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

This chapter will explore the context surrounding the transformation of the Nation's electricity system, including the critical role that electricity plays in the Nation's infrastructure, opportunities that the electricity system and widespread electrification and digitization have created to enhance economic value, the imperative to reduce carbon emissions to mitigate climate change, new management challenges for grid operators that have arisen due to recent trends in electricity generation and demand, and the national security implications of grid dependency. Though the jurisdictional structure of the electricity system is complex, the Federal Government will play a major role in managing the challenges and taking advantage of the opportunities that the 21st century grid presents.

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]

Electricity is essential for the Nation's consumers, commercial and industrial sectors, social fabric, and national defense. 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. *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.*

This chapter will explore the context surrounding the transformation of the Nation's electricity system, including the critical role that electricity plays in the Nation's infrastructure, opportunities that the electricity system and widespread electrification and digitization have created to enhance economic value, the imperative to reduce carbon emissions to mitigate climate change, new management challenges for grid operators that have arisen due to recent trends in electricity generation and demand, and the national security implications of grid dependency. Though the jurisdictional structure of the electricity system is complex, the Federal Government will play a major role in managing the challenges and taking advantage of the opportunities that the 21st century grid presents.

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

The second installment of the Quadrennial Energy Review (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 the first installment of the Quadrennial Energy Review (QER 1.1), which included electricity as part of a broader examination of energy transmission, distribution, and storage infrastructures.

QER 1.1 identified key trends that suggested the need for greater analysis to inform a set of recommendations that will help set a pathway for modernized electricity systems capable of meeting the

[a] A "customer" is defined as an entity that is consuming electricity at one electric meter. Thus, a customer may be a large factory, a commercial establishment, or a residence. A rough rule of thumb is that each residential electric meter serves 2.5 people. Of the Nation's 147 million customers, 13 million now purchase electricity from non-utility retail service providers, comprising 20 percent of all U.S. retail electric sales (megawatt-hours) and delivered mostly by investor-owned distribution utilities, in the 19 states and District of Columbia that allow retail competition.

Nation's needs in a 21st century economy. Trends for QER 1.2 include 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. Recommendations focus on research and development (R&D), storage, transmission planning, State financial assistance, valuation of new services and technologies, and interoperability of technologies. Added to this mix is the growing and near-complete dependence of other critical infrastructures on electricity, increasing consumer choice options for distributed generation, and new high-value information/communications industries and businesses.

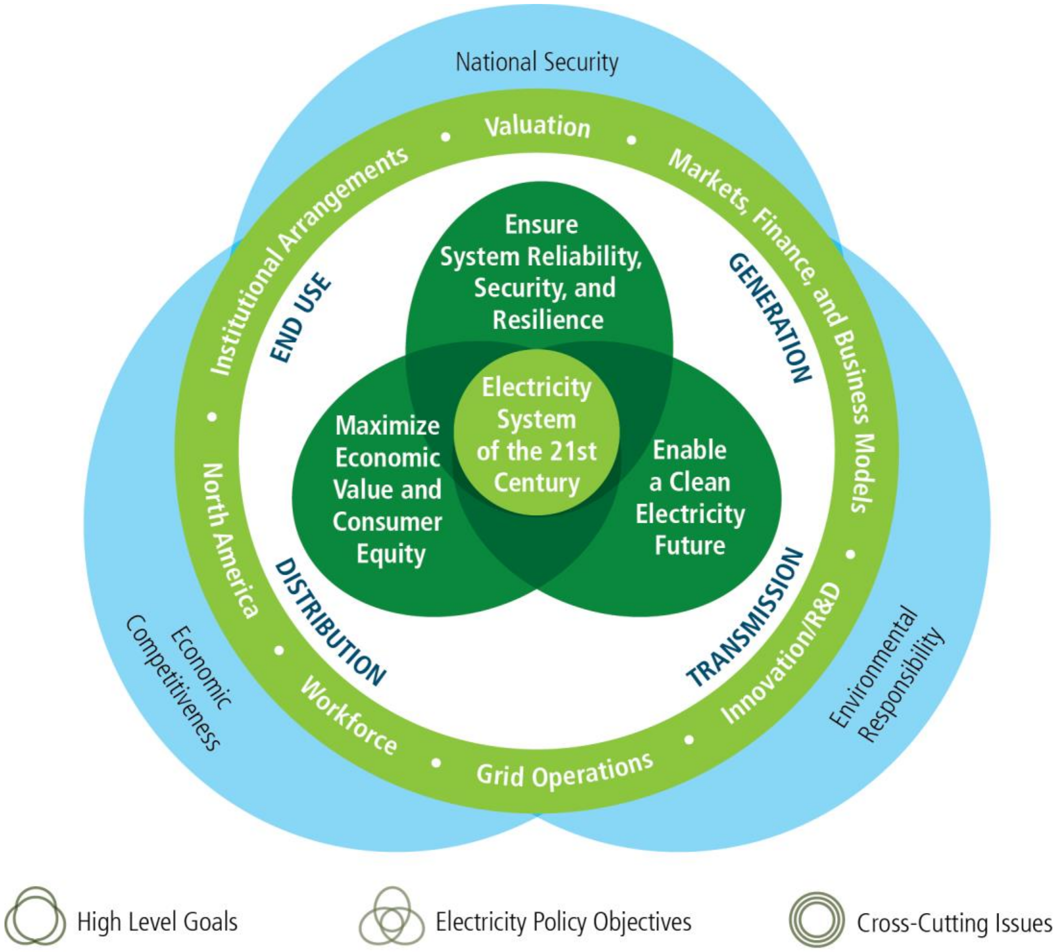
Underlying this is the need for ever-greater system security, driven by growing cyber and physical threats, expanding interconnectedness, and the increase in extreme weather events because of climate change. This evolution is and will be "bumpy"—the costs/benefits and investment requirements needed to accommodate deployment of new technologies and grid modernization are challenging the electricity industry and regulators alike to understand scale, scope, and operating changes required as the grid gets smarter, with the Supreme Court now in the position of resolving key jurisdictional issues.

1.1.1 National Goals for a 21st Century Electricity Sector

While respecting State, regional, and tribal prerogatives, QER 1.2 supports development of consistent Federal strategy to support a 21st century energy system.

QER 1.2 will analyze these issues in 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 overall structure of the study and its recommendations is depicted in Figure 1-1. Security, economy, and environmental responsibility are all interconnected and crosscutting. Transformation of the electricity sector must address all three national goals.

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.

Analyses were conducted with high-level national goals as guideposts: (1) national security, (2) environmental responsibility, and (3) economic competitiveness. Central to the QER 1.2 is a set of three analytically derived objectives that represent an integrated approach to enabling the electricity system of the 21st century through these high-level goals. These objectives are (1) ensuring security, system resilience, and reliability; (2) enabling a clean electricity future; and (3) increasing economic value and ensuring consumer equity. QER 1.2 also provides a comprehensive review of the Nation's electricity system and covers the history and key trends related to the electricity system, including (1) generation, (2) transmission, (3) distribution, and (4) end use.

1.1.1.1 Economic Competitiveness and the Electricity System

A key driver for U.S. economic competitiveness has been the supply and delivery of electricity that is affordable, accessible, and reliable. The reliability of electricity directly affects the efficiency of production processes, enabling the efficient/cost-effective coordination of economic activity without disruption. With some of the lowest electricity prices in the developed world,[11] the U.S. electricity sector supports economic competitiveness of U.S. goods and services in both domestic and global markets. Energy infrastructures should enable new architectures to stimulate energy efficiency, new economic transactions, and new consumer services. The modernization of the U.S. electricity system—through the growth of clean, smart, and resilient systems and services—will create demand for an enhanced workforce to enable this transition.

1.1.1.2 Environmental Responsibility and the Electricity System

The electricity system should be developed and managed in an environmentally responsible manner by, in part, addressing the central challenge of climate change and mitigating its impacts. The national objective of "deep decarbonization" by mid-century will challenge the electricity sector in many ways. Achieving this key objective will improve the health of Americans and the environment of the country, both of which are positive contributions to matters of economic competitiveness and national security. At the same time, policymakers, investors, and industry must consider and address the longstanding needs of the vulnerable segments of the population and appropriately address these issues as the electricity system is transformed.

Other critical environmental concerns include climate adaptation; further reductions in conventional pollutants; adequately analyzing, addressing, and managing the energy-water nexus; reducing land-use and other impacts of electricity generation, transmission, and distribution; and infrastructure lifecycle management.

1.1.1.3 National Security and the Electricity System

Electricity is essential for supporting and sustaining industrial output, government, emergency services, interdependent lifeline networks, and the U.S. national security apparatus. Lifeline networks include physical and information infrastructure that are required for communications, transportation, and almost every other element of economic and social activity. Even though it is essential to the economy, lifeline networks, emergencies, and the national security apparatus, electricity—unlike oil—cannot be stored at scale. The electricity system should be a consideration and included in the development of national security doctrine, policies, and plans. A continuous effort to maintain reliable electricity supplies in the face of a growing number of potential threats (cyber, electromagnetic pulse, terrorist attacks, and natural disasters) is required for the national defense, continuity of government, economic prosperity, and quality of life nationwide.

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

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.

1.1.2.1 Maximize Economic Value and Consumer Equity

The United States has relatively low-cost electricity and a highly reliable electricity delivery system (transmission and distribution). Power is generated from both central and onsite sources, such as distributed solar and combined heat and power installations. The sum of these capabilities is a platform on which a vibrant globally competitive economy thrives.

Although electricity is an energy carrier and not a primary energy source, electricity exhibits the interchangeable characteristics of a commodity—a kilowatt-hour generated by any resource can be easily used by any type of customer. Electricity is unique as a commodity, however, because it requires real-time balancing across multiple spatial and temporal scales (location-specific pumped hydro is an exception). This requirement for immediate matching of demand and supply can result in prices that vary significantly from minute to minute or season to season.

Because many aspects of the electricity system—including R&D in new technologies, emissions mitigation, and grid reliability—are public goods and will be underprovided by private industry, the U.S. government has played a critical role in developing a clean electricity economy and making sure that the electricity supply has continued to be available, affordable, and reliable to U.S. industry and citizens.

Historically, electricity consumption and gross domestic product (GDP) have tended to move in tandem—electricity consumption has tended to rise during economic expansions and fall during recessions (between 1950 and 2013, there was a 66 percent correlation between GDP and electricity use).[12] Over the last several decades, however, growth in electricity use has been lower than growth in GDP. This is due in part to a restructuring of the economy; also, across all economic sectors, energy efficiency has been remarkably successful over several decades in helping control costs and improving performance and productivity.

1.1.2.2 Enable a Clean Electricity Future

Much of the U.S. electric system was built out before the United States had a significant complement of modern environmental laws, and without the range of technologies that have been developed and deployed to reduce air emissions and other environmental impacts of power generation, transmission, and use.

The electricity sector today is the largest source of U.S. greenhouse gas (GHG) emissions, particulate matter, and acid precipitation; one of the largest users of fresh water; a major cause of land and ecosystems impact; and the principal source of radioactive waste. Addressing these environmental concerns may require a range of new policies, acceleration of technology innovation, and additional incentives for the deployment of new technologies. As noted, the U.S. electricity system is deeply linked to environmental quality; environmental policies must be carefully and purposefully balanced with other objectives. In addressing associated issues, the United States should build on past successes in reducing the public health and environmental impacts from the electricity system based on a mutually reinforcing cycle of technological improvements and policies.

Equity is a particular concern when addressing pollution from electricity generation, transmission, and distribution. Power plants and other electricity-related infrastructure are often located in or near low-income and minority communities, creating disproportionate impacts on these populations. Also, climate change impacts—such as heat waves, degraded air, and extreme weather—will add additional stressors that will disproportionately affect low-income communities.

1.1.2.3 Ensure Electricity Reliability, Security, and System Resilience

The United States faces complicated and evolving challenges that affect the reliability, security, and resilience of the electricity system. Operators of the grid must simultaneously meet existing performance standards and system requirements, as well as address a rapidly evolving system. These changes stress the public and private institutions created to support a legacy paradigm established over the last 100 years or more. The threat environment is also changing—decision makers must make the case for investments that mitigate catastrophic, high-impact, low-probability events.[13] Also, not all hazards can be prevented; improvements are needed in technologies and processes by which the grid can fail elegantly, recover quickly, and become more resilient over time.

In addition, the electricity system is vital to the Nation's increasingly interconnected, digitally dependent economy and society. Without access to reliable electricity, significant economic value and all electricity-enabled critical infrastructures are put at risk. These include national security and homeland defense networks that depend on electricity to help ensure the safety and prosperity of the American people.

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

Grid modernization requires actionable policies, practices, and investments that help ensure system security, reliability, resilience, and a clean electricity future. These objectives have overlapping and crosscutting considerations that must be recognized and managed. The crosscutting issues examined in QER 1.2 include valuation; markets, finance, and business models; innovation and R&D; grid operations; workforce; North America-wide impacts; and institutional arrangements that are foundational to the sector. Treatment of most of these complex topics is embedded into each QER 1.2 chapter.

