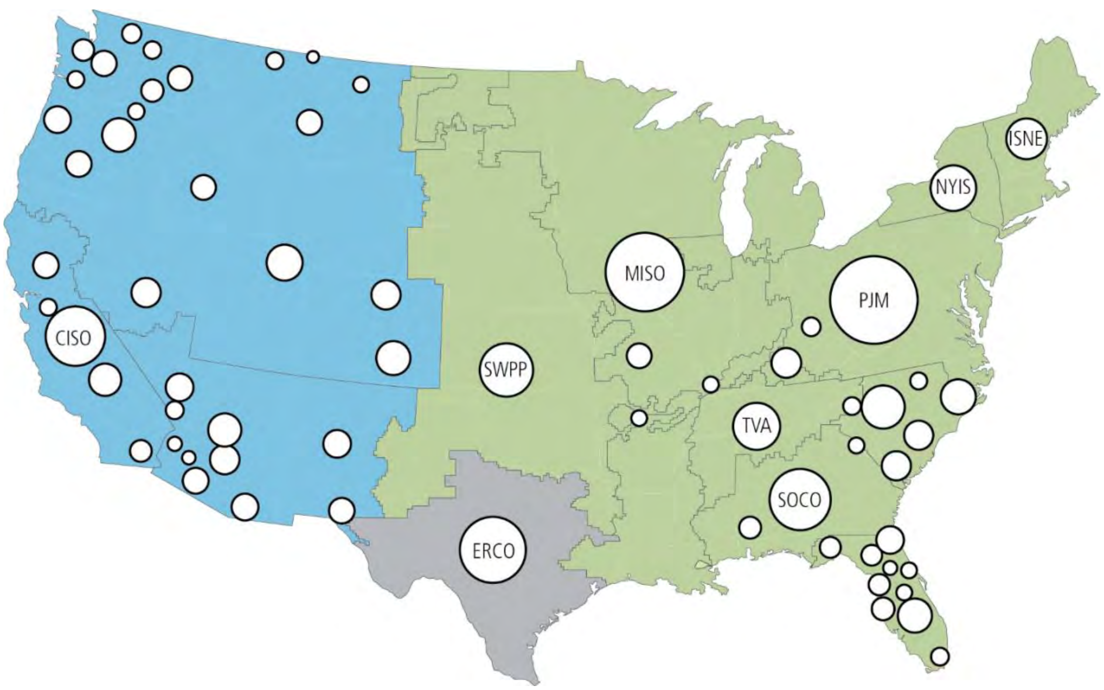
[m] NERC sets standards for the reliability of the bulk power system. The jurisdiction and authority of NERC is discussed in greater detail in Section A.3.2: Federal Actors.

[n] This figure is based on information from the North American Electric Reliability Corporation's website, which is the property of the North American Electric Reliability Corporation and is available at http://www.nerc.com/AboutNERC/keyplayers/PublishingImages/NERC_Interconnections_Color_072512.jpg. This content may not be reproduced in whole or any part without the prior express written permission of the North American Electric Reliability Corporation.

Providing electricity when and where it is needed is an incredibly complicated engineering process. Unlike most other consumer goods and energy sources, electricity is not stored in large quantities and must be produced at the instant it is needed. It is the job of power system planners and operators to ensure that electricity is produced when and delivered to where it is needed at every moment of every day.

The Nation is regionally subdivided into balancing areas, shown in Figure A-7, where balancing authorities operate regions of the grid on a day-to-day basis. Some of these regions overlap precisely with NERC reliability regions, while many others are smaller in geographic extent. On a daily basis, balancing authorities forecast demand, schedule generation supply, and schedule exchanges with neighboring regions. These decisions are generally guided by software optimization systems that minimize the total cost of meeting demand, subject to operating constraints and reliability criteria. Scheduling generation supply occurs on multiple time horizons, the most important of which include unit commitment (scheduling the availability of a generator days or hours ahead of time) and economic dispatch (providing operating instructions in near real time).

