U.S. DEPARTMENT OF ENERGY

Valuation of Energy Security for the United States

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Contents

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Executive Summary: The New Energy Security Paradigm

For the last 40 years, energy security in the United States has focused on decreasing the Nation's dependence on foreign oil. Policies have promoted the production of domestic oil resources, maintenance of the world's largest strategic oil reserve, increased vehicle fuel efficiency standards, and a host of other oil-related actions and policies. The United States is now the world's largest producer of crude oil and other liquids, and the largest producer of refined petroleum products. A net exporter of refined products and, for the first time in decades, the United States now produces more oil than it imports. In addition, the United States has become the world's largest producer of natural gas. The dramatic growth in gas production has lowered U.S. natural gas prices and allowed the United States to begin exporting liquefied natural gas (LNG), which has increased the competitiveness and transparency of international LNG markets.

Meanwhile, the global economy has experienced a period of unique transformation. Energy security concerns facing the United States have evolved to encompass oil, natural gas, and electricity and have become significantly more complex. The world's population has grown by almost 20 percent in the last 15 years alone, while global GDP grew by 120 percent. In many parts of the world, mechanical and analog systems traditionally energized by oil-products, are being replaced with automated and networked systems that rely on electricity. The number of devices connected to the Internet worldwide has grown from 400 million in 2001 to 25 billion in 2015. These changes have made electricity and natural gas, in addition to oil, key enablers of many facets of society and ensured that the modern world is completely dependent on energy.

In today's connected world, threats that are intended to disrupt the energy systems and markets in one country can affect multiple countries, regions, and the global economy. Thus, energy security concerns now include fuel supply chains; electricity generation, transmission, and distribution; the functioning of energy markets; and the ability of the energy system to withstand shocks and disruptions.

On the domestic front, the Department of Energy (DOE) is designated as the Federal Government's Sector Specific Agency for energy sector security. The DOE Organization Act of 1977, however, originally defined DOE's role in energy security emergencies only as "[facilitating] the establishment of an effective strategy for distributing and allocating fuels in periods of short supply and to provide for the administration of a national energy supply reserve." In short, DOE's organic statute, which remains unchanged today, focused solely on oil emergencies and does not, for example, contemplate electricity, or energy-related cybersecurity, electromagnetic pulses, or geomagnetic disturbances as components of federal energy security that might require emergency response. This oil-centric view is also found in the international arena, where for over 40 years, oil security has served as an organizing principal for the International Energy Agency's 29 member countries, including the United States. IEA members must "…hold reserves of crude oil and/or product equivalent to 90 days of the prior year's average net oil imports" and to which the government must have immediate access.

Although oil remains a key energy security concern for both the United States and its allies, DOE's role in energy security has been expanded in the last few years, specifically by Presidential Policy Directive 21, Emergency Support Function 12 and by the FAST Act of 2015, all discussed in detail in this analysis. On the international front, a broader, more modern definition of energy security was formulated by the G-7 energy ministers and the European Union in 2014 and adopted by their leaders through a joint declaration in Brussels that same year. These principles, discussed in greater detail throughout this analysis, articulate a 21st century framework for energy security:

1. Development of flexible, transparent and competitive energy markets, including gas markets.
2. Diversification of energy fuels, sources and routes, and encouragement of indigenous sources of energy supply.
3. Reducing our greenhouse gas emissions, and accelerating the transition to a low carbon economy, as a key contribution to enduring energy security.
4. Enhancing energy efficiency in demand and supply, and demand response management.
5. Promoting deployment of clean and sustainable energy technologies and continued investment in research and innovation.
6. Improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks and cyberattacks.
7. Putting in place emergency response systems, including reserves and fuel substitution for importing countries, in case of major energy disruptions.

The growing importance of electricity to both energy and national security; today's robust global oil markets; the developing global gas market; and a range of energy security threats, trends and changes, constitute a new broad and complex energy security mission for the Federal Government and DOE. To effectively ensure this expanded definition of energy security for the United States, a host of factors must be considered from both domestic and international perspectives, including: ensuring domestic access to energy, securing the electric grid, encouraging the development of global markets, and supporting alliances and partnerships that strengthen energy security.

Ensuring domestic access to energy. The United States is home to enormous oil and natural gas deposits, and it has seen a revival in oil and natural gas production over the past decade as a result of advanced technologies, especially horizontal drilling and hydraulic fracturing. The United States also maintains one of the most advanced and complex energy infrastructures in the world with an extensive system transporting oil, natural gas, and refined product to consumers: nearly 2.6 million miles of pipelines, 414 natural gas storage facilities, 330 ports handling crude petroleum and refined petroleum products, and more than 140,000 miles of railway distribution networks. Private industry maintains aboveground storage capacity for more than 600 million barrels of oil and underground storage for natural gas equivalent to nearly 2 months of U.S. consumption. This complex system enables the transport of oil, natural gas, and refined products from sources of supply, refineries, and import terminals to demand centers and export terminals across the Nation.

Despite considerable domestic energy assets, the security of the oil and natural gas sectors remains vulnerable to a growing number of threats. Oil and petroleum products are bought and sold on the world market, which leaves the U.S. economy exposed to supply disruptions anywhere in the world and the ensuing global price volatility. Meanwhile, the country's oil and natural gas infrastructures have not kept pace with changes in the volume and geography of oil and natural gas production, according to DOE's 2015 Quadrennial Energy Review (QER). The Colonial pipeline disruptions in September and October 2016 and the Southern California Aliso Canyon gas leaks in late 2015 are prominent examples of the infrastructure challenges faced by the United States in managing a system built decades ago. Sea level rise, severe weather, and storm surges put at risk energy infrastructure, including the 50 percent of U.S. refining capacity located in the Gulf Coast region. Finally, along with greater deployment of information and communication technologies to enhance the operational efficiency of our energy infrastructure, there has been a rise in intentional, malicious cyberattacks to the oil, gas, and electricity sectors.