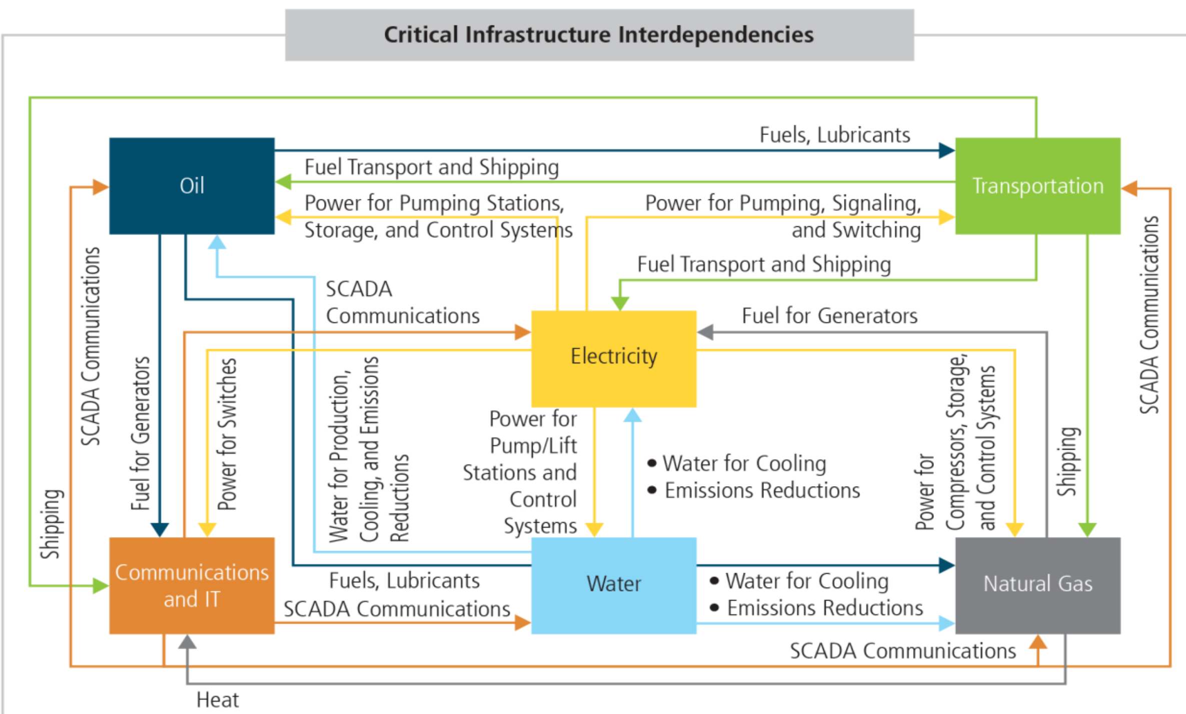
1.2 The Nation's Critical Infrastructures Depend on Electricity

QER 1.2's examination of the electricity system from generation to end use necessarily starts with a discussion of the dependence of the Nation's critical infrastructures on electricity. Critical infrastructure dependencies and interdependencies represent the core underlying framework that supports the

American economy and society. Electricity is at the center of key critical infrastructure networks that support these sectors, including transportation, oil and gas production, water, and telecommunications. These electricity-dependent critical infrastructures represent core lifeline networks that support the American economy and society.

These critical networks are increasingly converging, sharing resources and synergistic interactions via common architectures (see Figure 1-2). The oil and gas sectors rely heavily on electricity. Transportation is critical to power production because it enables the shipping of fuels; the sector also depends on electricity for key needs, such as power for signaling and switching and will become more so as more electric vehicles are deployed. Water systems are also "critical infrastructure." Water purification, movement, and treatment currently consume roughly 4 percent of the Nation's annual electricity generation;[18] in California, this amount can be up to 20 percent of electricity generation.[19] Many water facilities lack sufficient power back-up capabilities; at the same time, they meet key cooling requirements for power generation. Water availability is already a concern in many parts of the country, and climate change is expected to exacerbate this problem in key regions of the United States.[20]

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.

There is also a direct and critical link between the electricity system and the communications networks.[22] The Department of Homeland Security (DHS) identifies the information and communications technology (ICT) infrastructure as a critical infrastructure because it provides an "enabling function" across all critical infrastructure sectors. ICT infrastructure is critical to each stage in the electricity supply chain and to all other critical infrastructures seen in Figure 1-2. Within the electricity sector, ICT infrastructure is increasingly important for grid management, as well as for communications with customers and various distributed assets. In addition, electricity powers ICT systems equipment; its central control and operating systems; and even its heating, ventilation, and air conditioning systems.

The financial sector is another lifeline network that depends on electricity (through its role in enabling telecommunications) and other communications networks. DHS's 2015 "Financial Services Sector-Specific Plan" noted that, "Most of the sector's key services are provided through or conducted on information and communications technology platforms, making cybersecurity especially important to the sector. In addition, the sector faces ongoing risks associated with natural disasters, as well as the potential for physical attacks. Hurricanes, tornadoes, floods, and terrorist attacks all have the potential to cause physical disruptions that have significant impacts on Financial Services Sector operations."[23]

Natural gas and electricity interdependencies are also growing. The first half of 2016 was the first period where natural gas was the largest source of primary fuel for power generation in the United States. The increased use of natural gas for power generation introduces the potential for complications and disruptions, and it has, in fact, resulted in a futures market metric called the "spark spread" used to inform markets about the gas/electricity market relationship. The gas sector also relies on electricity in segments of the production chain, including use for field-gathering pumps, selected transmission pipelines, and gas-processing stations.

The interdependencies of key infrastructures and the essential role of electricity are illustrated by recent weather emergencies. Extremely cold weather in New Mexico in 2011 resulted in both natural gas and electricity outages; loss of electricity further reduced gas production as field-gathering pumps lost power.[24] Another example is after Superstorm Sandy in 2012 when utilities and the public experienced massive power outages in the Northeast. Recovery crews were hampered by simultaneous failures of communications systems that are almost entirely dependent on electricity (back-up systems generally provide 72–96 hours of power).

1.3 Electricity-Connected Systems and Digitization Create Significant Economic Value

The electricity system supports the increased electrification of all sectors of the U.S. economy. At the same time, almost every economic sector now relies, in varying degrees, on highly interconnected, data-driven, and electricity-dependent systems to manage operations and provide services. The evolving *electricity-information nexus* supports a wide range of products and services and has the potential for even greater value creation. It supports new information-driven enterprises, helps lower initial and ongoing costs, improves control of risks, saves time and effort, enhances productivity, and can create new market categories. The importance of the electricity system now and in the future—described in a recent study as the "central nervous system of a data-driven economy"—cannot be fully appreciated without a discussion about how digitization has enabled the Internet of Things (IoT).[25]

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

The IoT is defined as "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."[26] The rapid growth of the IoT is both a manifestation and key enabler of this major change in the economy. Electricity provides foundational support to the increasingly information-intense U.S. economy.

Digitization and ICT have enabled virtually instantaneous global communication. These networks and their associated devices are large and growing. According to a Federal Trade Commission report issued in

January 2015, "Six years ago, for the first time, the number of 'things' connected to the [global] Internet surpassed the number of people…Experts estimate that, as of this year, there will be 25 billion connected devices, and by 2020, 50 billion."[27] The manifestations of the growing digitization of the U.S. economy is stunning: 89 percent of Americans have access to high-speed broadband services of 25 megabits per second for downloads and 3 megabits per second for uploads;[28] 73 percent of American households use a computer with high-speed Internet at home;[29] 95 percent of college educated adults use the Internet; 87 percent of tax returns are e-filed;[30] and 64 percent of adults use smartphones.[31]

Not surprisingly, data-, information-, and communications-centric industries are increasing their value to the U.S. economy through digitization. Information and communications technologies comprised roughly 5 percent of GDP, based on 2014 metrics,[32] and technology-driven price declines are making ICT even more attractive for businesses. It is estimated that three areas of the economy alone—online talent platforms, big-data analytics, and the IoT—could increase GDP by as much as $2.2 trillion in 2025.[33]

The IoT is increasingly used by critical sectors of the U.S. economy. The healthcare industry, for example, is revolutionizing care operations through digital records, improving patient treatment and care by sharing patient information between hospitals. The automotive industry is pioneering electric vehicle technology for use in heavy equipment, long-haul auxiliary power units and truck stops, localized service fleets, and personal vehicles. Cities are integrating 'smarter'—inherently more electricity-intensive—cars to improve passenger safety. Urban areas with greater application of IoT technology and ICT have the potential to run more efficiently and sustainably. A study by Texas A&M University found that traffic problems and congestion in the United States alone costs more than $120 billion annually[34] without considering additional effects from increased pollution, decreased work productivity, or delayed delivery effects. The ability to coordinate various urban infrastructures (e.g., transportation, buildings, and the electricity distribution system) that can apply data intelligently would help improve operational efficiency, increase safety, lower costs, and contribute to system stability.

The IoT not only affects information flows on large systems, it is also affecting how energy consumers interact and control their home environments. Advanced thermostat devices, for example, automate temperature control, while learning software embedded in the technology integrates preprogrammed settings by the user with zip code location to identify the real-time weather—two inputs that the devices use to self-adjust. This and other home technologies, such as chore automation and remotely controlled security systems, are all part of a new era in which the IoT is utilized to provide greater comfort, efficiency, security, flexibility, and savings. Recent analysis suggests that the economic value of home automation and better integration of IoT technologies could be as high as $350 billion for the U.S. market alone.[35]

All sectors that rely on information and online activity—including email, social media, and Internet-connected business—are supported by data centers.[36] These data centers have been called "the backbone of today's digital economy," powering businesses, communications, and online consumer services and helping to make society more productive and efficient. These centers are distributed across the country, house roughly 14 million computer servers, and provide both domestic and global services. Data centers are one of the fastest-growing sources of electricity demand. More than 3 million data centers in the United States (of all sizes) now use roughly 70 billion kilowatt-hours of electricity annually.[37] This is about 1.8 percent of total national electricity consumption,[38] which is equivalent to the generation of 25 large (500 megawatt) coal-fired power plants.[39] Table 1-1 includes data for large data centers (>20 thousand square feet), which currently account for about half of total data center energy use.

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

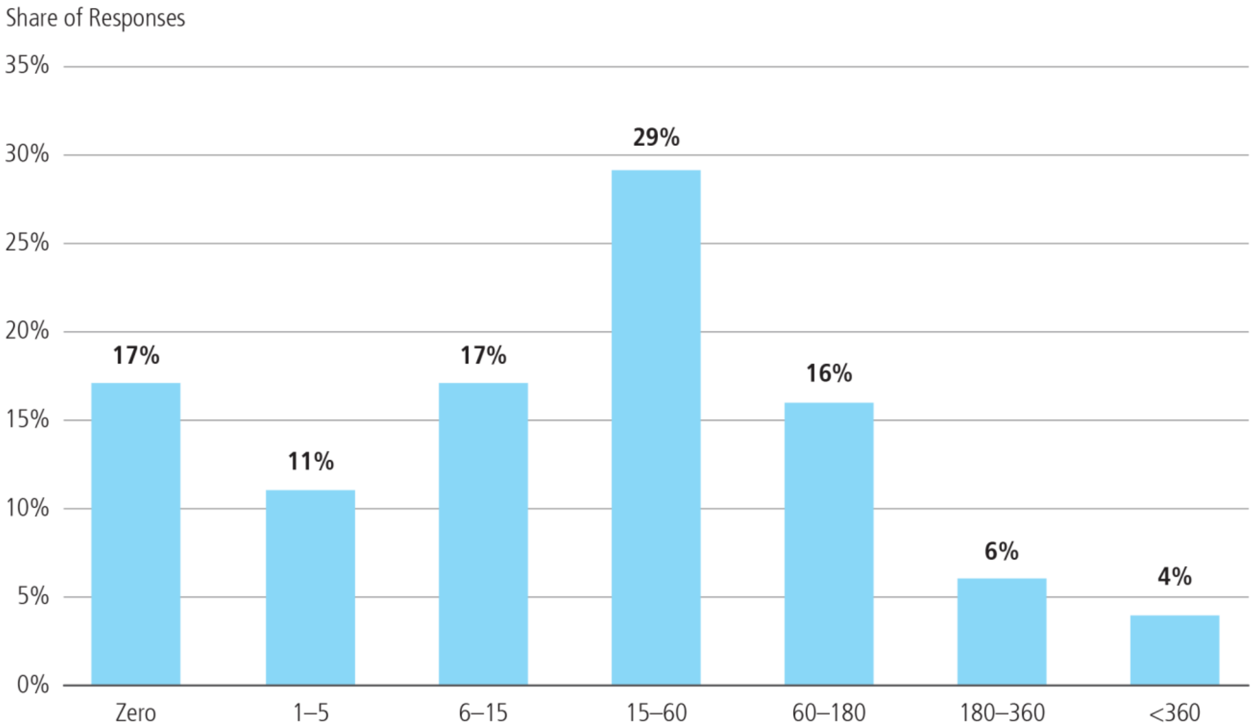
Large Data Centers (>20K square feet)	Nationwide
Number	9,500
Size	~320 million square feet
Server count	8 million
Power load	4 gigawatts
Storage	160 million terabytes
Energy consumption	37 billion kilowatt-hours
Back-up power description (Tier III+ only)	• "Redundant and maintainable" • Fully redundant 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.

All the value from data-driven, digitized enterprises is enabled by electricity that, by current standards, is highly reliable. Nationally, the average customer experiences a little over 3 hours of electric power unavailability per year.[41] [b] But even a short disruption in power can cause serious impacts on daily life and significant economic losses for information-dependent businesses. Figure 1-3 shows the results of a large survey of data center professionals who indicated that a power outage results in immediate economic losses for 17 percent of those surveyed; 45 percent experience significant losses—from $200,000 to $1 million an hour[42]—within 15 minutes.[43]

[b] Based on preliminary 2015 Energy Information Administration data. Information reported to the Energy Information Administration is estimated to cover approximately 70–80 percent of electricity customers.

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.