Figure A-7. Electricity System Interconnections and Balancing Areas[129]



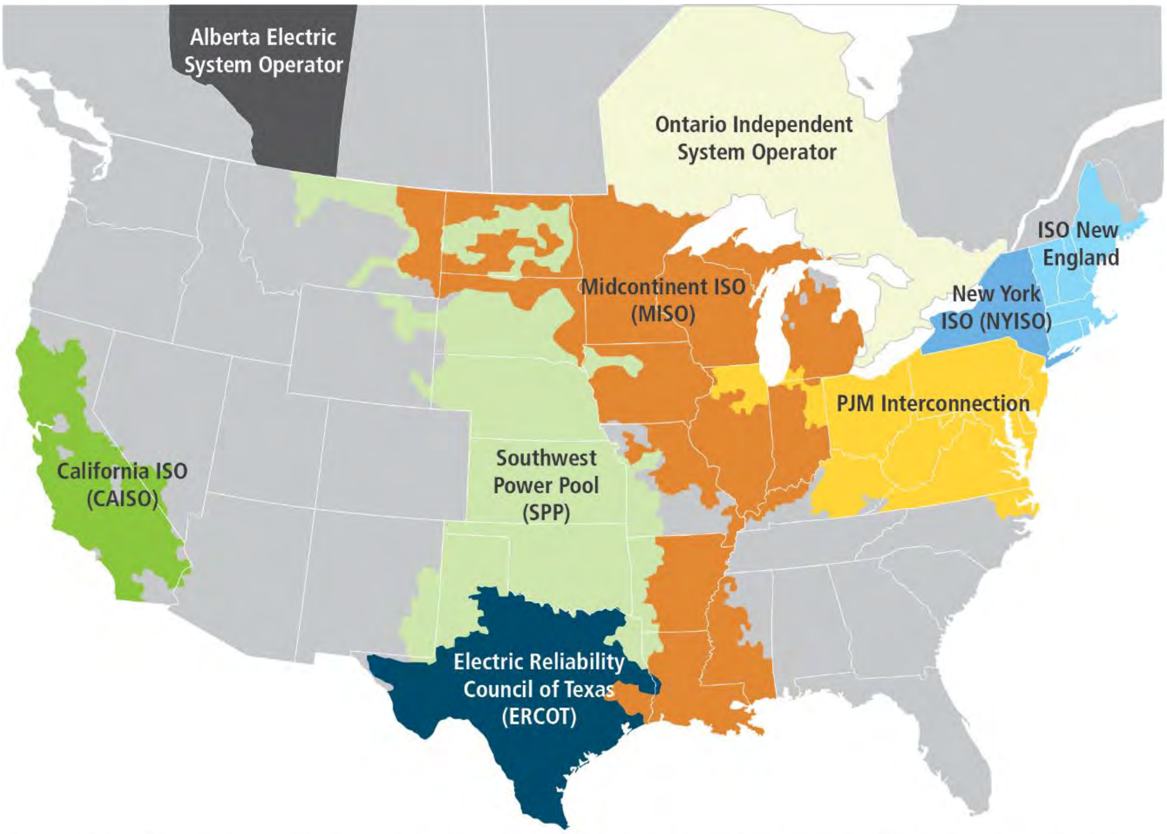
The electricity industry includes the three continental United States electricity system interconnections (Eastern, Western, and the Electric Reliability Council of Texas [ERCOT]), and the 66 balancing authorities that are responsible for maintaining a balance between supply and demand within their areas. The location of the balancing area bubbles is approximate, and the size represents a rough indication of the size of the system managed in each area.

Different operating approaches are used throughout the country, though all focus on minimizing costs and maintaining reliability. In some areas, utilities operate their own systems based on their costs for resource options and operating decisions. Other regions operate based on organized markets, where market participants place supply and demand bids into a centralized market, and a market operator determines the least-cost mix of bids.[o] Market participants then pay and earn money based on market

[o] The operations of markets are discussed in greater detail in Section A.5.3: Electric Power Markets.

prices for electricity and ancillary services. System operators in these areas are called ISOs or RTOs,[p] and their markets—except for Electric Reliability Council of Texas (ERCOT), which covers most of Texas—are overseen by FERC.[q]

Figure A-8. Regional Transmission Organizations (RTOs), 2015[130]



The Federal Energy Regulatory Commission encouraged voluntary formation of ISOs and RTOs through a series of landmark orders that paved the way for open access to transmission and created large organized power markets in the United States. There are currently seven ISO/RTOs in the United States, and their geographic extents change periodically.