Securing the electric grid. The U.S. power grid is a vast, complex, and interconnected machine that provides just-in-time delivery of power through the use of more than 7,700 operating power plants that generate electricity from a variety of primary energy sources. The system includes 200,000 miles of high-voltage transmission lines, 55,000 substations, 5.5 million miles of local distribution lines, and 3,300 providers who deliver electricity to 135 million customers. The value of the electricity supply chain from fuel to generation to transmission to distribution is estimated at about $1 trillion. The U.S. electricity grid is an impressive engineering feat, hailed as the supreme engineering achievement of the 20th century by the National Academy of Engineering.

Nearly every sector of the modern economy depends on electricity. A secure, reliable electric power sector is essential for economic growth, public safety, societal well-being, and proper functioning of vital infrastructure, including national security, defense, transportation, communications, water, and sewage. Meanwhile, the electric power sector is rapidly evolving in ways that affect its security. Some changes have resulted in improvements to the energy security of the system: electricity markets have become more liquid, transparent, and competitive and electricity generation sources have become more diversified. Other trends have created new complexities and prompted changes in how the electric power sector operates to maintain energy security, such as new technologies for electricity generation and distribution, migration away from traditional models of baseload generation, and additional distributed energy resources. Furthermore, growing threats from severe weather, emerging cyber and physical attacks, and aging infrastructure have increased the vulnerability of the sector. To add to the complexity of managing these changes, the electric power sector is overseen by multiple government levels and agencies, spanning federal, state, local, and tribal levels, all of which exercise some amount of jurisdictional authority and oversight.

Encouraging the development of global markets. The liberalization of global energy trade has caused many energy markets that were traditionally regional in nature to become increasingly subject to the forces of energy supply and demand around the world. Energy is now traded among all major regions of the world: Africa buys and sells electricity, oil, and natural gas from and to Europe and the Middle East; North America and South America trade oil and natural gas; Asia trades all three energy commodities with Europe; and the Middle East sells oil and natural gas to nearly every region of the world. This geographic interdependence has brought global benefits when issues emerge that affect the functioning of energy markets.

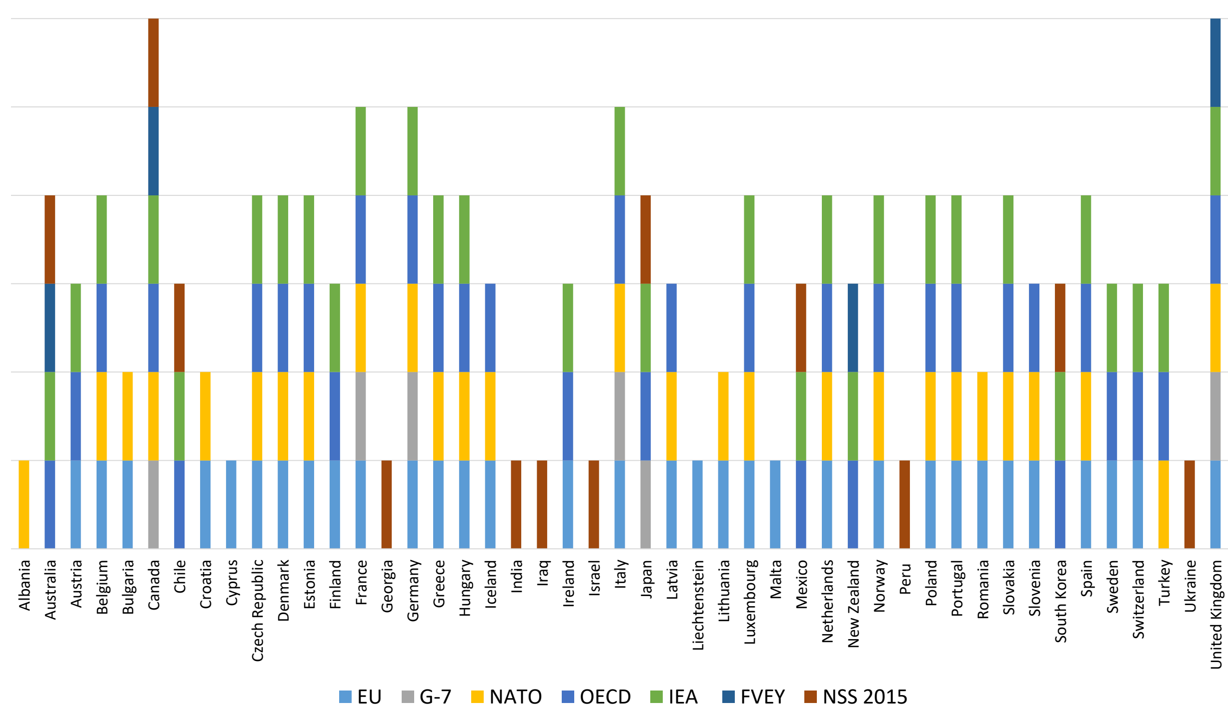
A primary benefit of the globalization of energy markets is that countries all over the world have access to energy during an emergency, which brings stability to the global economy and potentially prevents costly interventions by the United States and other countries. For instance, following the Fukushima nuclear accident in March 2011, Japan temporarily replaced domestic nuclear power with imported natural gas for electricity generation. This change significantly increased Japan's demand for natural gas and resulted in a spike in Asian natural gas prices. To deliver natural gas to Japan, as well as other countries with growing demand, new liquefied natural gas (LNG) export capacity came online in Asia, the Middle East, and North America. The new LNG capacity, particularly that in the United States, increased competition and price transparency in these other natural gas markets, which created an opportunity for many importers of LNG to renegotiate their contracts under more attractive terms.