This 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. Larger Tier III+ data centers[c] have the most extensive alternative power arrangements with redundant power systems and onsite generation; these are limited, however, by available battery storage capacity, onsite fuel storage (72–96 hours),[45] and liquid fuel resupply agreements.[46]

In 2014, U.S. customers spent nearly $2.5 billion in capital costs to purchase and install back-up alternating current generation[47] and $3.2 billion for uninterruptible power supplies.[48] It is estimated that this back-up generation represents roughly 200 gigawatts of generation potential[49] (in contrast to a primary installed capacity of 1,100 gigawatts). Generally, these back-up systems come at a capacity cost of $200–$600 per kilowatt, but this cost profile is for a narrow set of a much wider universe of asset types that include combined heat and power, natural gas-fired units of varying sizes, fuel cells, and various storage solutions.[50]

Businesses build onsite generation because they face significant economic losses from a momentary loss of electricity or slight variation in frequency. This represents a source of lost revenue for utilities—a form of "defection;" it could also present an opportunity for utilities to provide higher-quality services than

[c] Data centers are classified by use of a four tier system established by the Telecommunications Industry Association. Tier I is the simplest level, while Tier IV is the most stringent level designed to host mission critical computer systems. Tier III+ data centers are available at least 99.982 percent of the time.

those required by the typical customer. Evidence suggests that some electricity customers are willing to pay very high prices for the incremental difference between the current measure of reliability and what they require for their business.[51]

Utility customers that install back-up systems and/or onsite generation are, understandably, hedging the risks to their businesses without regard to the overall impacts on the system. This raises a range of concerns, including the possible need for new standards of reliability and associated policy parameters; the modernization of back-up generation as part of modernization of the grid; possible incentives for onsite and back-up power generation; and interoperability needs and standards.

An aggregate average cost for all types of installed back-up power is not maintained by industry or government, and the total installed base of accessibly operational back-up power nationwide is not known; there is no Federal or other database that tracks all installed assets, their scale, fuel sources, typical annual run times, cumulative emissions effects, or performance characteristics such as how often they fail when called into operation. In addition, the Federal Government does not have any explicit government-wide back-up power standards that concern *operational* requirements; although many states have emissions control standards or building code requirements that impact back-up generation.

1.3.1.1 Information and the Electricity Sector

ICT and 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.

The use of supervisory control and data acquisition (SCADA) systems by the electricity industry has evolved over the last 90 years alongside advances in grid control technology and increases in computing and networking capabilities. Early control systems in the 1920s were installed to reduce the need for utility personnel to staff substations 24/7. Inter-utility interconnections, developed to support the war effort in World War II, demonstrated the advantages of inter-utility transactions and spurred their adoption. By the 1950s, analog computer systems were adopted to accurately monitor electricity flows. This helped enable faster and more comprehensive processing of information, which, in turn, supported improved operations, planning, and overall enterprise management.

The Great Northeast Blackout of 1965, during which 30 million people in an 80,000 square mile area of the United States and Canada were left in the dark, underscored the need for increased information coordination to support the reliability of a dynamic grid. Institutional structures—power pools and reliability councils—were improved and enhanced after the blackout. By the late 1960s and 1970s, the advent of digital computers and the rise of microprocessors and programmable logic controllers allowed for greater control and monitoring of automated utility processes.

The development of local area networks in the 1990s enabled formerly isolated and independent SCADA systems to connect to each other. Around that same time, restructuring of the power industry and new requirements for cross-border interconnections had major impacts on electricity market structure and business models. While utilities in some regions began specializing in generation, transmission, or distribution, there were also increasing requirements for entities such as regional transmission organizations (RTOs) and independent system operators (ISOs) to monitor and gather electricity data across large regions and multiple states. Both trends required greater network management, with significant increases in data flows related to comprehensive and real-time system management, in turn making SCADA systems critically important to grid management.[52, 53] Figure 1-4 visualizes the dramatic change seen in electric utility control systems.

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

Digitization can result in improved efficiencies across a utility, allowing for optimized generation, improved workforce productivity, better visibility into customer behavior, and faster diagnostics—all of which can improve reliability and reduce costs to the utility and customer. Demand response (DR) and distributed generation (DG) can be more fully integrated and managed by utilities through digitization, particularly through smart meters. Estimates done for the Department of Energy's (DOE's) Grid Modernization Initiative (GMI) suggest that if every U.S. retail seller of electricity deployed grid modernization technology to reduce the average planning reserve margin from 13 percent to 10 percent, it would result in $2 billion annual savings to the economy.[55] It is estimated that the digitization of utility processes—from smart grid, to workforce tools, to automation of business management processes—can boost profitability 20–30 percent.[56] Utility analytics is an emerging business growth area estimated to grow at a rate of 13.5 percent per year (from $1.8 billion in 2016 to $3.4 billion in 2021), with most growth in the United States.[57] Digitization also creates new business opportunities for utilities, such as remote building energy management and energy efficiency services.

Grid modernization will be enhanced by the integration of operations technology (OT systems and information technology (IT) systems, that currently tend to serve important but distinct utility functions. OT provides the control system that executes and monitors the electricity system, aiming to protect the network, prevent electric outages or blackouts, and reduce the cost of operations. OT provides oversight and control of the physical assets that create the electricity system in real time—from generators, substations, and distribution networks to meters at the point of use. Systems that are in the realm of OT applications include distribution management systems, energy management systems, geographical information systems, and SCADA systems.

IT, on the other hand, is generally used for decision making on the enterprise level. This usually involves a variety of teams that must be closely synchronized to provide consistent operation, spanning areas such as business processes management, resource and asset allocation, workflow coordination, and energy and operations planning. IT software applications include energy portfolio management, customer information systems, advanced metering infrastructure (AMI), DR management, and mobile workforce management.[58]

As the electricity system becomes more digitized, connected, and complex, increased integration of IT and OT systems could enhance operational efficiency; minimize duplication of systems and processes; reduce costs; improve asset management; and integrate information and operations technology, data, and communications systems.[59]

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

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.[60] As of 2015, 43 percent of residential electricity customers are serviced through smart meters, and a small but growing number of residential customers are on dynamic electricity pricing tariffs.[d, 61] Microgrids are also becoming more prevalent as DG, storage, and demand management technologies have decreased in price and the public begins to place greater emphasis on ensuring system reliability during grid outages and natural disasters. While the total capacity of microgrids is now fairly small, communities and states are increasingly encouraging their deployment.[62 63, 64]

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.

It is important to note that the smart grid is part destination and part vision. How the smart grid evolves will be highly dependent on many factors, including policy, regulatory jurisdictions, investment, regional needs and requirements, market structures, and technologies. Examples of smart grid systems include the following:

- AMI, which consists of smart meters, communications networks, and information management systems, is capable of delivering electricity usage data every 15 minutes or faster to utilities and their customers. AMI features include remote meter reading and remote connects/disconnects, saving utilities millions of dollars. In addition, meters can be used to support outage restoration efforts and voltage optimization practices in distribution feeders. The practical application of time-varying rates is also made possible by AMI, with results showing up to 30 percent of peak demand reduction among residential customers (observed in the American Recovery and Reinvestment Act of 2009 [ARRA] projects).[65]

[d] Smart meters are defined here as advanced metering infrastructure, or AMI.

- Fault location, isolation, and service restoration technology enables the near-instantaneous reconfiguration of distribution circuits through switches and reclosers and greatly reduces outage time experienced by utility customers.[66]
- Voltage optimization technology permits grid operators to actively adjust voltage levels along distribution feeders to ensure proper levels. When operated to keep voltage levels low, but within required ranges, less power is required to meet load requirements and customers save energy (up to 3 percent or more of their total load).[67]
- Equipment health monitors measure temperature, voltage, and the levels of other parameters in transformers and other devices, permitting a utility to observe deterioration and operate devices more efficiently.[68]
- Synchrophasor systems—consisting of phasor measurement units, communications networks, and data visualization systems—send time-synchronized data on voltage, current, and frequency conditions 30 times per second (or greater) to transmission grid operators, allowing them to detect and diagnose problems that conventional SCADA technology cannot observe. For example, synchrophasor technology can see transmission grid oscillations that can result from improperly set controls, inadequate models, or malfunctioning equipment—permitting grid operators to quickly adjust and correct the system.[69]

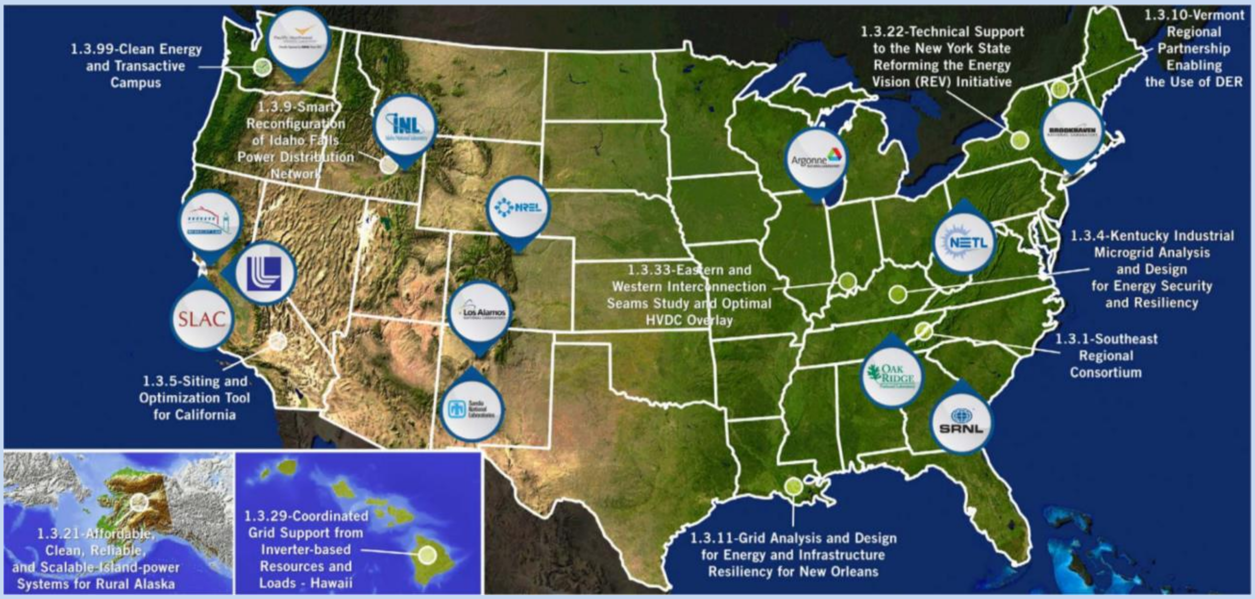
In 2009, DOE received $4.3 billion in ARRA[e] funds to support the demonstration and deployment of these smart grid technologies across the Nation. By adding to efforts well underway in the electric power industry, ARRA helped catalyze the advancement of smart grid technologies, including smart meters, programmable communicating thermostats, automated feeder switches and capacitors, equipment health sensors, and phasor measurement units plus requisite communications and information management systems. In some cases, utilities were able to accelerate their smart grid deployment plans by up to 5 years, while others less familiar with the technology were able to start their modernization efforts with ARRA support.[70] An important use of ARRA smart grid funding was to provide the initial support for DOE's ongoing GMI, which is described in detail in the box below.

[e] ARRA was a stimulus package enacted by the 111th United States Congress in February 2009 and signed into law on February 17, 2009, by President Barack Obama. ARRA supported many of the initiatives presented within Title XIII (Smart Grid) of the Energy Independence and Security Act of 2007.

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*	Investigation, development, and analysis of the risks, costs, and benefits of a microgrid utilizing renewable energy systems at the UPS WorldPort and Centennial Hub facilities. Develop roadmap to help industries evaluate microgrid adoption by defining institutional and regulatory challenges associated with development of industrial-based resilient systems.	United Parcel Service, Waste Management, Burns & McDonnell, Harshaw Trane, Louisville Gas and Electric, State of Kentucky

Project	Summary	Partners
Midwest Interconnection Seams Study *National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory*	Convene industry and academic experts in power systems to evaluate the high-voltage, direct current and alternating current transmission seams between the U.S. interconnections and propose upgrades to existing facilities that reduce the cost of modernizing the Nation's power system.	Southwest Power Pool, Midcontinent Independent System Operator, Western Area Power Administration, Solar Energy Industries Association, Minnesota Power, Xcel Energy, Tetra Tech, Transgrid Solutions, Utility VariableGeneration Integration Group, Bryndan Associates
Grid Analysis and Design for Resiliency in New Orleans *Sandia National Laboratories, Los Alamos National Laboratories*	Conduct technical evaluations to assess energy and critical infrastructure vulnerabilities and to identify cost-effective options to improve the resiliency of both the electrical grid infrastructure and the community.	City of New Orleans, Rockefeller Institute, Entergy, U.S. Army Corps of Engineers

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

There is a new set of demands on grid function and structure that was not fully appreciated 7 years ago when ARRA funds were made available. As the number of integrated, intelligent assets increases, the speed of communication, coordination, and control will require more distributed, automated (machine to machine) intelligence dealing with sub-second decisions that cannot be managed by human operators in real time. The scope of "smart" must evolve to include machine learning to manage the co-optimization of systems and subsystems while maintaining system reliability as more DER are integrated into grid operations.

The key ingredient to enabling this capability are ICT networks that not only support grid operations, but also permit, where appropriate, its convergence with other infrastructures, including buildings, transportation, water, and natural gas infrastructures. It is envisioned that the integration of intelligent assets across these systems will provide enhanced levels of efficiency, asset utilization, and innovation. Speed and precision will be essential elements for ensuring a highly reliable electricity system. Well-designed smart grids are structured to enable adaptation to ever-changing device characteristics and requirements. At the same time, new devices that impact the grid and utilities are finding that vendors are retiring the manufacture of analog meters, which means that when meter replacement is required, it will lead to the need for building automated meter infrastructure.