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Maintaining operational reliability of the power system requires focusing on a set of essential reliability services, called ancillary services, provided by generation and load that aid in maintaining frequency and voltage of the system within acceptable bounds during normal operations and immediately after minor system disturbances.[r] Examples of these services include frequency response (automatic generator

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[p] There are small distinctions between ISOs and RTOs, though they are insignificant for the level of discussion in the QER. Throughout, the terms will be used synonymously.

[q] The jurisdiction and authority of FERC is discussed in greater detail in Section A.3.2: Federal Actors.

[r] The term Essential Reliability Services is used by NERC to describe a set of necessary operating characteristics of resources on the bulk power system required to reliably operate the bulk power system in North America. For voltage support, it includes reactive power/power factor control, voltage control, and voltage disturbance performance. For frequency management, it includes inertia, frequency disturbance performance, operating reserves, and active power control (which includes frequency control and ramping capability). Ancillary services are a subset of Essential Reliability Services. Source: North American Electric Reliability Corporation (NERC), *Essential Reliability Services Task Force: A Concept Paper on Essential Reliability Services that*

response to grid frequency deviations) and spinning reserves (generators that remain running and able to increase or decrease their output when instructed). Some ISO/RTO market regions procure ancillary services through markets that mirror their energy markets. Additional services are procured in these regions through cost-of-service payments. In non-ISO/RTO regions, many ancillary services are provided under a cost-of-service basis. The evolving composition of the electricity generation fleet has implications for long-term availability of these system-essential reliability services.[131]

Reliability and the Role of the North American Electric Reliability Corporation (NERC)

Over the past 50 years, Federal oversight of the reliability of the bulk power system has increased. The 1965 Northeast power blackout precipitated the formation of NERC, but bulk power system reliability standards were voluntary and subject only to industry oversight.[132] A 2003 blackout that affected more than 50 million customers led to the inclusion in the Energy Policy Act of 2005 of requirements for mandatory bulk power reliability standards and enforcement, including designation of an electric reliability organization.[133] The Federal Energy Regulatory Commission oversees NERC in its development and enforcement of mandatory reliability standards for the bulk power system. States retain oversight of local reliability, which includes lower voltage transmission lines and distribution systems. NERC mandatory reliability standards address weaknesses in the prior voluntary system that were identified in the 2003 blackout investigation.

A.5.2 Business Models

Electricity in the United States is produced and delivered by a diverse set of actors using a range of business models. Depending on the operating model in question, these actors can be subject to regulation and oversight by different combinations of local, state, and Federal agencies. A key factor for differentiating between actors is ownership: companies can be investor-owned, publicly owned, or cooperatively owned. Within each of these three ownership models there are significant variations in purpose, regulatory oversight, prevalence, and size. Table A-4 provides overview statistics for the most common types of utility ownership . In addition to these primary ownership models, there are a number of businesses that provide distributed resources like demand response aggregation and distributed solar. Figure A-5. Broad Overview of Jurisdictional Roles in the Electricity Industry provides a taxonomy of utility business models by ownership and asset types.

Table A-4. Characteristics of Major Utility Types[134, 135]

Utility Type	Number of Utilities	Number of Customers	Miles of Power Lines	
			Transmission	Distribution
Investor-Owned Utilities	169	107,566,949	3,467,216	459,480
Municipal Utilities	1,834	15,151,058	320,953	27,585
Rural Electric Cooperative Utilities	814	19,232,195	2,397,111	116,635
Federal and Publicly-Owned Utilities	124	5,280,112	333,720	95,962
Total	**2,941**	**147,230,314**	**6,408,000**	**699,662**

Municipal utilities are the most numerous of the various utility types, though IOUs serve far more customers. Rural electric cooperatives have a higher proportion of distribution miles per customer served than investor-owned or municipal utilities.

Characterizes Bulk Power System Reliability (Atlanta, GA: NERC, October 2014), http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Concept%20Paper.pdf.

IOUs are privately owned, for-profit utilities whose retail service is regulated by state PUCs that may be either vertically integrated or restructured to only own transmission and distribution. IOUs earn a regulated rate of return based on investments made to serve their ratepayers.