As a second example, the increasingly connected natural gas market has also reached Europe, which has historically depended on Russia for natural gas under opaque supply arrangements. As one of the largest exporters of natural gas in the world, Russia actively maintains "take-or-pay" contracts with pricing strategies that often seem designed to support political allies and undermine others. (Under take-or-pay gas contracts, buyers have to pay for the natural gas even if they do not want to take delivery of it.) Russia has leveraged its market power over Europe for many decades, but more recent contract disputes, such as with Ukraine, have had global consequences. The rapid growth of global LNG trade—which could grow by 75 percent between 2016 and 2020 based on capacity currently under construction—has made the market more competitive, forcing Russia to compete with gas suppliers throughout the world. As a result, the share of competitively-purchased gas in the European market has increased from 15 percent in 2005 to 64 percent in 2015. As additional evidence of the effect of this more competitive marketplace, since September 2015, Russia has auctioned roughly 3.4 billion cubic meters of natural gas, which represents a significant shift in strategy to allow the market and not foreign policy to determine the price of natural gas exports.

A third benefit of global energy markets is their ability to cost-effectively satisfy the energy demands of the developing world. Non-OECD countries, according to EIA, will represent the largest share of global energy demand growth for the next few decades as their energy demand is expected to increase by 71 percent by 2040 to support basic goods and services, such as electricity, clean water, and healthcare. More than half of the projected increase is expected from China and India, and is likely to be fueled by cheap fossil fuels. This growth will impact global energy flows and contribute to the emissions of greenhouse gases and other pollutants. However, the need to balance the developing world's demand for affordable energy with the global desire to reduce damage to the environment is more easily accomplished in the connected, modern world. For example, the growth in trade of natural gas serves as a lower cost alternative to more emission-intensive fuels such as coal.

Supporting alliances and partnerships that strengthen energy security. Today's complex energy security challenges are increasingly addressed through our economic, military, and humanitarian alliances and partnerships. Critical alliances for the United States include the North Atlantic Treaty Organization (NATO), the European Union (EU), the Organisation of Economic Co-operation and Development (OECD), the Group of Seven (G-7), the International Energy Agency (IEA), countries specifically mentioned in the 2015 National Security Strategy, and the Five Eyes (a group of countries that regularly share classified intelligence), among many others (see Figure 1). In recent years, these allies have made great progress in enhancing our collective energy security interests. NATO, for example, adopted an enhanced policy and action plan in 2014 that protects all cyber systems owned and operated by countries in NATO. This involves a commitment to enhancing information-sharing and mutual assistance in preventing, mitigating, and recovering from cyberattacks. As another example, the G-7 leaders committed in June 2015 to reducing energy poverty while accelerating access to renewable energy in developing countries. This includes eliminating fossil fuel subsidies and incentivizing investments toward low-carbon, growth opportunities.

Figure 1. U.S. allies and partners critical to addressing today's energy security issues



Despite the strength of these alliances and partnerships, modern energy security challenges are affected by shifting balances of power. This is most apparent in Europe, where Russia has played an increasingly larger role in creating energy security challenges for allies and partners of the United States. For example, over the past decade, Russia has disrupted natural gas shipments to Europe; waged cyberattacks on European energy systems; increased its ownership of European pipelines, refineries, power plants, and nuclear fuel contracts; and promoted opaque energy deals to limit international competition. Furthermore, Russia has invaded multiple countries of the former Soviet Union, including Chechnya, Georgia, and most recently, Ukraine. Because of the connected nature of these challenges, Russia's actions have spurred developments that affect energy security beyond Europe: natural gas markets are becoming increasingly transparent and global; military alliances are expanding in many regions of the world; and new foreign investments are being made in energy infrastructure projects that limit oil, gas, and electricity market exposure to Russia. Meanwhile, Russia is increasingly looking to Asia and Latin America to expand its influence, which represents new challenges for these parts of the world that seek access to reliable supplies of affordable energy.

I. Redefining U.S. Energy Security

Today's changes in energy security call for a reassessment of the Nation's energy security goals to reflect our complex and interconnected global and domestic energy markets. Reflecting this changing perception, the energy ministers of the Group of Seven (G-7) member countries—Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States—agreed in June 2014 to a set of principles that reflect broader ideas of energy security both for individual nations and collectively. In an effort to articulate a new energy security paradigm, the G-7 endorsed a set of seven energy security principles:

1. Development of flexible, transparent and competitive energy markets, including gas markets.
2. Diversification of energy fuels, sources and routes, and encouragement of indigenous sources of energy supply.
3. Reducing our greenhouse gas emissions, and accelerating the transition to a low carbon economy, as a key contribution to enduring energy security.
4. Enhancing energy efficiency in demand and supply, and demand response management.
5. Promoting deployment of clean and sustainable energy technologies and continued investment in research and innovation.
6. Improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks and cyberattacks.
7. Putting in place emergency response systems, including reserves and fuel substitution for importing countries, in case of major energy disruptions.

These principles, with their focus on well-functioning and competitive energy markets, diverse sources and routes of energy supply, environmental protection, efficiency and infrastructure improvements, energy innovation, emergency response, and resilience, are guiding the work currently being done by the Department of Energy (DOE) and our interagency partners. In its 2015 Quadrennial Energy Review (QER), the Administration recommended viewing U.S. energy security and the infrastructures that support it, both physical and geopolitical, in terms of this more comprehensive definition.

II. Energy Security Valuation Framework

Fully incorporating this new definition of energy security into policymaking requires that appropriate measures be adopted to allow the Federal Government to value energy security contributions. Building from the G-7's seven principles, the Fixing America's Surface Transportation (FAST) Act (Pub. L. No. 114-94, § 61005 (Dec. 4, 2015)) requires the Secretary of Energy, in collaboration with the Secretary of State, to develop a report that will do the following:

- Evaluate and define United States energy security to reflect modern domestic and global energy markets and the collective needs of the United States and its allies and partners;
- identify transparent and uniform or coordinated procedures and criteria to ensure that energy-related actions that significantly affect the supply, distribution, or use of energy are evaluated with respect to their potential impact on energy security, including their impact on:
    - consumers and the economy;
    - energy supply diversity and resiliency;
    - well-functioning and competitive energy markets;
    - United States trade balance; and
    - national security objectives; and
- include a recommended implementation strategy that identifies and aims to ensure that the procedures and criteria referred to in [the above bulleted point] are:
    - evaluated consistently across the Federal Government; and
    - weighed appropriately and balanced with environmental considerations required by Federal law.