1.4 Electricity Systems and Grid Management Are Facing New Challenges

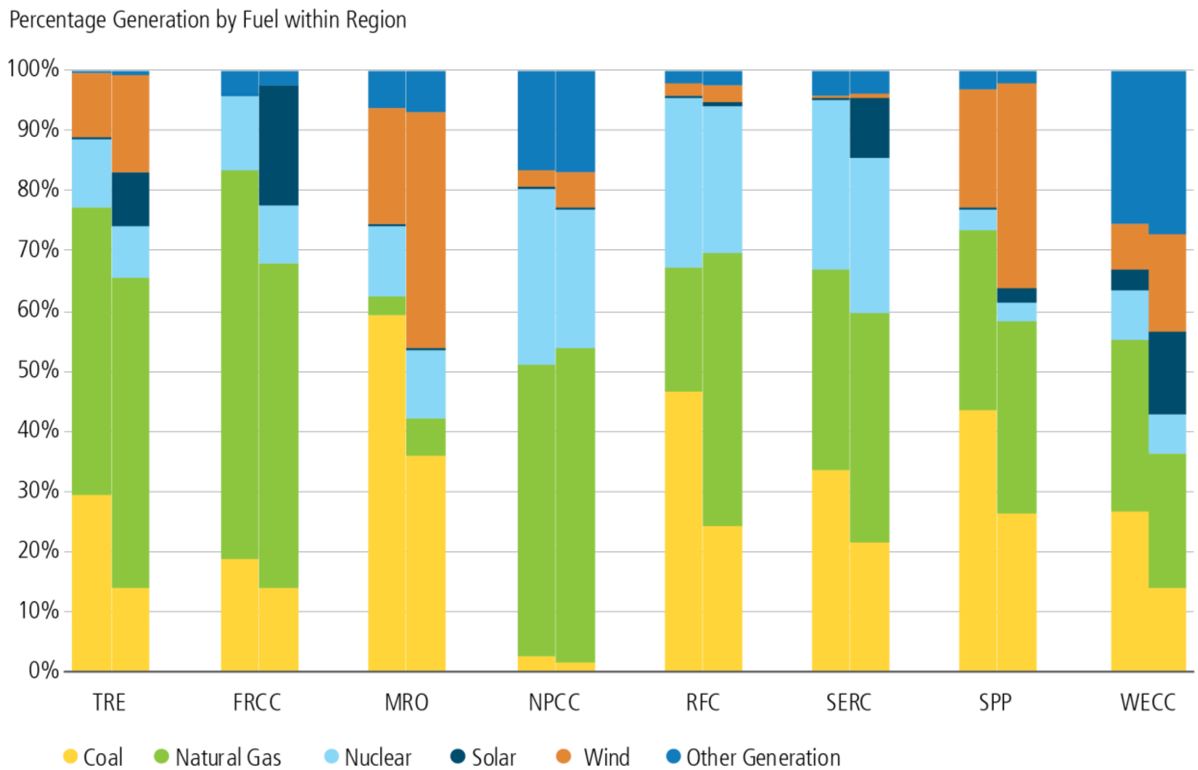
While electrification and digitization have created new opportunities for utilities to improve reliability and reduce costs, other trends in electricity generation have created new challenges for grid management. Increasing deployment of variable energy resources (VERs) such as wind and solar power, the interaction of DER with baseload generation, and the changing role of electricity customers have increased the complexity of matching electricity supply with demand at all times. At the same time they pose challenges, each of these trends has distinct advantages, such as helping to enable the decarbonization of electricity generation, increasing consumer options and services, and advancing grid management solutions, such as flexibility and grid-scale storage. Many of these trends are discussed in detail in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

1.4.1 The Changing Generation Profile

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.[73] In 2005, the top six generation sources in descending order were coal, nuclear, gas, hydro, petroleum, and renewables. By 2015, gas and coal were tied at the top, followed by nuclear, renewables, hydro, and petroleum.

Generation changes between 2016 and 2040 (see Figure 1-6) are expected to be uneven, both by technology and region. Over this time period, nuclear and hydroelectric generation is projected to be relatively flat. The shift from coal-fired to natural gas-fired generation is strongest in the eastern half of the country (where growth in renewable electricity is modest), while the western United States is experiencing rapid growth in renewables.[74] Regional generation mixes vary significantly from the national generation profile, and there are major differences among the regions in both generation mix and the addition and retirements of capacity.

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.

VERs are increasing in both capacity additions and generation. These additions have been enabled by new technologies, cost reductions, and a range of policies. Specific policies to support VERs (and other clean energy options) include State and Federal production and investment tax credits, renewable portfolio standards in 27 states, and net metering policies or other incentives in 43 states. California offers an example of VER potential. The California ISO expects to achieve a 30 percent penetration level of VERs by 2020 and 50 percent penetration by 2030.[76]

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

The introduction of new grid control and optimization algorithms that take advantage of VERs and DERs and load flexibility could contribute to U.S. grid reliability and have a range of benefits, including the reduction of renewables curtailment; the reduction in transmission and distribution congestion; and improvements in power and grid vulnerability quality.[77]

Renewable resources—both utility scale and distributed—are, however, more variable in their power production, requiring investment in assets, systems, and processes to mitigate such variability. VER-dominated resource portfolios will require more rigorous grid controls than those currently exercised by today's grid operators. Also, in the absence of comprehensive visibility to grid operators of, and information about, DER and automated DR techniques, it is unclear how much decarbonization potential is being underutilized and undervalued.

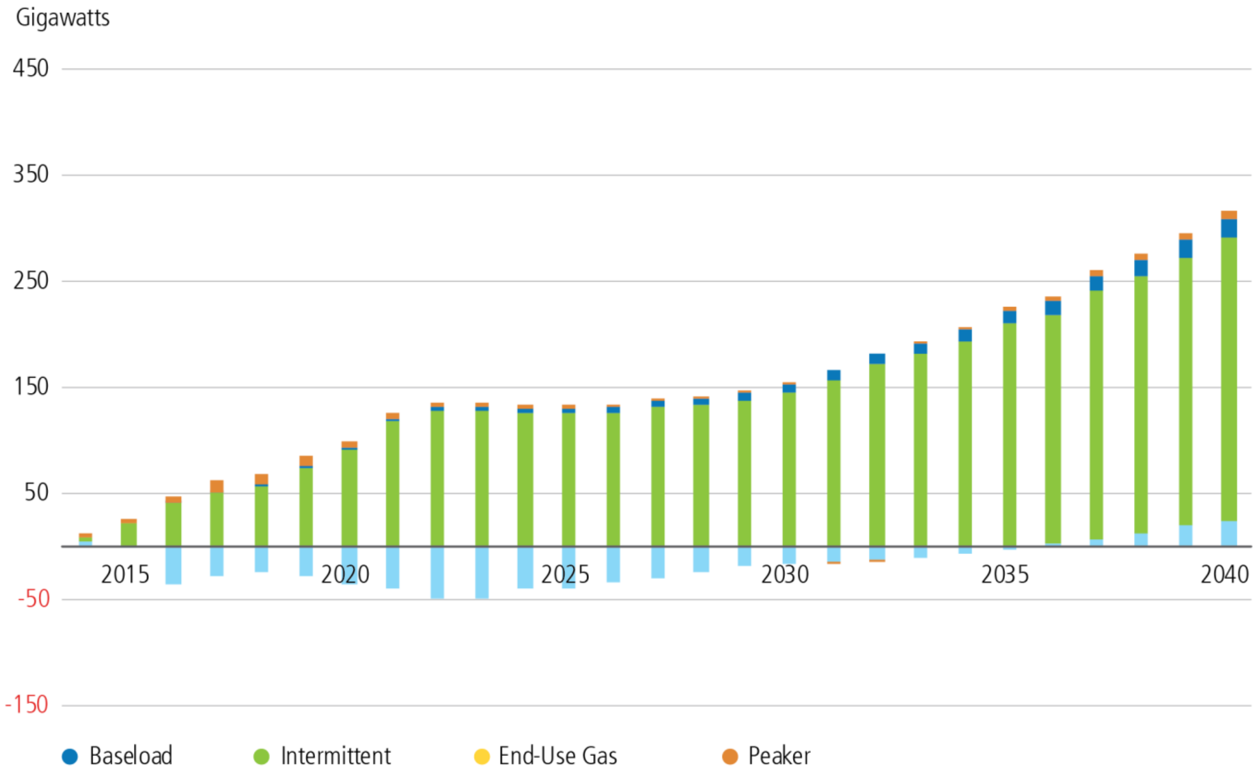
In addition, the absence of comprehensive information on the total available and active power production from distributed resources, principally solar, can complicate grid management. States are working to address these issues. The California Solar Initiative, for example, is part of a California Public Utilities Commission mandate to build and maintain a publicly accessible data set of capacity and technical specifications of DG systems throughout the state.[78] In Hawaii, a collaboration between DOE and the Hawaiian Electric Company is designing new capabilities for energy management systems,[79] introducing greater visibility of DG by factoring advanced 15-minute, short-term wind and solar forecasting into its energy management systems decision-making process.

1.4.1.2 Role of Baseload Generation

Electricity demand has always been variable. To manage this variability, system operators have traditionally relied on a generation mix that falls into three general categories: baseload, intermediate and peaking plants, and some demand-side resources such as DR. Because baseload units are usually capital-intensive generators with low operating costs, they are operated at high output, typically with capacity factors above 50 percent.[80] Intermediate units vary their level of output to keep the system in balance with changing levels of customer demand. Peaking plants have low capital costs and high operating costs and are used in periods when demand is high (peaks). There is an optimal mix of these three types of resources based on the tradeoff between capital costs and operating costs—recognizing the amount of time each type of resource is expected to operate.

Notwithstanding gains in VERs, today's electricity system is highly dependent on baseload generation (see Figure 1-7). Approximately 86 percent of the current grid-connected electricity is fueled by coal, natural gas, and nuclear.[81] Based on the Energy Information Administration's *business-as-usual* projections, by 2040 the United States still will rely on coal, nuclear, and natural gas to provide 74 percent of its grid-connected power.[82] In the long run, grid-scale storage could be a game changer, affecting the need for traditional baseload in the very long term. Storage technology costs and barriers and diffusion rates will, however, greatly affect the role of grid-scale storage in transforming the electricity system.[83]

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.

Historically and in business-as-usual projections, baseload generation has provided a range of essential reliability services. High capacity factor and low- or zero-carbon-emitting generation plants can reduce reliability risks, as system operators work to manage the increased complexity associated with variable generation and controllable load. In a future where significant DG co-evolves with utility-scale renewable resources—notably solar—there are several issues to consider regarding baseload generation, including:

- Changes in defined baseload characteristics and requirements as the sector transforms to higher VERs and DER and utility-scale storage.
- The extent to which central station, large-scale power generation is the least cost/best fit platform for an electricity sector with diversified utility scale and distributed resources of all types.
- The degree to which long-term resiliency requirements for ensuring a robust and secure system argue for or against baseload generation.
- How reserve margin requirements might change in low net demand/high resource markets.

The amount of baseload generation needed to support load and balance resources has long been addressed through established ratemaking processes and State-level energy planning. Consideration of these issues and the ongoing value of traditional baseload resources is, however, a new and important question for DOE, the Federal Energy Regulatory Commission (FERC), the North American Electric

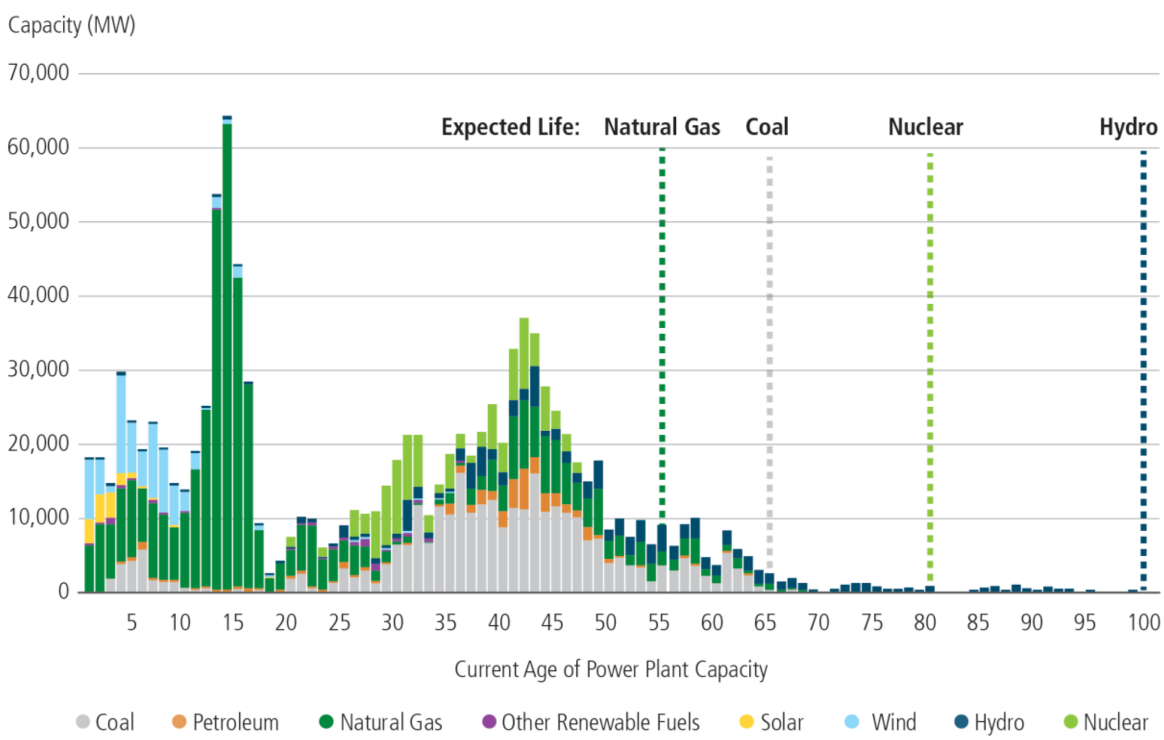
Reliability Corporation, the states, industry, and the range of stakeholders involved in system changes and transformation.