Rural electric cooperatives include nonprofit, member-owned distribution utilities and generation and transmission utilities. The cooperative business model is predicated on providing its customers with reliable, affordable energy that is locally owned and operated. The model is unique in that customers are "members" of the cooperative and, as such, hold ownership and voting stakes. Management is democratically elected by the membership, and the prevailing methodology is one meter, one vote.[136] Cooperatives receive a significant portion of their financing both directly and indirectly from the Federal Government, through both the Department of Agriculture's Rural Utility Service and cooperative banks like the National Rural Utilities Cooperative Finance Corporation. Electric cooperatives are not subject to Federal income tax, and thus must collaborate with a third party to monetize tax credits available for utility and generation investments.

Public power utilities are owned by a governmental entity, such as municipalities, states, public utility districts, or irrigation districts, and vary in size and scope from small distribution utilities to large, vertically integrated utilities. Public power also includes joint-action agencies that may own generation, transmission, and power purchasing services for their member utilities, such as the Lower Colorado River Authority and Missouri River Energy Services. Joint action agencies allow small distribution-only public power utilities to aggregate their demand and contract for and/or build generation, transmission, and other common services.

Federally owned utilities operate in the generation and transmission segments of the power system in several parts of the country. Four Power Marketing Administrations market hydropower generation at dams operated by the Bureau of Reclamation or the Army Corps of Engineers. TVA has a portfolio of generation and transmission to sell wholesale electricity to public power and cooperatives in its footprint. Federal law grants preference for electricity marketed by Federal utilities to public power and cooperative utilities.[s] Federally owned generation resources produce approximately 7 percent of all power in the United States, and they own approximately 14 percent of all transmission lines.[137, 138]

Merchant/independent power producers (IPPs) sell power through markets and bilateral contracts with utilities and other customers. IPPs typically have market-based—rather than cost-based—rates and do not have captive customers. They may or may not be affiliated with an IOU through a holding company. In 2014, IPPs produced approximately 40 percent of the Nation's electricity.[139] IPPs are often subject to hard-to-predict market conditions and can experience volatile cash flows and returns.

Competitive retail energy suppliers are companies that sell power to end users in states with competitive retail markets. As such, they do not earn a regulated rate of return. Although distribution utilities are the only entities that can *deliver* power directly to retail customers, in certain states customers can choose the *suppliers* of that power. In practice, this "retail choice" means that a consumer can sign a contract with a qualified third-party electric service provider who could, in turn, contract with a generator (on a bilateral basis), self-generate, or purchase power in the wholesale market, and pay the necessary tariffs to the transmission owner and distribution utility.

Energy service companies (ESCOs) were traditionally providers of turnkey energy efficiency retrofits, but ESCOs are now offering biomass, geothermal, wind, and solar generation, bill management, energy

[s] Preference clauses for Federal power sales originate from a series of congressional acts regarding Federal land reclamation and hydropower development, beginning with the Reclamation Act of 1906. See GAO-01-373 for further details.

monitoring, and energy procurement.[140] ESCOs explicitly guarantee energy savings for the consumer and charge a fee below that savings, known as an energy savings performance contract.[141]

Demand-response aggregators contract with large groups of end users to curtail their load if called upon to do so by the local utility or balancing authority. This flexibility is useful for reliability and economic reasons. There are many different providers of demand-response aggregation, including existing utilities and third-party providers.[142] The terms and conditions of third-party access to wholesale markets differ between ISOs and RTOs, but, generally, aggregators can participate in both energy and capacity markets to provide energy and ancillary services (including synchronized reserves).[143] Of 9.3 million participants registered in demand response in 2014, by count, over 90 percent are residential customers. However, over 75 percent of actual peak-demand savings came from commercial and industrial customers in 2014.[144]

Table A-5. Taxonomy (Ownership/Scope) of Utility Business Models with Representative Firms[145]

	State-Regulated IOU	Rural Electric Cooperative	Publicly Owned	Federally Owned	Merchant	Competitive Retail Energy Supplier*
Vertically Integrated**	Oklahoma Gas & Electric	–	Los Angeles Department of Water & Power	–	–	–
Transmission and Distribution	Pepco	Southern Maryland Electric Cooperative	Clallam County Public Utility District	–	–	–
Generation and Transmission	–	Basin Electric G&T	New York Power Authority	Tennessee Valley Authority	LS Power	–
Generation and Distribution	DTE Energy; Consumers Energy	Fox Island Electric	Lansing Board of Water & Light	–	NRG	–
Transmission Only	–	Upper Missouri Power Cooperative	Transmission Agency of Northern California	Western Area and Southwestern Power Administrations	ITC; Hudson Transmission; Transource Energy; Clean Lines Energy Partners	–
Distribution Only	Mt. Carmel Public Utility Co.	Kenergy	Nashville Electric Service	–	–	–
Generation Only	–	–	Wyoming Municipal Power Agency	Bureau of Reclamation	Calpine; BP Energy; Tenaska	–
Retail Sales Only***	–	–	–	–	–	Direct Energy; Veteran Energy

* Competitive retail energy suppliers are a special category of market participants that buy and sell electricity, but do not own any generation or infrastructure. Some ESCOs are retailers.