This report presents an analysis of how energy-related policies and actions are valued, both qualitatively and quantitatively, with respect to their effect on energy security. The report does *not* attempt to assess the extent to which the United States and our allies and partners are energy secure, although it points out several instances where recent developments and policies have contributed to improved energy security. Instead, this report suggests how the United States can consistently value the benefits of policies and actions that increase energy security. This helps establish a baseline for future efforts to develop energy security implementation strategies related to the aforementioned categories. The report considers both the domestic and collective aspects of energy security.

Within the report, energy security is discussed in depth according to the categories described in the FAST Act, with the exception of the United States trade balance. Broadly, the U.S. trade balance is determined by complex economic factors and influenced by the fact that the U.S. dollar acts as the global reserve currency. Although U.S. economic policy must account for a variety of indicators, trade deficits or surpluses do not necessarily indicate a problem or strength for the Nation's energy security. There is a brief discussion of the U.S. trade balance in Chapter 1 to further articulate these issues. Conversely, changing levels of energy imports can play a role in determining U.S. energy security through their contribution to U.S. GDP. As a result, this report discusses the economic effect of varying levels of energy imports and exports in the "Consumers and the economy" category.

Table 1. Mapping G-7 Energy Security Principles to FAST Act Energy Security Areas

FAST Act Energy Security Areas

G-7 Energy Security Principles

Energy Security	Consumers and the economy	Energy supply diversity and resiliency	Well-functioning and competitive energy markets	National security objectives	Environmental considerations
Development of flexible, transparent and competitive energy markets, including gas markets			●		
Diversification of energy fuels, sources and routes, and encouragement of indigenous sources of energy supply		●			
Reducing our greenhouse gas emissions, and accelerating the transition to a low carbon economy					●
Enhancing energy efficiency in demand and supply, and demand response management	●				
Promoting deployment of clean and sustainable energy technologies	●				●
Improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks and cyberattacks		●		●	
Putting in place emergency response systems in case of major energy disruptions.				●	

This report finds that many aspects of the modern definition of energy security are not qualitatively or quantitatively discussed as rationales for policies or actions that affect energy security. The report recommends a variety of research agendas that could better support the quantitative inclusion of the energy security benefits resulting from energy-related policies and actions. But in the absence of those quantitative estimates, the following questions are provided as a guide for policymakers to consider when evaluating the effects of a particular policy on energy security. Answering any of these questions in the affirmative would suggest that the policy or action under consideration provides energy security benefits; conversely, answering in the negative suggests the policy might come with energy security costs. Some policies may, in fact, provide both energy security benefits and costs. A qualitative discussion of energy security benefits and costs, as they relate to the questions below, would improve the consistent treatment of energy security in policymaking.

With respect to ***consumers and the economy***, does the policy or action:

1) Offer consumers of energy more flexibility in the event of a supply disruption, which might include higher energy prices or energy outages?
2) Improve energy efficiency in the demand or supply of energy?
3) Enable energy consumers to respond more quickly to energy price increases?

With respect to ***energy supply diversity and resiliency***, does the policy or action:

4) Support the diversification of energy fuels, sources and routes?
5) Reduce dependence on critical energy-related materials?
6) Improve the responsiveness of domestic supply to disruptions?

With respect to ***well-functioning and competitive markets***, does the policy or action:

7) Reduce transaction costs or increase transparency for market participants?
8) Increase competition in ways that lower market prices?

With respect to ***national security***, does the policy or action:

9) Promote the modernization of energy infrastructure?
10) Develop fuel reserves or substitute fuels that can be used in an emergency?
11) Support U.S. national security and homeland defense systems?

With respect to ***environmental considerations***, does the policy or action:

12) Reduce carbon emissions and other pollution to the air, water, or soil?
13) Support RD&D in clean and sustainable energy?

The report is divided into four chapters. The first two qualitatively discuss the types of energy-related policies and actions that affect energy security: first, in the oil and natural gas sectors, and second, in the electric power sector. Policies and actions are grouped according to the categories defined by the FAST Act, which parallel the G-7 principles (see Table 1): consumers and the economy, energy supply diversity and resiliency, well-functioning and competitive energy markets, national security objectives, and environmental considerations required by law. The third chapter examines how energy security is currently valued by the Federal Government in Regulatory Impact Analyses and other types of Federal rulemakings. The fourth chapter concludes the report with a discussion of the estimates currently available in the literature that could be used to quantify energy security benefits across the Federal Government. This final chapter also includes research strategies that would facilitate a more complete quantitative valuation of energy security benefits for policy purposes.

III. Policies Addressing Energy Security in the United States

The U.S. government has advanced a variety of policies aimed at improving energy security for the oil and natural gas, and electricity sectors. The following section provides an executive-level perspective of these policies and actions in the context of the FACT Act categories.

A. Consumers and the economy

Oil and natural gas sectors. Energy security is improved to the extent that consumers, defined as both households and businesses, can reduce their expenditures on fuel when prices for oil, natural gas, or petroleum products rise. This is achieved through policies that offer consumers substitute fuels or through demand-side and energy efficiency measures intended to lower energy consumption overall. Specific examples of U.S. policies include the following:

- Mobile Source GHG Standards and Corporate Average Fuel Economy (CAFE) standards for light-, medium-, and heavy-duty motor vehicles;
- The Renewable Fuel Standard, which requires the use of renewable fuel substitutes such as ethanol to be blended into gasoline and diesel fuels;
- Tax incentives to promote the commercialization of hydrogen, natural gas, and electric vehicles;
- Subsidies for low-income households to offset high heating oil costs, improve energy efficiency, and transition to less expensive fuels for heating or cooling; and
- Energy efficiency standards that reduce the consumption of natural gas in furnaces and other gas-using equipment.