1.4.2 Aging Infrastructure: Challenges and Opportunities

Like any infrastructure, the physical components of the electricity system are constantly aging. The continual maintenance and replacement of electricity system infrastructure components, however, provides an important opportunity to modernize the electricity system. Replacement of antiquated infrastructure with new technology can enable better failure detection, upgrade technical capabilities, and improve cybersecurity.[85] Investments in new control and distribution management systems can harness the latent capabilities of smart meters, digital communications systems, and system control devices to reduce outages and increase efficiency.[86] New transmission technologies allow operators to get more capacity out of the same rights-of-way and better monitor the health and status of the grid.[87]

The electricity infrastructure is, however, large and complex, and equipment has a long lifespan; modernization is an ongoing process.[88] Only a small minority of power plants will reach their expected lifespan over the next two decades (see Figure 1-8). Refurbishment, upgrade, and maintenance can extend the useful life of a power plant far beyond its planned service life. Power plants are overhauled on a regular basis, and some are repowered to run on a different fuel or at a higher output capacity at some point during their useful lives. Large portions of a facility may be replaced over many years, providing opportunities to increase efficiency, add new technologies, and otherwise modernize plants.

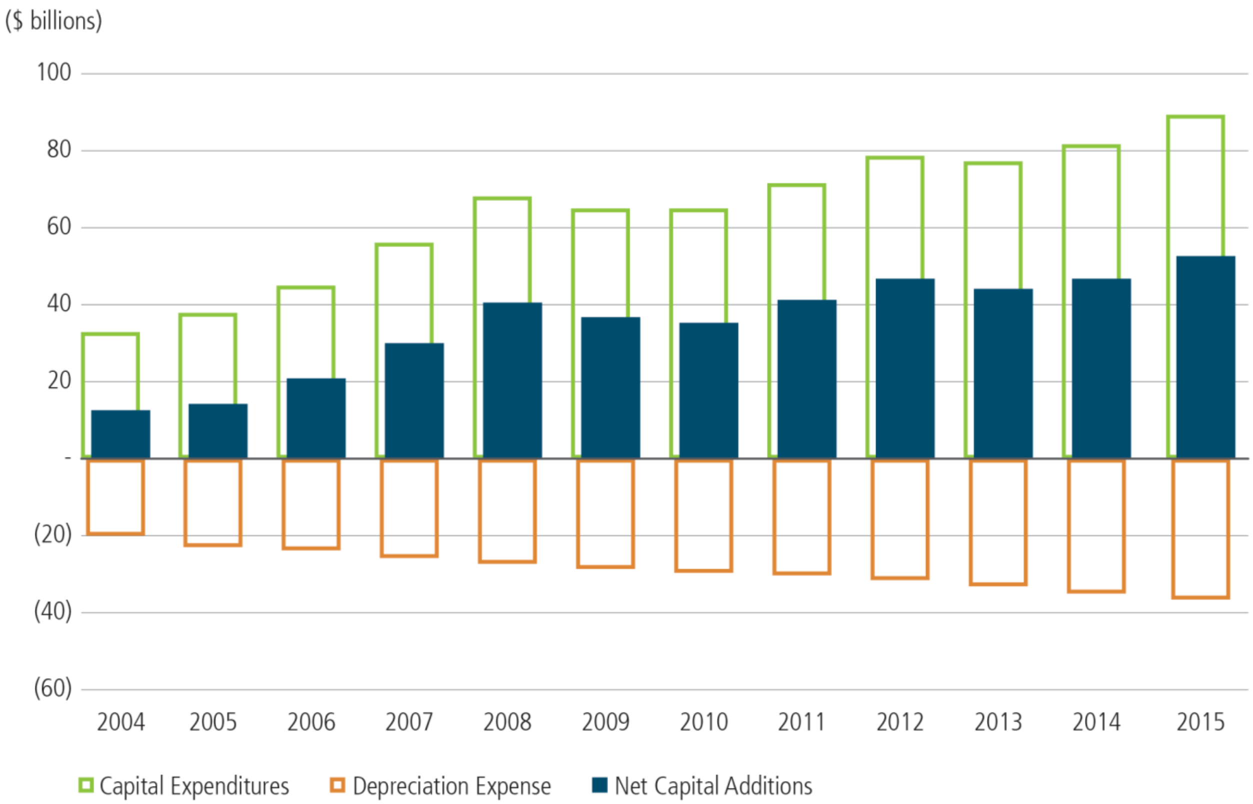
Figure 1-8. Current Age and Expected Life of Generation Fleet by Nameplate Capacity, 2015 [89]



Much of the U.S. generation fleet is 11–20 or 41–50 years old, with plants over the age of 50 being dominated by coal and hydropower. Much of the U.S. generation fleet is 11–20 or 41–50 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.

For distribution systems, asset monitoring, investment, and replacement is at the core of a utility's mission and business model; utilities and their regulators are diligently ensuring the continued reliability of their systems through proactive replacement and repair. Data availability is a challenge for comprehensive analysis of distribution utility infrastructure; over 3,000 utilities have cumulatively installed millions of poles, small transformers, and other distribution equipment. Financial records provide some insights into the aggregate age of a utility's overall assets and suggest that investment in grid assets is outpacing the depreciation of the overall asset base; this is shown in Figure 1-9, which depicts the widening change between capital investments and depreciation charges.

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

For over 100 years, the electricity system has been operated through one-way flows of electricity and information. Figure 1-10depicts this historical one-way flow of electricity service, from power produced to power consumed, with customers largely functioning in an analog environment.[f]

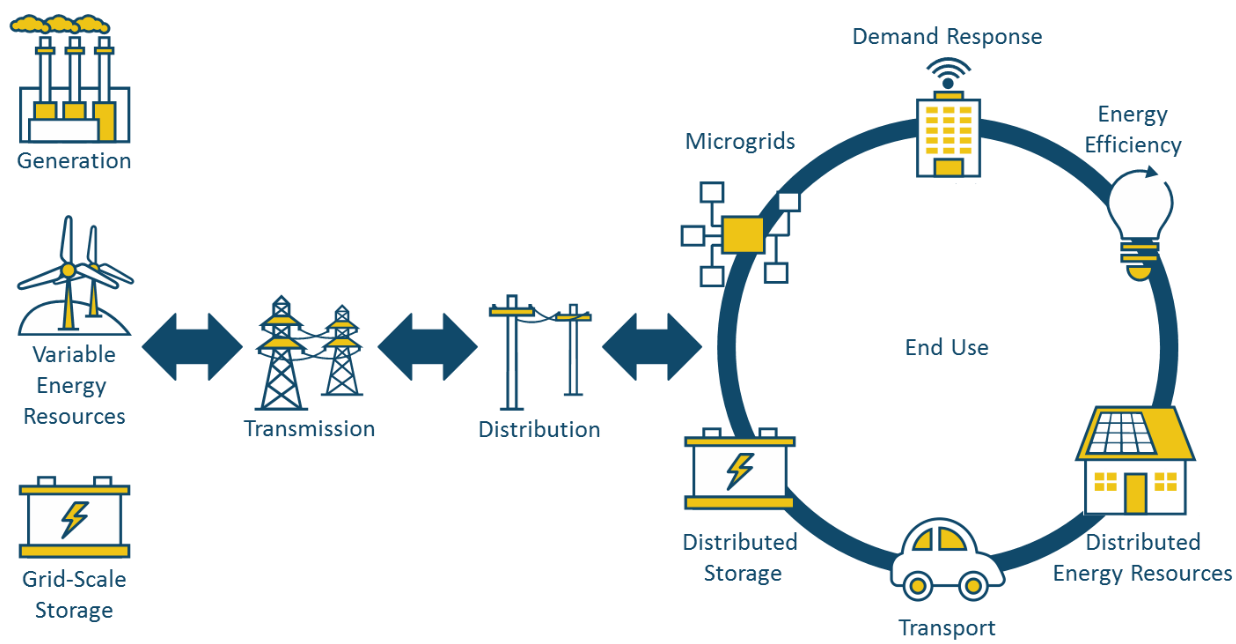
[f] Analog and digital technologies both transform information into electric signals. Analog technology translates information into electric pulses of varying amplitude, while digital technology translates information into binary form (zeros or ones) where each bit is representative of two distinct amplitudes.

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.

The generation and smart grid technology innovations described earlier can reduce grid costs and improve efficiency, as well as save time and effort; but until recently, computer processing speeds and low-cost digital measurement and sensor technology limited the ability of grids and consumers to manage end-use behavior in highly granular ways. The development of new technologies to manage these end uses has also enabled two-way flows on the electricity system. Figure 1-11 summarizes key changes in the electricity system, where such 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.

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.*

New control technologies and an evolution in electricity market design will facilitate the reliable and economic operation of the new capabilities in a 21st century grid. ICT has already improved the operations of the grid within and across regions. For example, advanced inverters on distributed solar resources can provide a variety of localized grid support functions, including voltage regulation and frequency ride through.[g] [93] Nearly all market regions have incorporated active power control of wind turbines into their dispatch procedures to manage transmission congestion.[94] Also, several market regions have changed market rules to reflect the fast reaction of energy storage to frequency regulation operating signals.[95]

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

The role of the electricity customer has been changing since Thomas Edison first launched the electricity industry. Throughout the 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 much more, and more simply, customer-centric.

States and utilities are exploring new distribution utility business models while the private sector is providing new products and services to consumers. In the past decade, the electricity industry has seen a large increase in the number of businesses focused on providing electricity-related products and services outside of traditional utility business models.[96] These businesses have found opportunities to provide value to customers through innovative technologies, novel business models, and supportive State and Federal policy decisions—they are also changing the role of some ratepayers from passive consumers of electricity to informed shoppers and producers of electricity and related end-use services.[97] Many of these services are enabled by the recent widespread adoption of advanced electricity metering and communication systems that provide ratepayers with unprecedented levels of information regarding their own energy consumption patterns.[98] The distribution utility business model is discussed further in Chapter II, *The Electricity Sector: Maximizing Economic Value and Consumer Equity.*

Many businesses are now providing distributed generation, end-use energy services, and aggregated demand services. These "aggregators" are playing a growing role in this customer-centric view of load. Aggregation involves grouping distinct end users in an electricity system including traditional consumers; consumers that produce power for grid use; third-party onsite producers, such as energy service companies; competitive retailers; and facilities management service entities. This aggregation of consumers enables them to act as a single entity, providing a service to utilities under a contract, or to centrally-organized wholesale markets operated by ISOs/RTOs through participation in resource auctions. In short, aggregators are enterprises that orchestrate and manage aggregated electricity-related services enabled by new technologies and the smart grid. Value realized through aggregation transactions is typically shared between aggregators and their clients.

The core workflows of aggregators involve applying technical services such as engineering analytics, process system design, asset acquisition and installation, and ongoing operations and maintenance, as well as economic services such as leasing to support adoption of services, shared savings-based transactions that reduce client costs, and ownership of systems for which a monthly fee is charged to clients. While there are many variations of these general enterprise activities, Figure 1-12 provides a general depiction of the consumer and buyer categories for aggregators and the potential system value that could be associated with various aggregations.

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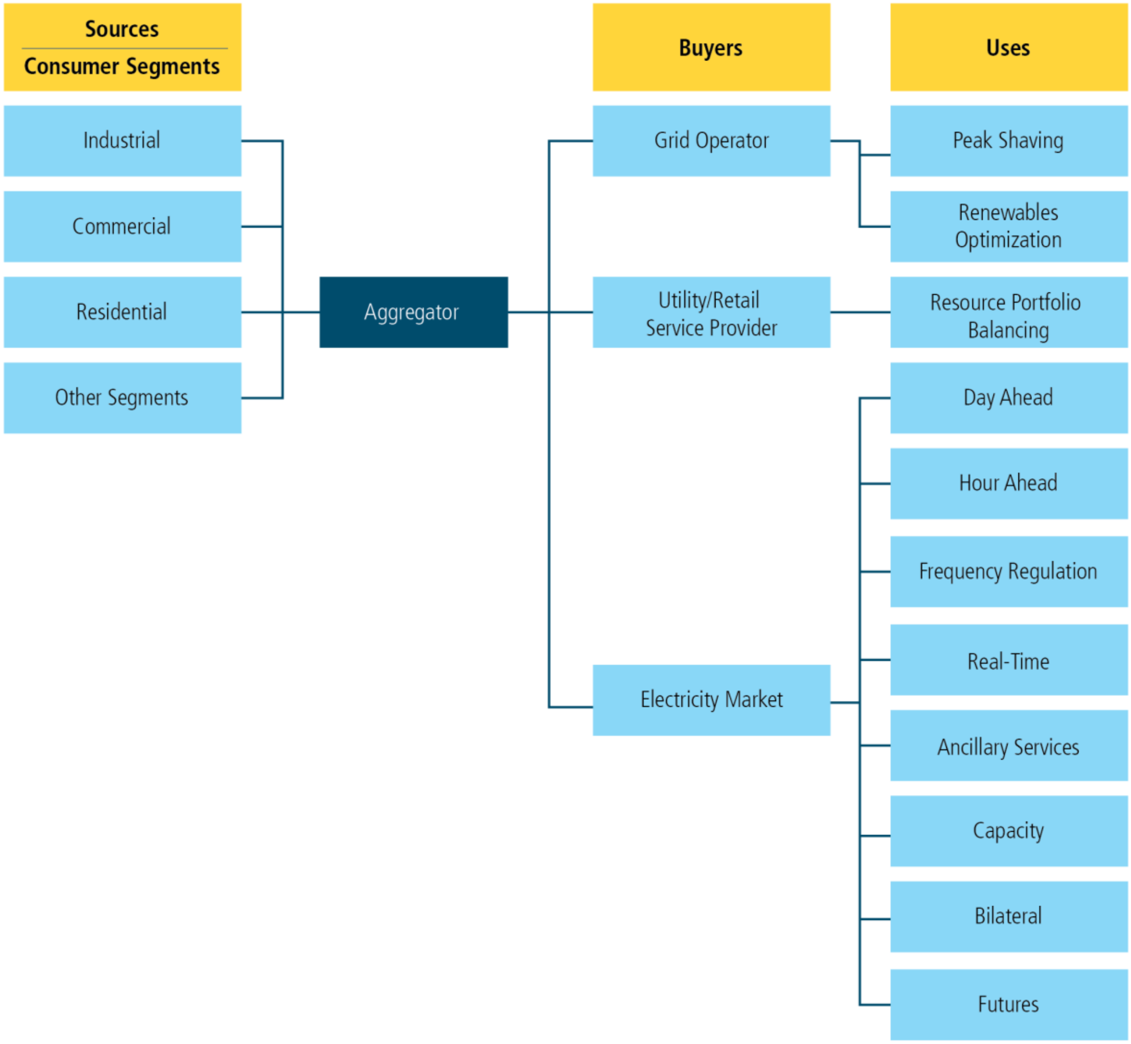
[g] Frequency ride through refers to the ability for a generation technology to maintain operating through momentary grid disturbances like a dip in voltage or frequency.