** Vertically integrated entities integrate generation, transmission, and distribution.

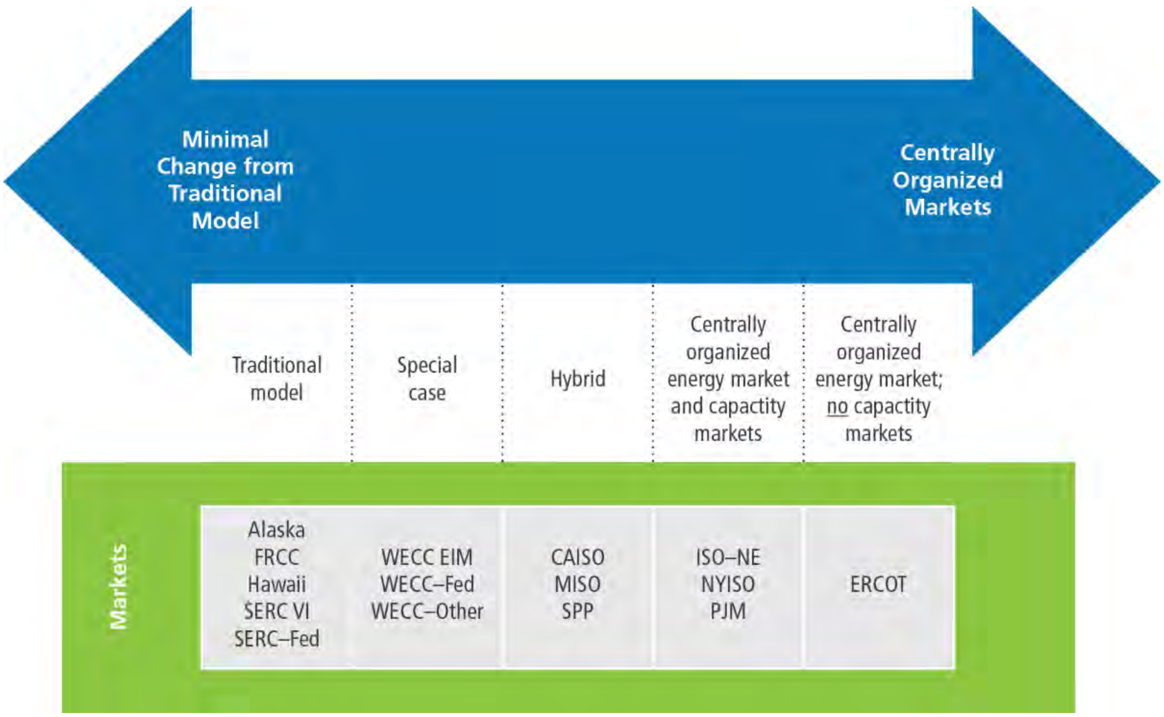
*** All business model categories in this table may include retail sales in addition to other services.

Utilities in the U.S. electricity sector have a variety of ownership and asset structures.

A.5.3 Electric Power Markets

Rather than consisting of a single overarching market, the U.S. electricity industry can instead be considered something of a patchwork, with different regional markets pursuing different mechanisms to provide electricity service to end users. The simplest characteristic differentiating these markets is whether resources are scheduled, dispatched, and compensated by a centrally organized RTO/ISO, or if they operate under the more traditional model wherein vertically integrated utilities operate within their franchise areas and receive revenues based on the cost of service. From this bifurcation, the organized markets can be further classified according to the types of resource adequacy constructs they use. These two attributes form a useful framework for analyzing the degrees to which the various markets differ from one another, and also underscore the diversity of approaches to electricity policy amongst the states.