These policies affect consumers differently depending on the region of the country in which they reside. For example, consumers in New England are more likely to take advantage of heating oil subsidies than consumers in the South. These subsidies help ensure that consumers have access to affordable energy. Similarly, incentives to promote natural gas or electric vehicles are most effective in areas with natural gas or electric fueling facilities.

Electric power sector. Policies that increase the adaptability of consumers, and thus the economy, to disruptions in the electric power sector also improve electricity security. For example, energy efficiency standards reduce consumer exposure to changes in electricity prices and smart meter programs provide a mechanism for consumers to be rewarded for reducing energy use when intraday electricity prices are high. To facilitate those efforts, DOE's Building Technologies Office has promulgated 42 new or updated energy conservation standards since 2009 that are estimated to have saved consumers $543 billion. In addition, The American Recovery and Reinvestment Act of 2009 provided $4.5 billion in funding for smart grid demonstration projects. In addition, the U.S. government, through the Department of Health and Human Service's LIHEAP program and DOE's WAP program, offers financial support to low-income households to offset high energy bills and invest in energy efficiency improvements, respectively.

B. Energy supply diversity and resiliency

Oil and natural gas sectors. Energy security is improved when firms cannot exercise market power with respect to oil or natural gas production, processing and refining, or distribution. The U.S. oil and gas industry is highly diversified because it is comprised of many privately held businesses that respond to market forces to increase or decrease production of oil and natural gas. Through technical innovation and entrepreneurial initiative, these firms have brought about a renaissance in oil and gas production in the United States over the last decade. This increased production of oil and natural gas has improved domestic, and thus global, energy security in a variety of ways. For example, oil production in the United States from unconventional sources averaged over 1 million barrels per day by 2011, when Middle Eastern and North African oil exports were lost as a consequence of the Arab Spring. The increase in U.S. oil production reduced the magnitude of spikes in world oil prices that otherwise would have threatened the world economy. As a second example, the rapid increase in the production of natural gas in the United States over the past decade has led to a decline in U.S. imports of LNG and made more LNG available for the rest of the world. In 2004, it was expected that imports of LNG into the United States would grow as high as 10 billion cubic feet per day (bcf/d) by 2025. Natural gas production in the United States increased to meet domestic demand, however, so imports never grew to that level. LNG exports that were intended for the U.S. market were sent to other markets, reducing the price of LNG.

With respect to infrastructure resilience, aging infrastructure represents an ongoing challenge in the United States, as evidenced by the recent leak and explosion of the Colonial pipeline and release of natural gas from Aliso Canyon storage facilities. To address the challenges associated with aging oil and gas infrastructure, DOE prepared the 2015 Quadrennial Energy Review on energy transmission, storage, and distribution. The report presents a variety of recommendations and priorities with respect to oil, natural gas, and refined product infrastructure resilience. Other policies advanced by the U.S. government to improve the resilience of infrastructure include an increase in data sharing among entities managing energy infrastructure and activities to improve U.S. preparedness and mitigation strategies for cyberattacks.

Electric power sector. Policies that encourage diversity in the fuels used to generate electricity and in the location of electricity generators improve energy security, providing a buffer against disruptions that might affect any particular type of fuel or location, such as from weather or a terrorist attack. Federal policies to mandate a particular level of diversity do not exist, and instead, decisions about fuel and location diversity are primarily left to privately held firms that internally manage the risk of disruptions. On a national scale, the U.S. electric power sector is highly diversified in terms of types of fuel used and location of generators. Concerns have recently been expressed by utilities, utility commissions, and regulators, however, about the growing reliance on natural gas in some parts of the country and associated constraints for fuel delivery. For example, a 2016 report by the North American Electric Reliability Corp found that of the four areas in the United States where natural gas represents at least 40 percent of the fuel mix, New England faces the greatest risk of outages and is most likely to experience constrained operating conditions.

The Federal Government has historically provided a variety of incentives for particular types of generation, such as nuclear energy loan guarantees and renewable generation tax credits. State governments also advance policies that promote particular types of energy. As of August 2016, 29 states and the District of Columbia have renewable portfolio standards that require an increasing share of renewable power generation. For example, Colorado's standard requires 30 percent of electricity generated by select utilities to be from renewable sources by 2030, and Oregon's standard requires 50 percent of electricity to be from renewable sources by 2040.

C. Well-functioning and competitive markets

Oil and natural gas sectors. More liquid, transparent, and competitive energy markets improve energy security, and the United States has advanced multiple policies toward this end. In 2015, the U.S. government lifted a decades-long ban on crude oil exports, and in 2016, the first shipments of domestic LNG from the lower-48 state were exported from the Gulf of Mexico. Although the volume of exported oil and LNG have been relatively small to-date, their introduction to the marketplace makes global energy markets more transparent, liquid, and competitive. For example, U.S. LNG contracts are offered without destination clauses, which gives customers maximum flexibility to resell the LNG on the spot market, increasing market liquidity. In addition, the natural gas price that underlies U.S. LNG contracts is set by the competitive and transparent Henry Hub market and not pegged to the price of oil, as with many European and Asian LNG contracts. These innovations have put pressure on other sellers of LNG to adopt a similar contract structure and have caused a much greater share of LNG to be traded through short-term contracts. Other actions the government has taken to improve the transparency of oil and natural gas markets include providing public access to energy-related data through federal sources such as EIA, increasing transparency about infrastructure permitting, creating policies that promote private sector innovation and free trade, and requiring open access policies for energy infrastructure.

Electric power sector. Policies that improve the liquidity, transparency, and competitiveness of electricity markets also advance electricity security. Emerging trends in the electric power sector, such as large-scale variable resources, distributed energy resources, increased use of natural gas and emerging storage technologies, have prompted changes in the design of electricity markets that have improved their operation, as well as the reliability of the sector. The Federal Government has implemented multiple types of policies to improve market competitiveness and operation, which include enabling third-party access to infrastructure and increasing transparency in data about market fundamentals. Federal regulators and independent system operators have promulgated a variety of new rules and regulations that improve market performance by limiting the ability of any individual firm from exerting market power and affecting electricity prices.