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.

The roles that non-utility aggregators play can be of great value in supporting grid reliability and flexibility. The growing penetration of DER increases the depth and diversity of value-added services aggregators can offer. Aggregators are not, however, regulated entities; their value propositions tend to be riskier than those of regulated entities. Their client engagements are also subject to negotiated terms and conditions that can result in an uneven distribution of benefits between members of an aggregation, as well as between the aggregator and all clients. To maximize their value to the electricity system and grid operations, aggregators need adequate capitalization, sufficient pooling of clients to ensure reliable execution of DER-related services, and improved execution of client-related activities. Their activities also need to be both visible and reliable for distribution utilities to maximize the value of these services to the operation of the grid.

Regulated utilities can also aggregate demand through specific programs approved by regulators. The economic and reliability value of DR programs depends on customer availability and commitment to participate. DR challenges include: partial delivery against contracted DR volumes; the inability to sustain DR commitments for the entire duration of an event; or nonparticipation when called on for service. These challenges impact daily resource planning and production where gaps in DR performance must be addressed with other resources; these challenges devalue DR and inhibits its optimization as a resource for load shaping and following.

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

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 system. 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 system.

The United States has also been experiencing a long-term population shift from rural to urban areas since the start of the last century. According to the U.S. Census Bureau, around 20 percent of the U.S. population lived in rural areas in 2010, while more than 70 percent lived in urban areas.[99] This makes it especially challenging for utility companies located in rural areas to retain and attract a high-skilled workforce. Also, since the early 2000s, baby boomers are retiring in increasing numbers.[100] Industry surveys indicate that roughly 25 percent of employees will be ready to retire within the next 5 years.[101] [102] Fifteen percent of lineworkers are forecasted to retire between 2016 and 2020, in addition to 19 percent of technicians, 17 percent of non-nuclear plant operators, and 15 percent of engineers.[103] One recent survey suggested that 43 percent of utilities view retirements and an aging workforce as one of their most pressing challenges.[104] These workers retiring have experience and skillsets that are difficult to replace.

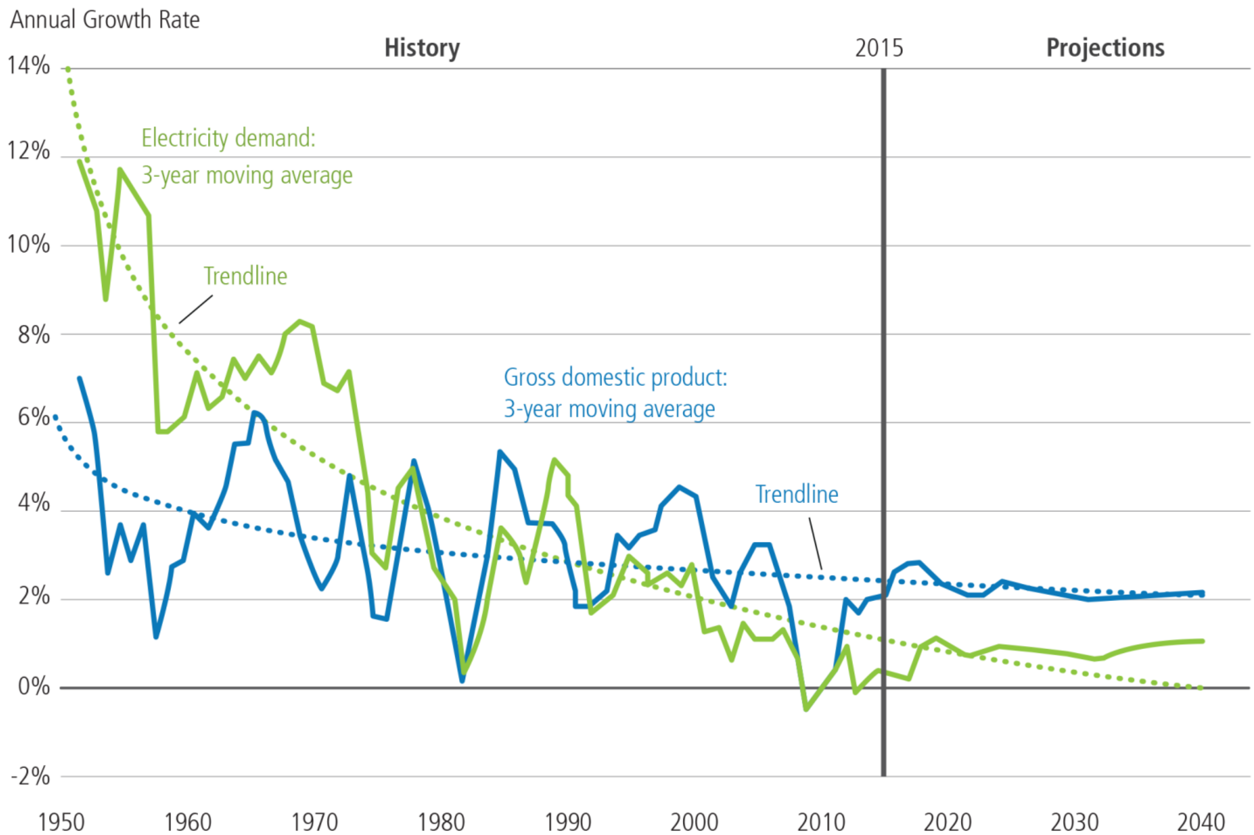
Jobs in the electricity industry require a varied range of new skills. Traditional utility jobs include lineworkers, power plant operators, technicians, pipefitters and pipe layers, and engineers. Additional field support includes truck drivers, inspectors, mechanics, and electricians.[105] While traditional jobs such as lineworkers will continue to be needed, increases in renewable energy generation and ICT will change the skillsets required for some jobs and the relative need for employees in different roles.

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

While electricity is the workhorse of the economy, it is also responsible for 30 percent of U.S. GHG emissions.[106] U.S. power sector emissions declined by 20 percent since 2005, largely due to a slowing of electricity demand growth and the accelerated deployment of lower-carbon generation.[107, 108]

Since the 1950s, growth in U.S. electric consumption has gradually slowed each decade (see Figure 1-13). A number of factors have led to this gradual slowing of electricity demand growth rate, 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.[109, 110]

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.

Past and future electricity demand growth rates are driven by several sector-specific trends that reflect broader economic changes. For example, while industrial demand growth is virtually flat, productivity (as measured by units of GDP produced per unit of energy consumed) is growing. The industrial sector's electricity productivity nearly doubled between 1990 and 2014. Projections suggest that grid-purchased electricity will rapidly increase in the industrial sector from 2010 until 2025, after which growth is projected to slow to 2040 when it reaches 1,218 terawatt-hours (25 percent above the 2010 level).[112]

1.5.1 Decarbonizing the Electricity System

U.S. power sector emissions declined by 20 percent since 2005, largely due to a slowing of electricity demand growth and the accelerated deployment of lower-carbon generation.[113] Low natural gas prices have led to substantial substitutions of lower-emitting gas for high-emitting coal. 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. 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. It will also play a major role in the levels of decarbonization needed from other sectors such as transportation. Many of these trends are discussed in detail in Chapter IV (*Building a Clean Electricity Future*).

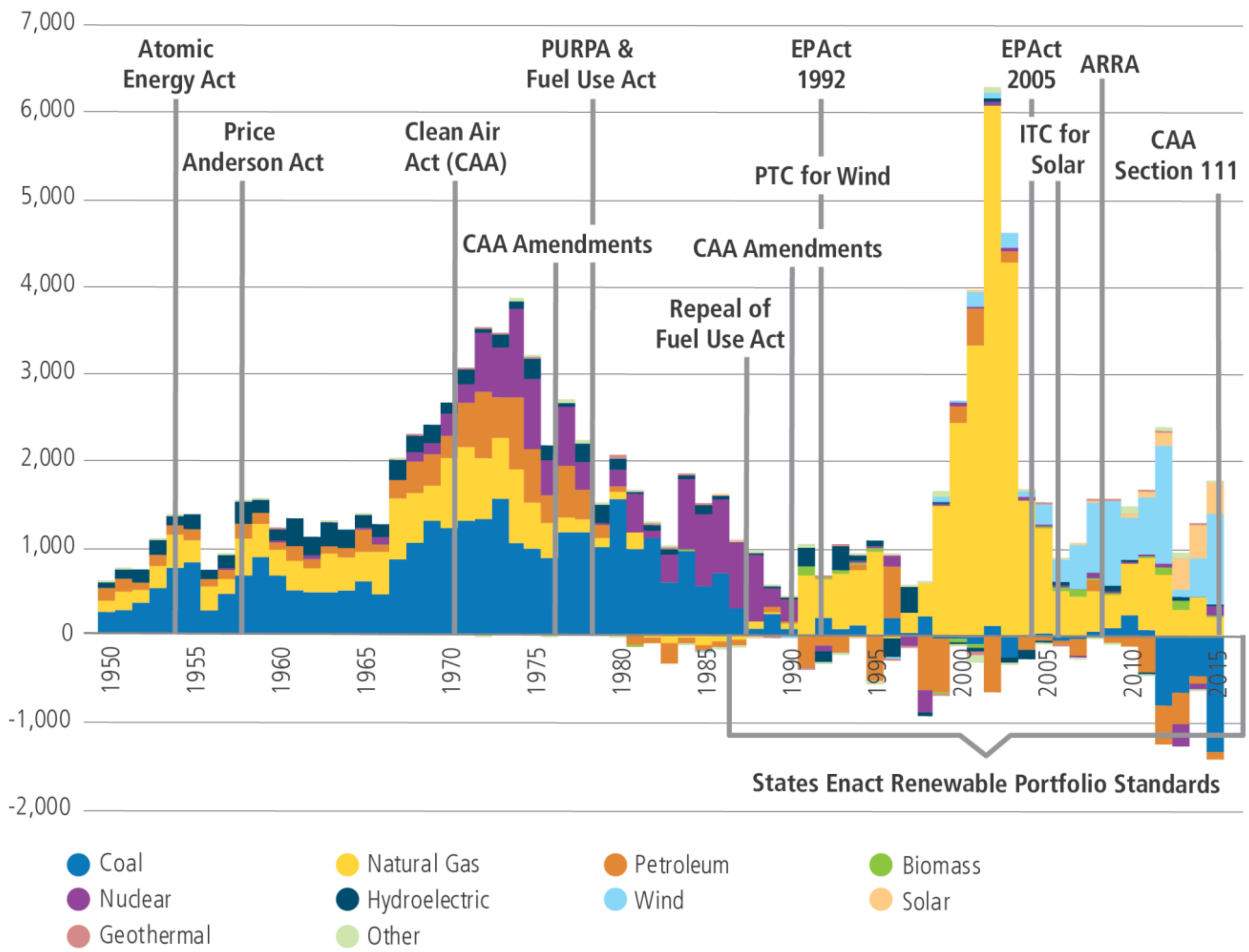
The importance of decarbonization argues for ensuring that Federal and State policies provide compelling incentives for transitioning the electricity sector as part of achieving national goals. Options for decarbonizing the electricity sector must address significant barriers in three broad categories: technical (e.g., long time frames for research, development, demonstration, and deployment [RDD&D] gestation); structural (e.g., long time frames for capital stock turnover); and policy (e.g., difficulties in mobilizing needed investment).

Investment in innovation is needed, including investment in advancements of known technologies, as well as in fundamental breakthroughs. The potential for research, development, and demonstration to increase deployment of existing technologies and unlock future technologies is significant, and long-range planning must take technology time scales and deployment timelines into account. The innovation process is iterative, requiring early deployment and technology learning over time. Also, beyond enabling domestic GHG reduction and improving economic well-being, innovation can significantly accelerate and ease the path to global emissions reductions, both of which are critical to reducing adverse climate impacts.

In addition, transitioning to a low-carbon electricity future requires policies that accelerate deployment of low-carbon generation.[114] The long time frames for capital stock turnover also motivate early action. There are Federal tax credits and State policies, such as renewable portfolio standards, that are driving investment in energy efficiency and renewable power, but additional policies may be needed for the accelerated deployment of these and other critical grid-related technologies.

Well-designed policies can help facilitate and enable market mechanisms that drive least-cost approaches to mobilizing and leveraging public and private investment, minimizing the risk of stranded assets and reducing emissions. Conversely, policies that replace or significantly interfere with market mechanisms can have unintended and long-term impacts. For example, as Figure 1-14 demonstrates, the passage of the Powerplant and Industrial Fuel Use Act (FUA) in 1978 in response to the Arab oil embargo of 1973 and perceived shortages of natural gas fundamentally outlawed the use of natural gas in power generation. After the passage of the FUA, there was a significant drop in natural gas generation capacity additions. Gas capacity only began to grow again after the repeal of the FUA in 1987 and the development of natural gas combined-cycle turbines. In the interim years when the law was in effect, significant coal generation capacity was added to the U.S. generation fleet, with long-term impacts on the generation mix and carbon emissions. Figure 1-14 shows several additional examples of polices driving changes in the generation mix. Further details on these policies can be found in the Appendix (Electricity System Overview).