Figure A-9. Spectrum of Electricity Markets[146]



This graphic illustrates the degree to which various U.S. regions have changed from the traditional market model. The two primary characteristics measured here are resource adequacy constructs and whether the market is centrally organized. Markets include: ERCOT, ISO New England (ISO-NE), New York ISO (NYISO), the PJM Interconnection (PJM), California ISO (CAISO), Midcontinent ISO (MISO), the Southwest Power Pool (SPP), and the Energy Imbalance Market (EIM) in the Western Electricity Coordinating Council (WECC) region. The markets listed under “special case” and “traditional model” are classified by NERC region and are not standardized designations.

Regions Address Resource Adequacy with a Variety of Mechanisms

Resource adequacy is “the ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.”[147] Planning for adequate investment in generation and transmission capacity to ensure resource adequacy is a critical component of ensuring a reliable electricity system.

Traditional, vertically integrated regions and some utilities in hybrid markets conduct an integrated resource planning process to plan for necessary capacity investments. Some centrally organized markets have implemented capacity markets as a mechanism for ensuring future resource adequacy. In these markets, the system operator conducts an auction process, and retail service providers procure resources to meet the electricity demands of their customers. These markets can be mandatory (PJM Interconnection and Independent System Operator [ISO]–New England); voluntary, where utilities can choose to operate under an integrated resource planning process (Midcontinent ISO); or voluntary backstopped by a mandatory process (New York ISO).[148] Other regions (California ISO and the Southwest Power Pool) have capacity obligations where market operators require utilities to procure necessary generation reserves, either through ownership or through contracts with third-party providers. Another market-based approach, used in the Electric Reliability Council of Texas, relies on energy prices alone and does not have formal requirements or markets for capacity. In this approach, market scarcity pricing, or relatively high energy prices during high-demand periods reflecting the lack of ample additional resources, provides necessary financial incentives for investment in generation capacity.

“**Traditional” markets** (the Southeast of the United States, for example) are dominated by vertically integrated IOUs that operate under a regulated cost-of-service model, serving customers in a defined franchise area. Public power and rural cooperative utilities also have a significant presence in some regions, and their utility asset ownership models can vary from vertically integrated to distribution-only. IPPs can also operate within these regions to some degree. However, the majority of power is produced and delivered by the integrated utilities.

Power purchases between these various entities are generally limited to bilateral trades. These can be made to take advantage of price discrepancies or cover shortfalls in supply. These bilateral transactions represent a small portion of the total generation in traditional markets and are typically in the form of long-term power purchase agreements instead of short-term trades. For example, in 2015 FERC estimated that short-term trades, called spot transactions, in the Southeast region accounted for less than 1 percent of overall supply.[149]

Centrally organized markets (ERCOT and New York ISO, for example) are markets where utilities were required to sell their power generation assets and keep only the “wires” component of the business. Generation assets were sold to IPPs who now operate these assets and build new generation based on expected market earnings. These assets work in a competitive fashion, with the IPP owners either (1) looking to sell power under bilateral contracts to utilities or other off-takers, such as industrial users, or (2) dispatching their power into wholesale energy markets.

In wholesale “energy-only” markets, units bid in on a day-ahead basis what price they are willing to produce power at, based on an assessment of their operating costs, fuel costs, and return expectations. The system operator (RTO/ISO) then pools these bids in a centralized fashion and determines a clearing price that matches supply, demand, and congestion forecasts for a given period. Notably, all units receive that marginal clearing price for that period, even if their bid prices are significantly lower than the clearing price determined by the ISO. In addition, the typical markets maintain price caps that limit what can be charged in any particular hour in order to limit the potential for market manipulation.

“**Hybrid” centrally organized markets** (for example, California ISO and the Southwest Power Pool) combine elements of centrally organized energy markets and traditional resource adequacy mechanisms.

In fact, several of these markets had moved toward more of a pure restructured model before moving back to elements of the more traditional regulated approach.

A.5.4 Transmission Access, Competition, and Planning

While Congress has found that generation can be provided through competitive mechanisms and therefore encouraged restructuring in that segment of the industry in the 1990s, increasing competition among transmission owners and reducing barriers to using transmission have been more incremental processes.