D. National security objectives

Oil and natural gas sectors. Energy security is improved when the U.S. government can take actions during an emergency to reduce the economic effects associated with disruptions in energy markets. Toward this end, the United States maintains the Strategic Petroleum Reserve and two regional refined product reserves. Releases of oil from the SPR are often done in cooperation with the member countries of the IEA and are designed to reduce spikes in the world price of oil that would damage the global economy. The United States is currently undertaking a significant investment to modernize and upgrade the SPR to ensure its continued effectiveness. These upgrades have been prompted by changes in the source of crude oil inputs of inland refineries, which, with the renaissance in U.S. oil production, now process large quantities of domestic oil and no longer process significant quantities of imported oil. During a foreign oil supply disruption, these inland refineries would no longer have the capacity to process SPR oil, and thus the SPR would not prove to be as effective as the distribution infrastructure capacity suggests. Consequently, if the SPR is to distribute large volumes of oil following a disruption, it must ship more oil from marine terminals. The Bipartisan Budget Act of 2015, Section 404, authorized DOE to raise up to $2 billion through sales of SPR crude oil to build dedicated marine terminals to increase the system's distribution capacity and make other investments to modernize SPR infrastructure (42 U.S.C. § 6239 Note, P.L. 114-74). In addition, the IEA is working to increase the transparency of emergency oil stockpiles by countries outside of the OECD and identify mechanisms for coordinating releases in the event of future supply problems.

Electric power sector. Energy security is improved when the probability of experiencing an outage is reduced and when any outages that do occur are short, with minimal damage to society and the sector. As a result, the reliability and resilience of the electric power sector represent energy security priorities. *Reliability* is defined in this report as the ability of the electric power sector to provide a stable source of electricity to consumers, and *resilience* is the ability of the electric power sector to withstand and recover from disruptions created by events such as extreme weather, cyberattack, or terrorism. Over the past decade, several trends have emerged that have required changes in how the electricity system maintains reliability, including a high penetration of renewable generation, broad deployment of distributed energy resources, and increased variability in demand. Meanwhile, the growing interconnectedness of the electric power sector has increased the exposure of large sections of the power sector to disruptive events, such as physical or cyberattacks, geomagnetic disturbances, natural disasters, and extreme weather. Compounding the potential severity of these threats are aging infrastructure, workforce capability shortages, and changing technical, regulatory and operational requirements. To improve the reliability and resilience of the electric power sector, and in particular lifeline networks, the Federal Government has advanced several different types of policies and standards:

- New reliability standards promulgated by the Federal Energy Regulatory Commission;
- Changes in the design of electricity markets such as the introduction of fast ramping payments and capacity performance penalties;

- Federal funding for the development of next generation technologies and practices such as the Grid Modernization Initiative; and
- New standards and Presidential Policy Directives designed to help the sector prepare for and respond to extreme weather and cyberattacks.

In addition, the growing national security implications of the U.S. power sector have increased the importance of emergency authorities given to DOE, which can be important for many sectors of the economy, and importantly the work of the U.S. military, intelligence, defense, and security systems. The Department of Defense, for example, is the largest electricity consumer in the United States and relies on commercial power providers for nearly 100 percent of its electricity supply. According to the Defense Critical Infrastructure Program, this included 91 percent of the Department of Defense's most critical assets as of 2009, defined as assets located in the United States or abroad, that if incapacitated or destroyed would have a very serious, debilitating effect on the ability of the department to fulfill its missions.

E. Environmental considerations

Oil and natural gas sectors. Policies that reduce fossil fuel use, or encourage the transition to a low-carbon economy, also support energy security by ensuring the sustainability of energy resources. The most important U.S. policies with respect to oil are the Mobile Source GHG Standards, which are administered in conjunction with the Corporate Average Fuel Economy Standards by the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA). The current standards are anticipated to approximately double light-duty fuel economy between 2010 and 2025 and save 4 billion barrels of oil over the lifetime of the vehicles covered. Another important policy is the Renewable Fuels Standard, which is expected to replace 15 billion gallons per year of gasoline and diesel with qualified renewable fuels by 2017. The legislative goal is to replace 36 billion gallons per year by 2022. DOE is actively supporting the ambitious 2022 targets through grants for commercial expansion of cellulosic biofuel projects. Finally, the Federal Government has a variety of policies designed to encourage the research, development, and deployment (RD&D) of electric, natural gas, and hydrogen vehicles.

Electric power sector. Energy security is improved when electricity can be generated without posing a threat to the environment, from either higher emissions of greenhouse gases (GHGs) or other risks, such as other air or water pollution. The electric power sector produces roughly 30 percent of U.S. GHG emissions, and further decarbonizing the power sector will be critical to meeting national emissions targets, such as those established after the 2015 Paris Agreement. Already, a range of federal policies have been implemented to achieve environmental considerations in the electric power sector, including the Clean Air Act (CAA) and Clean Water Act (CWA), both of which are foundational laws designed to protect human health and the environment from the effects of air and water pollution. Recent initiatives such as President Obama's Climate Action Plan and EPA's Clean Power Plan (80 Fed. Reg. 64662 (Oct. 21, 2015)), the extension of renewable energy tax credits, and loan guarantees for clean energy generation further support the transition to an electric power sector that is less dependent on fossil fuels. Additionally, some states and cities have promulgated market-based policies such as carbon taxes or cap-and-trade programs to further encourage the adoption of clean energy technologies.

IV. Policies Addressing Energy Security for U.S. Allies and Partners

The international allies and partners of the United States face a diverse set of energy security challenges that directly affect U.S. energy security. The following section provides an executive-level perspective of these policies and actions in the context of the FACT Act categories. In this analysis, "allies and partners" refers to a select group of countries shown in Figure 1, which include members of the EU, IEA, and OECD.