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.

Many generation owners and most economists maintain that a price on carbon is the most efficient means of achieving decarbonization. Many investors already assume a shadow price on carbon when making investment decisions. States have also taken a number of actions to reduce conventional pollution and, more recently, GHG emissions beyond what is required under national environmental statutes. In addition, many cities have set explicit goals to reduce GHG emissions and have enacted policies to help meet those goals. Finally, several RTOs/ISOs have issued studies on the effects of adding a carbon charge to wholesale markets. ISO New England stakeholders are, for example, discussing changes to their ISO market design that includes a carbon price.[116]

States are also pursuing a range of energy efficiency policies with climate co-benefits. These efforts are important and effective, but they tend to underestimate the value of other zero- and low-carbon technologies, such as nuclear power and carbon capture and storage for both natural gas and coal generation. The GHG mitigation benefits of the existing fleet of nuclear power plants, which provide 60 percent of U.S. zero-carbon generation, merit consideration as valuable, sustainable resources, where current wholesale market designs and regulatory-based cost-of-service valuations tend to not "price in" these values. Hydropower is also carbon-free and a major source of electricity storage as well.

Finally, the United States has already made significant progress toward a higher-efficiency, lower-carbon electricity system, and more progress is expected going forward. To fully realize the carbon reductions potential of electricity sector from generation to end use, digitization to create a more connected, interactive, and integrated system will be essential. Decarbonizing the power sector will also require increased carbon-free energy; improved energy efficiency; active energy management of end-use facilities; and improved grid controls, including more responsive centralized generation—all of which can be optimized by data and communications systems.[117]

1.6 Electricity Dependency Is a 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. The Center for Naval Analyses in a November 2015 report on the electric grid and national security noted that

> "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."[118]

As we consider the central role electricity plays in the 21st century economy and electricity's broader role in national security, it is instructive to briefly review the U.S. policy response to oil dependence. A single action—the 1973 Organization of Petroleum Exporting Countries oil embargo—exposed the U.S. economy's dependence on a single commodity. Since the embargo, reducing the country's overall dependence on oil, as well as imported oil, has been a fundamental component of U.S. national and energy security. A sustained, 40-year Federal policy commitment has enabled a robust, global oil market; a diversity of petroleum suppliers; the world's largest strategic oil reserve; international mechanisms for concerted action in the event of disruptions; increased domestic oil production; a shift away from oil-fired power generation; more efficient vehicles; and a host of other benefits. The U.S. government is also modernizing its Strategic Petroleum Reserve to more appropriately manage its value as articulated in statute—reducing the harm to the U.S. economy from oil price shocks and global supply disruptions.

The United States now needs an analogous approach to electricity. Unlike the supply of oil in the 1970s, most of the electricity consumed in the United States is generated domestically (though current cross-border transmission between Canada and the United States—and likely Mexico in the future—can make increasingly significant contributions to grid reliability and resilience in the future). As in the 1973 Organization of Petroleum Exporting Countries embargo, disruptions in the flow of electricity in the United States would have profound effects on the economy and national security. Unlike oil, however, electricity cannot currently be stored at scale. 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. Doing so is challenging but achievable.

1.6.1 The Threat Environment Is Changing

The electricity system faces a range of growing threats to its reliability and security. These include cyber and physical threats, natural disasters and increased extreme weather events due to climate change, aging infrastructure, interconnectedness of an increasingly data-driven economy, and a changing technical and operational environment. Many of these issues are discussed in detail in Chapter IV, *Ensuring Electricity System Reliability, Security, and Resilience.*

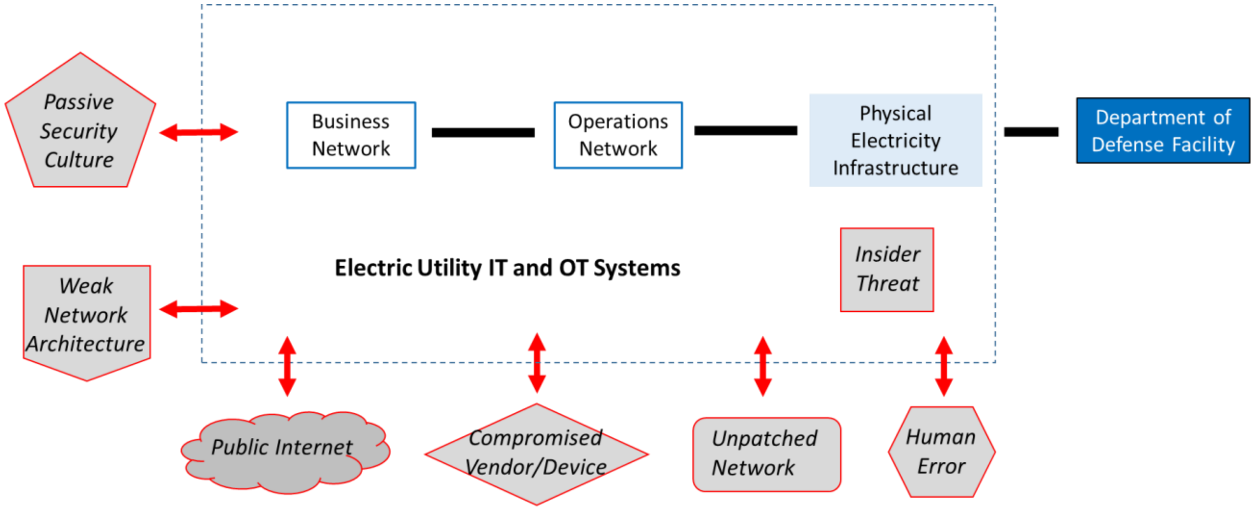
Cybersecurity is a particular concern for national and homeland security. Cyber attacks increasingly may resemble conventional attacks that are designed to disrupt physical systems. Malicious cyber activity against the electricity system and its suppliers are growing in sophistication. The cyber attack on Ukraine's electricity systems in December 2015 serves as a warning. Three of Ukraine's regional electricity distribution companies experienced simultaneous cyber attacks on their computer and control systems, precipitating the disconnection of multiple electricity substations. The result was several outages that caused approximately 225,000 customers in three different distribution-level service territories to lose power for hours.[119]

One of the hackers' strongest capabilities was their performance of the long-term reconnaissance operations required to learn the environment and execute a highly synchronized, multi-stage, multi-site attack. These highly targeted, long-term campaigns, called *advanced persistent threats*, are generally designed to satisfy the requirements of international espionage and/or sabotage.[120] This type of well - funded and staffed attack has long worried U.S. security officials. Michael S. Rogers, Commander, U.S. Cyber Command and Director, National Security Agency, in testimony before the House Select Committee on Intelligence in October 2014, noted that, "There shouldn't be any doubt in our minds that there are nation-states and groups that have the capability [to do that,] to enter our systems...and to shut down...our ability to operate our basic infrastructure, whether it's generating power…moving water and fuel…"[121]

Another effective form of coordinated cyber attack is through the use of a botnet. The Mirai botnet, which involves a global network of infected IoT devices, was used to attack multiple targets on October 21, 2016.[122] This was the largest recorded distributed denial of service attack in history. Attacks against Internet systems that support the U.S. power grid, like the Mirai botnet attack, are of significant concern. In most cases, IoT devices are easier to infect than traditional computer systems due to the lack of embedded security and the limited ability to patch known vulnerabilities. With the rapid deployment of IoT devices worldwide, including smart printers, home routers, monitors and cameras, and thousands of others, the opportunity for hackers to disrupt the flows of electricity is growing significantly.

The reliance of our critical energy infrastructures on electricity places a very high premium on a reliable, modern, and hardened electric grid, as well as our efforts to understand, develop, and evolve our emergency response capability to address ever-changing and evolving cyber threats. As a result, electric utilities face significant challenges in securing their IT and OT networks and systems from many cyber attack vectors (see Figure 1-15). Utilities also depend on each other; large and small public and private utilities need strong cybersecurity techniques and processes. Given that "systems are only as strong as their weakest links,"[123] sector-wide improvements in grid security will be essential and require collective action both within the industry itself and with government.

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

DHS lists five basic missions in its "2014 Quadrennial Homeland Security Review," three of which directly relate to the electricity system and the other critical infrastructure sectors that depend on it: preventing terrorism and enhancing security, safeguarding and securing cyberspace, and strengthening national preparedness and resilience.

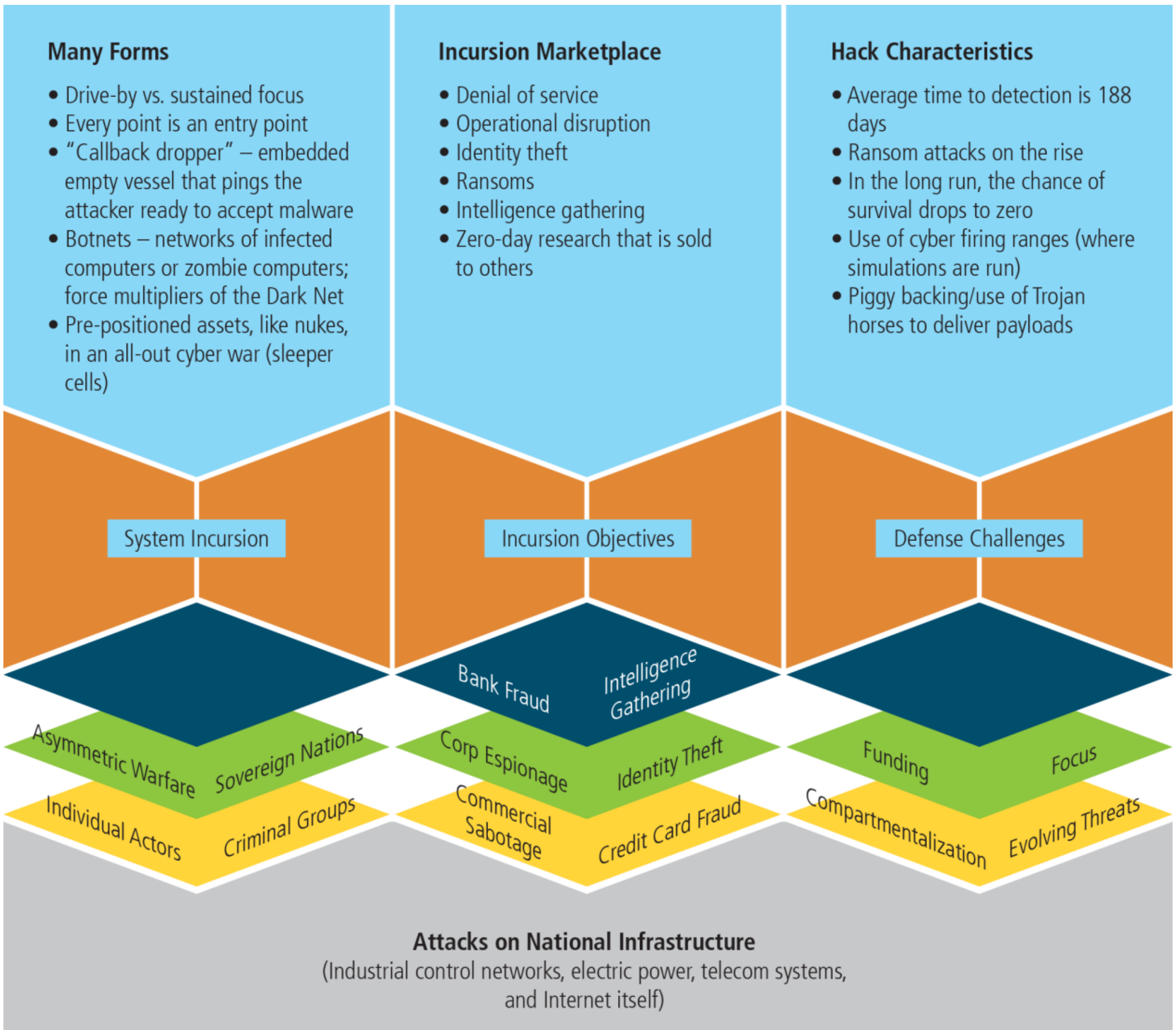
The operational components of Federal and State homeland security agencies are heavily dependent on electric power to function. The Customs and Border Protection (CBP) agency within DHS offers a case in point. To secure the United States across roughly 8,000 miles of land and coastal borders—while simultaneously ensuring a smooth flow of legal trade and travel from the borders through the country's interior—CBP utilizes a vast network of electricity-dependent facilities, sensors, and other operational infrastructure. Radiation portal monitors, for example, are deployed by CBP nationwide (at seaports, land border ports of entry, and other locations) to safeguard the United States from nuclear devices and dirty bombs.[125] The monitors and networks to which they are linked rely on electricity to function.

Other components of the DHS network, especially the Transportation Security Administration, are equally reliant on electric power to conduct their operations. This is also the case for homeland security agencies and emergency operations centers for State, local, tribal, and territorial governments, which typically have emergency power generation capabilities that will be at increasing risk (in terms of generator burnout and fuel resupply) if long-duration, wide-area power outages occur.

Catastrophes caused by human or natural hazards entail twin challenges for homeland security, both of which will place a premium on grid resilience. First, as revealed in the Clear Path-IV and Cascadia Rising exercises in 2016, severe earthquakes and other catastrophic events will pose immediate threats to public health and safety as water and wastewater systems, hospitals, and other critical assets are damaged and lose power. Second, response and recovery operations will be disrupted unless electricity is available to help support the large-scale logistics and transportation operations (including for mass evacuation) that such events will require. Most critical facilities have back-up power. However, providing for sustained resupply of fuel for back-up generators will become increasingly difficult in long-duration outages, especially in earthquakes or other events that severely disrupt transportation infrastructure, fuel supply chains, and communications.