Originally, incumbent transmission owners largely controlled third-party access to transmission lines, effectively precluding competition at the wholesale level. Buyers and sellers of wholesale power that did not own the transmission connecting them had difficulty reaching each other over another's transmission lines at reasonable cost. EPAct 1992 resolves this issue by providing FERC with greater authority to provide transmission access for wholesale buyers in procuring wholesale electric supplies. Since 1992, FERC has taken multiple actions to increase operational and economic efficiency and equity of transmission operations and pricing.

FERC adopted Order No. 888 and Order No. 889, which require electricity utilities that own transmission lines used in interstate commerce to offer transmission service on a nondiscriminatory basis to all eligible customers, including non-jurisdictional entities such as public power, rural cooperatives, and Federal utilities. Order No. 2000 further encouraged utilities to join RTOs to improve the efficiency and equity of the transmission systems. FERC Order No. 890 built upon Order No. 888 to encourage more transparent planning and use of the transmission system and to reduce opportunities for undue discrimination.

FERC Order No. 1000 covers concepts such as (1) precluding, in most circumstances, incumbent transmission owners from having Federal rights of first refusal to build transmission within their service territories, (2) the opportunity for entities not previously recognized as transmission owners in the region (non-incumbents) to compete to develop transmission facilities and allocate the costs of those facilities, and (3) the requirement that project costs be allocated in a manner that is at least roughly commensurate with expected benefits from the projects.

Transmission owners, operators, and regional coordinators implement structured transmission planning processes to identify solutions that can more efficiently or cost-effectively maintain system reliability and accommodate changes in generation capacity and demand. Meeting the transmission planning goal requires both technical (engineering) analysis of different power systems configurations and economic analysis of projects proposed to meet the identified needs. In the United States, the transmission planning process generally falls into three geographic categories: local, regional, and interregional coordination.

Local transmission planning activities are carried out by incumbent transmission owners. These transmission owners assess their system and implement local solutions within their own service territory. Regional transmission planning includes assessment of solutions within a given planning region that spans several transmission owner service territories. Regional transmission planning relies on extensive stakeholder engagement, power system simulation modeling, and long-term economic impact analysis of alternative transmission projects. Interregional coordination is implemented for solutions that involve more than one ISO/RTO or planning entity. Interregional coordination activities are mostly guided by the principles outlined in FERC Order No. 1000.

A.6. Endnotes

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List of Acronyms and Units

AC	alternating current
AMI	advanced metering infrastructure
AML Fund	Abandoned Mine Lands Reclamation Fund
ARC	Appalachian Regional Commission
ARRA	American Recovery and Reinvestment Act of 2009
BTU	British thermal unit
CCUS	Carbon capture, utilization, and storage
CES	Clean Energy Standard
CHP	combined heat and power
DC	direct current
DER	distributed energy resources
DG	distributed generation
DOE	U.S. Department of Energy
DR	Demand response
EE	Energy efficiency
EERS	Energy Efficiency Resource Standard
ERCOT	Electric Reliability Council of Texas
ESCO	energy service company
EV	electric vehicle
FAST Act	Fixing America's Surface Transportation Act
FERC	Federal Energy Regulatory Commission
GDP	gross domestic product
GHG	Greenhouse gas
GW	Gigawatt
HVAC	heating, ventilation, and air conditioning
ICT	information and communications technology
IEEE	Institute of Electronics and Electrical Engineers
IoT	Internet of Things
IOU	investor-owned utility
IPP	independent power producer
ISO	independent system operator
ITC	Investment Tax Credit

kWh	kilowatt-hour
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LIHEAP	Low Income Home Energy Assistance Program
MEL	miscellaneous electrical load
MISO	Midcontinent Independent System Operator
MW	Megawatt
MWh	megawatt-hours
NEMS	National Energy Modeling System
NERC	North American Electric Reliability Corporation
NGCC	Natural gas combined cycle
PMU	phasor measurement units
PPA	power purchase agreement
PTC	Production Tax Credit
PUC	public utility commission
PURPA	Public Utilities Regulatory Policies Act
PV	Photovoltaic
QER	Quadrennial Energy Review
Quads	Quadrillion British thermal units
RD&D	Research, development, and deployment (RDD&D = Research, development, demonstration, and deployment)
RPS	Renewable Portfolio Standard
RTO	regional transmission organization
SCADA	supervisory control and data acquisition
T&D	Transmission and distribution
TOU	Time of use
TWh	Terawatt-hour
VER	variable energy resource