Oil and natural gas sectors. Many allies and partners of the United States do not possess large domestic energy endowments (with exceptions such as Australia, Canada, and Mexico) but exhibit a high level of energy security. Most U.S. allies and partners have worked to decouple the historical link between economic growth and energy consumption through policies that reduce the energy intensity of their economy, such as taxes on consumption of petroleum products, fuel economy standards and other energy efficiency measures, incentives for the deployment of renewable energy, and investments in advanced rail transportation.

U.S. allies and partners have also improved their energy security position by removing trade barriers that restrict or limit imports or exports of energy and expanding their links to global energy markets. Mexico, for example, has reversed many decades of national policy restricting foreign involvement in its energy sector. Constitutional changes now allow private sector imports of diesel and gasoline, and upstream reforms will boost energy production and exports in the coming years. The European Union is continuing to pursue efforts to enable consumers of natural gas in Central and Eastern Europe to access a more diverse suite of suppliers by financing infrastructure build-out and enacting regulatory reforms. Progress has also been made in Korea, where refinery upgrades are enabling the country to become a leading Asian refiner and exporter of petroleum products.

U.S. allies and partners are also ensuring that their energy markets maintain sufficient transparency, liquidity, and low barriers to entry. Mexico and Australia are following the United States and several European countries in seeking membership in the Extractive Industries Transparency Initiative. Although Japan and Korea lack robust upstream sectors, they continue to publish relevant data, including forecasted demand and import requirements, to better inform both national and multilateral energy security planning efforts. All U.S. allies and partners have submitted Intended Nationally Determined Contributions under the United Nations Framework Convention on Climate Change and the Paris Agreement and are now working to implement their commitments.

U.S. allies and partners do retain significant vulnerabilities, as evidenced most recently by Russian aggression in Ukraine. Europe faces declining indigenous oil and natural gas production, higher import requirements, and natural gas pricing that is not competitive. Eastern and Southern Europe remain vulnerable to Russian market power because they depend on Russia as their only or dominant natural gas supplier. Korea and Japan are entirely dependent on seaborne trade of oil and LNG to meet strong domestic demand, making their energy ports some of most critical infrastructure in those countries. And U.S. allies and partners remain vulnerable to the same types of threats from weather, physical attack, and cyberattack faced by the United States.

To a varying extent, the vulnerabilities faced by U.S. allies and partners could have cascading impacts on U.S. energy security, and thus, continued U.S. engagement is capable of mitigating these risks to the United States. U.S. global leadership contributed to the completion of the Baku-Tbilisi-Ceyhan oil pipeline in 2006 and has helped move forward construction of the Southern Gas Corridor to diversify Europe's sources of supply. The United States has also been a leader on global efforts to reduce fossil fuel consumption. A recent trilateral agreement with Canada and Mexico to cut methane emissions from the oil and gas sector offers an example of how the United States can collaborate with and leverage the capabilities of its allies and partners to pursue shared energy security goals. Through bilateral and multilateral forums, the United States works with allies and partners to address shared energy security concerns.

Electric Power Sector. In North America, the electricity security of both Canada and Mexico directly affect the United States because of the highly integrated electricity markets. Even among geographically separated electricity markets, there are shared economic interests, including trade, travel, finance, data storage, and defense. These shared interests establish a mutual desire among countries to maintain high standards of reliability and resilience for our electric power sectors. Recent advances in European electricity policy, such as the incorporation of cybersecurity standards, mirror those occurring in the United States. Japan and South Korea are highly dependent on imported fuels, but are taking steps similar to those in the United States to ensure a more secure, reliable, and diversified portfolio of clean sources.

To advance modern energy security principles and promote the development of policies and technologies that increase energy security globally, DOE has engaged in various multilateral forums with our allies and partners:

- ***Mission Innovation*** is a global initiative of 20 countries committed to doubling government investment in clean energy research and development over 5 years. The first Mission Innovation Ministerial was held in San Francisco on June 1–2 and included Mexico, Brazil, and Canada.
- ***The Energy Climate Partnership of the Americas*** is a primary multilateral mechanism for advancing the deployment of clean energy technologies and practices across the Western Hemisphere. Focus areas include renewables, energy efficiency, energy infrastructure, energy poverty, and adaptation.
- ***The International Partnership for Energy Efficiency Cooperation (IPEEC)*** is an autonomous partnership of nations founded in 2009 to promote collaboration on energy efficiency. Its membership now includes 16 countries that represent over 80 percent of global energy use and over 80 percent of global greenhouse gas emissions.

- Through the G-7 and G-20 ***Energy Ministerials***, leading up to the Leaders Summits in 2016, DOE and the Department of State are working to secure action by our partner countries to reduce fossil fuel subsidies, counter cybersecurity threats to our energy systems, enhance the safety of civil nuclear energy activities, and assist Ukraine's efforts to establish a greater degree of energy security.

Each of these provides energy security benefits to the United States by improving the security of U.S. allies and partners.

V. Energy Security Applications in Federal Rulemaking

In principle, a wide range of Federal actions relate to energy security. In practice, however only a limited set of actions has addressed energy security through a quantitative analysis in Regulatory Impact Analyses (RIAs), although a broader group of policies and actions has considered energy security in a qualitative way. RIAs, issued by DOE, EPA, the Department of Transportation (DOT), and other federal agencies over the past decade, have generally focused on benefit categories associated with the traditional definition of energy security, rather than the broader set of categories identified in the recent G-7 energy security principles and the FAST Act. For most of the rules identified in this review, the respective agencies determined qualitatively that the rules would not be "likely to have a significant adverse effect on the supply, distribution, or use of energy." Overall, the agencies addressed the requirements in a brief statement.

The most complete and extensive discussion of energy security was done for DOT and EPA's RIAs for rules setting fuel efficiency standards for cars and trucks, as well as rules implementing a mandate for renewable fuels. That said, only benefits for consumers and the economy from reducing oil consumption (and oil imports) and environmental benefits from transitioning away from fossil fuels were considered. There is no discussion of impacts on resilience, innovation, diversification, or other energy security goals identified by the G-7.