Traditionally, grid reliability has mainly focused on the physical aspects of the electricity system. Growing digitization and reliance on data is making information infrastructure increasingly important to grid reliability as well. Physical systems are impacted by intentional acts of vandalism or attempts to cripple equipment that is critical for electricity service delivery. Information, or cyber systems are significantly more complex from a threat mitigation perspective; the incursion pathways are more diverse and evolve rapidly, as do attack objectives that can range from intelligence gathering to intentional destruction of grid integrity and operations capability. Figure 1-16 below summarizes these more complex cyber challenges to the reliability of the grid.

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

The Department of Defense (DOD) is the largest customer of the electric grid in the United States, a system which is largely owned and operated by the private sector. It uses electricity to execute the Armed Services' mission essential functions by energizing the systems that fuel trucks, tanks, and ships; powering the heating, ventilation, and air conditioning systems and other installation infrastructure necessary for military bases to function; and supporting a wide range of other defense operations and assets essential for mission assurance. The degree to which electricity is mission critical for DOD elevates the level of resilience beyond what may be deemed sufficient for market purposes.

The growing national security implications of the U.S. electricity grid have inspired new laws and regulations to adapt to this imperative and evolving threat landscape. Presidential Policy Directive (PPD)-21 advances a unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure focusing on all hazards on both physical and cyber systems. The critical role of electricity to the Nation's defense was also recognized in the Fixing America's Surface Transportation Act of 2015 (commonly known as the FAST Act). Section 61003 of the Act requires the Secretary of Energy, in consultation with other appropriate Federal agencies, to identify facilities in the United States that are: (1) "critical to the defense of the United States," and (2) "vulnerable to a disruption of the supply of electric energy provided to such a facility by an external provider."[126]

Electricity is especially vital for powering defense networks and enabling broader command, control, and communications functions. DOD's 2015 "Cyber Strategy" highlights the role of a "wired" world, the essential role of electricity as an enabler of these connections, and the vulnerabilities this dependence creates. The strategy notes that, "DOD's own networks are a patchwork of thousands of networks across the globe, and DOD lacks the visibility and organizational structure required to defend its diffuse networks effectively… DOD relies on critical infrastructure across the United States and overseas for its operations, yet the cybersecurity of such critical infrastructure is uncertain."[127]

The Defense Science Board in 2008 noted that, "DOD's key problem with electricity is that critical missions, such as national strategic awareness and national command authorities, are almost entirely dependent on the national transmission grid."[128] This dependence on the grid—which continues today—means that DOD faces many of the same challenges faced by all electricity customers. In 2015, DOD facilities experienced approximately 127 utility outages that lasted 8 hours or longer, an increase from 114 events in 2014.[129] Nearly half of the outages were caused by weather, while the other half were caused by equipment failure. DOD's 2015 "Annual Energy Management Report," in discussing reliance on commercial power supplies, noted that, "DOD recognizes that such events could result in power outages affecting critical DOD missions involving power projection, defense of the homeland, or operations conducted at installations in the U.S. directly supporting warfighting missions overseas."[130]

Since the Defense Science Board's 2008 study, military bases and defense communications networks have taken aggressive actions through a broad range of initiatives to strengthen their ability to operate on emergency power if blackouts occur, including providing back-up generation at critical facilities; developing priority relationships with utilities; and building alternative electricity supply configurations, such as microgrids. Improvements in grid resilience can greatly enhance the military's ability to carry out its missions, especially if resilience initiatives are focused on supporting especially critical defense facilities and functions.

Onsite back-up generation is DOD's primary method for sustaining operations during grid outages. According to DOD in 2011, most facilities use diesel generators to support operations and critical missions, with enough fuel to sustain basic functions for 3–7 days or more at many installations.[131] Improvements in grid resilience can greatly enhance the military's ability to carry out its missions. For longer-duration outages, however, broader grid resilience initiatives will be essential to improve mission assurance. The longer an outage, the more cascading the effect, with interdependent systems increasingly implicated. After 7 days without electricity generation, the broader impact of defense systems dependent on electricity becomes a concern, including water, fuel, and telecommunication systems. DOE works with DOD to develop back-up power generation to support the interdependent systems that rely on electricity. DOD is supporting DOE in developing ways to ensure the resilience of power transformers and other critical equipment. DOD is also strengthening collaboration with utility providers, and State and local emergency management agencies remain a central focus to enhance the resilience and rapid restoration of commercial grid infrastructure that supports mission critical installations and facilities.[132]

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.

Strengthening the resilience of the electricity system not only limits the disruptive effects of adversary attacks on DOD mission assurance, it can also reduce the risk of certain types of attacks occurring in the first place. Resilience initiatives can help strengthen "deterrence by denial." By improving the ability of electricity systems to survive cyber and kinetic attacks, and accelerating power restoration when blackouts do occur, resilience projects can raise an adversary's uncertainty as to whether an attack will achieve the intended consequences. That increased uncertainty can help reduce the potential attractiveness of such an attack—especially if the adversary believes that the United States can effectively respond if an attack occurs. In noting the importance of bolstering deterrence by denial, the Obama Administration's "Report on Cyber Deterrence Policy" calls for "building strong partnerships with the private sector to promote cybersecurity best practices." The report also recommends measures to "architect resilient systems that recover quickly from attacks," and "lend credibility to national efforts to increase network resiliency."[133]

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

DOE's role in addressing the electricity system as a critical component of national security is growing as the threat landscape has evolved. PPD 21 establishes a policy framework and unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure focused on all hazards. Under PPD 21, DOE is identified as the Sector-Specific Agency for Energy, making DOE the lead Federal interface with energy sector infrastructure owners and operators. Responsibilities also include supporting infrastructure protection efforts within the sector and incident management. As such, DOE leads the Federal Government's Emergency Support Function #12, which is designed to facilitate the reestablishment of damaged energy systems and components. Finally, Congress passed the FAST Act in 2015 (discussed in greater detail in Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations*). The FAST Act includes actions to improve the security and resilience of electricity infrastructure. One of the most important measures provides the Secretary of Energy with broad new authority to address grid security emergencies. "Grid security emergency" is defined to include a physical attack, "a malicious act using electronic communication or an electromagnetic pulse, or a geomagnetic storm event."[134] In the FAST Act, DOE is the statutorily designated sector-specific agency for electricity sector cybersecurity.

The FAST Act also gives new authorities to the Secretary of Energy to protect and restore the reliability of critical electricity infrastructure or defense critical electricity infrastructure during a cyber, physical, electromagnetic pulse, or geomagnetic disturbance emergency. In addition, the Act gives the President authority to act if there is "imminent danger" of such an attack. This requires constant monitoring and updating of information, as cyber threats are evolving. DOE, as the lead agency on cybersecurity for critical electricity infrastructures, must maintain ongoing capabilities to fulfill a critical advisory role for the President about imminent dangers, as well as to respond to actual emergencies under the new authorities in the FAST Act. Finally, the interdependencies between electricity and natural gas is a growing national security concern; maintaining information on, and ongoing situational awareness of, natural gas infrastructures sufficient to meet DOE's statutory requirements and responsibilities under the FAST Act are essential.

DOE's organic statute—the DOE Organization Act—addresses energy emergencies in its purposes section as "[facilitating] the establishment of an effective strategy for distributing and allocating fuels in periods of shorty supply and to provide for the administration of a national energy supply reserve." This statute, passed in 1977, does not contemplate cybersecurity, electromagnetic pulses, or geomagnetic disturbances; the issues raised in PPD 21 and Emergency Support Function #12; and those addressed in the FAST Act. These issues that have evolved over time, combined with the growing importance of electricity to our national security, constitute a new broad and complex mission for DOE. Given the critical nature of these issues and this mission, adequate resources and appropriate organizational structures within DOE are essential. This could be addressed through a stronger relationship between DOE and FERC.

1.7 The Federal Role in Modernizing and Transforming the Grid

The Federal Government is facilitating the transition of the electricity system via avenues that include regulation, procurement, RDD&D, taxation, and the utilization of it convening powers. In the 21st century, the electricity system will still be composed of a diverse mixture of actors in regulated and competitive environments, but will include an expanded array of technologies and actors.

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

The United States has been a global leader in innovation, and technology development has proved to be one of the great engines of our economy. Innovation investments directly expand the pipeline of new technologies, reduce technology costs, and mitigate risks of new technologies or systems. These benefits, in turn, reduce the cost of policies and incentives[135] and allow decision makers in both government and the private sector to consider options that would otherwise not be available.

The Federal R&D portfolio is one of the most significant contributions to our energy transition. Achieving a clean, flexible, reliable electricity system will require constantly improving the cost and performance of our energy technologies. R&D, coupled with demonstration and deployment (i.e., RDD&D), creates a ‘technology push’ that reduces the cost of the ‘policy pull’ generated through regulatory, tax, environmental, and other policies. Current levels of Federal support for electricity and other energy-focused research, development, and demonstration need to be substantially increased. Regional variation in innovation capabilities, infrastructure, markets, policies, and resources also point to a need to address electric sector innovation through regional approaches.[136] Impacts of Federal RDD&D are described in further detail in Chapter III, *Building a Clean Electricity Future*.

Two key examples of expanding Federal RDD&D investment in the electricity sector are Mission Innovation and DOE's GMI (discussed earlier). DOE's GMI is a crosscutting RDD&D effort to generate technologies that measure, analyze, predict, protect, and control the grid of the future. These technologies are needed to integrate conventional generation, renewable generation, and energy storage; enable smart buildings and end-use devices; and ensure that the grid is resilient to growing physical, cyber, and extreme weather threats. Mission Innovation is an effort by 22 countries and the European Union—spearheaded by the United States and announced at the Paris Climate Summit in 2015—to dramatically accelerate public and private global clean energy innovation, including doubling the public sector investment in clean energy RDD&D over 5 years.

1.7.2 Jurisdictional Relationships and Limitations

Responsibility for regulating and overseeing the numerous actors that comprise the electric power industry is vested in multiple government levels and agencies, and new technologies are putting pressure on traditional jurisdictional boundaries. Regulatory authorities span Federal, State, local, and tribal levels. At the Federal level, FERC is responsible for regulation of transmission and wholesale sales in interstate commerce. In addition, other Federal authorities are involved with various aspects of regulation or oversight, including DOE, the Environmental Protection Agency, Department of Justice, Securities and Exchange Commission, Commodity Futures Trading Commission, Department of the Interior, Department of Agriculture, Automated Commercial Environment, and Nuclear Regulatory Commission, among others. Collectively, they oversee many industry actors. Responsibilities are wide-ranging and relate to environmental protection, land use, anti-trust protection, and transmission siting. Congress passed legislation in 2005 giving FERC oversight responsibility for mandatory reliability standards and authorized the agency to partially certify an electric reliability organization to develop and enforce those standards.[137] FERC must approve a reliability standard before it is enforceable. FERC certified the North American Electric Reliability Corporation, a nonprofit corporation, as the electric reliability organization.

In each state, regulatory power is vested with the state public utility commission for regulation of the investor-owned utilities within its state boundaries (and certain public power and cooperative utility activities in some states). Additionally, State policymakers (governors and legislatures) establish laws that industry actors must abide by and that the public utility commissions carry out. State environmental/energy authorities carry out relevant Federal and State legislation and review the environmental impact of certain industry activities within the state. They also control in-state siting of generation and transmission, although the Energy Policy Act of 2005 establishes a significant role for DOE in transmission siting. Local authorities typically include the local governing body of a city, town, or county, or the elected or appointed boards that oversee public power or cooperative electric utilities. Tribal governing bodies are entities that oversee a range of electric industry activities that occur on tribal lands.

The current jurisdictional divide of regulatory authority between the Federal Government and the states, established in the Federal Power Act and clarified by subsequent Supreme Court and lower court decisions, is the result of the evolution of a regulatory structure; in general, Federal regulators have authority over the bulk power system and wholesale electric sales in interstate commerce while State and local regulators have oversight of the distribution system and retail sales. This division of authorities between the Federal Government and states, as written in the Federal Power Act, has been described as a "bright line"; this bright line is, however, becoming increasingly hazy as new technologies and services create more two-way connections between the transmission and distribution systems.

Moreover, the structure of the industry has changed from one primarily characterized by vertically integrated monopolies operating under cost-of-service regulation to one characterized in some locations by significant wholesale and retail competition among many diverse entities. These changes in technologies and the overall structure of the electricity industry can create jurisdictional uncertainty and market misalignment.

The operational characteristics and attributes of new and emerging energy technologies do not fit neatly into existing jurisdictional divisions. As noted, DG technologies have enabled two-way power flow, preventing a simple "hand off" of jurisdiction from Federal to State regulation as electricity flows (and increases or decreases in voltage) from generation through delivery to ultimate consumption. Instead, new DER (including energy storage) can be interconnected to either the FERC jurisdictional high-voltage transmission grid or the State 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 DR that can provide) several kinds of both wholesale and retail grid services, with benefits that extend across the traditional generation, transmission, and distribution classifications.[138]

The scale and scope of the transition already underway also requires the co-evolution of the Federal role; this installment of the QER (i.e., QER 1.2) will therefore consider the Federal role in this transition. The Federal role merits evaluation in terms of the efficiency of markets and rate structures in incenting clean, reliable, and affordable power; emerging technical and operational issues concerning grid reliability, resilience, and flexibility; and the role of institutional structures, including Federal, State, and local jurisdictional boundaries. Key issues for this evaluation include actionable roles the Federal Government should play in facilitating sector transition and whether new responsibilities should be established to ensure desired outcomes.

The Federal Government is facilitating the transition to the 21st century electricity system by convening diverse stakeholders both formally and informally, managing critical activities concerning an emergency response, collecting and disseminating data, procuring power and selling it through the Power Marketing Administrations, supporting financing of energy projects through loan guarantees, and funding the world's largest Federal energy R&D portfolio. The recommendations based on the analysis in this chapter are covered Chapter VII, *A 21st Century Electricity Sector: Conclusions and Recommendations.*

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