The regulatory analyses for DOE's energy efficiency standards—largely addressing products that use electricity or natural gas—focus on both the potential cost savings of the standards and the compliance costs of producing more efficient products. In the few cases where these rules were projected to reduce oil consumption, the regulatory analysis projected very small changes in oil use and did not evaluate further the energy security effects in terms of a change in oil prices and imports. After the Obama Administration placed a priority in 2009 on reducing carbon emissions, DOE's regulatory analyses for these rules included a monetized benefit estimate for the reduction in GHG emissions.

The RIAs for most other rules are not consistent in their treatment of energy security benefits. DOT's safety rules focus on reductions in mortality and injury-related risks, and these benefit categories represent the vast share of their monetized benefits. In discussing the fuel consumption effects of these rules, five of the eight DOT rules that were examined for this report provide quantified estimates; the remaining RIAs offer only qualitative descriptions. Three of the eight RIAs also discuss at least some aspect of the rule on changing levels of oil imports, and four include a discussion of reduced carbon emissions—although only one includes a monetized benefit estimate.

The focus of EPA rulemaking—apart from the rules implementing the Energy Independence and Security Act, which focused on carbon emissions reductions and renewable fuel mandates—is on environmental improvement and reducing public health risks and environment-related adverse welfare effects. EPA's RIAs for rules addressing the electric power sector typically address carbon emissions and reliability issues, and in several instances, they offer a qualitative discussion of the deployment of sustainable energy technologies.

In addition to Federal regulatory actions, the U.S. government also considers energy security in other policy contexts, such as permit decisions and energy-related Presidential Directives. For example, DOE has the responsibility under the Natural Gas Act to regulate imports and exports of natural gas, including LNG exports. To support its permitting decisions, DOE has completed several studies of the effects of LNG exports on the domestic natural gas market, the U.S. economy, and the environment. Criteria DOE considers in evaluating the public interest of an application to export natural gas to non-free trade agreement countries, includes the effects of the exports on the domestic natural gas markets, the national economy, international trade, and the environment.

VI. Valuation of Energy Security Benefits

Although Federal energy-related policies and actions deliver a wide range of energy security benefits, those benefits are not evaluated consistently across the Federal Government. There are two principal reasons for these inconsistencies: (1) many of the energy security benefits were not part of the traditional definition of energy security and thus were probably not recognized as benefits; and (2) many of the benefits have not been monetized in a way that is amenable to inclusion in traditional benefit-cost analysis or other types of quantitative analysis. The first two chapters address the first issue by discussing the modern definition of energy security and the types of policies that advance energy security. To address the second issue and develop a strategy that consistently evaluates energy security benefits across the Federal Government, DOE reviewed the valuation literature for best practices in monetizing energy security benefits.

In general, the benefits derived from energy-related policies and actions fall into one of two categories: market benefits and non-market benefits. Market benefits are those benefits that are currently priced by the market and show up as changes in consumer and producer surplus associated with changes in supply or demand of a commodity. (Consumer surplus is a measure of the difference between the price paid for a good or service and the value placed on that good or service by the consumer. Producer surplus is a measure of the difference between the price a producer receives for a good or service and the variable cost to produce that good or service.) Typically, the market benefits of an energy-related policy or action can be quantified using economic models of the whole economy or particular sectors, assuming the models include an understanding of how the policy or action affects the relevant equations that make up the model. For example, economic models can capture the benefits and costs of energy-related policies and actions that do the following:

- Directly affect energy prices, such as taxes, production subsidies, and end use energy subsidies;
- Indirectly affect energy prices, such as tradable emissions limits, emissions taxes, regulations on pollutants, fuel efficiency standards, and energy efficiency standards;
- Make markets more transparent and efficient, such as by allowing the export of domestically produced energy, making information more available to customers, facilitating data sharing agreements, and allowing the market to determine prices;
- Encourage diversification of electricity generation, through the use of production tax credits, other subsidies, loan guarantees, and tradable fuel and portfolio standards; and
- Provide the U.S. government with an emergency response system to a supply disruption that can reduce oil or refined petroleum product prices, such as the Strategic Petroleum Reserve.

The non-market benefits are effects, or externalities, that have not been priced in a market. Pollution is the canonical example of an externality; other examples are the unpriced effects of oil price shocks on the U.S. economy and unanticipated electricity outages. Since there are no market prices for those benefits, other methods must be used for estimating their values. For example, surveys of customers are used to gather information to estimate the value of reducing the frequency or duration of electricity outages. Estimates of the value of a non-market benefit can then be applied to estimates of how much a policy or other action changes the frequency with which the benefit is experienced, as determined by simulation modeling, empirical analysis, or a survey of experts.

A. General Quantification Opportunities

Various economic models, typically categorized as sectoral, general equilibrium, input-output, or macroeconomic models, can be useful for monetizing energy security benefits although there is considerable room for improvement in the individual models and in the ability of the models to simulate both the energy sector and its interaction with other important sectors of the economy. Efforts to improve these models are ongoing but could be accelerated to address the needs of those estimating energy security benefits.

This report does not focus on valuations for any particular policy or aspect of energy security. Rather, the focus is on identifying methodologies that can be used to value the benefits that derive from a variety of energy-related policies and actions. Priority research needs are then associated with the various benefit categories. To coordinate the valuation of energy security benefits across federal agencies, an energy security model could be developed that aggregates energy security benefits and monetizes them consistently.

B. Quantification of Benefits for Consumers and the Economy

Significant literature has been devoted to understanding the implications of higher oil prices on consumers and the U.S. economy, but additional research could be done to elucidate several benefits from energy-related policies:

- ***Oil sector.*** The benefit of reducing oil imports, also called the oil import premium, has been estimated for historical conditions, yet conditions are constantly changing and certainly look different today with respect to oil imports than they did in 2008 or 2010. EPA and DOE have regularly re-estimated the oil import premium for many successive EPA/NHTSA rulemakings over a range of EIA Annual Energy Outlook projected conditions. This premium should continue to be updated using the best available modeling techniques such that the results remain applicable to current and forecasted future conditions.
- ***Oil sector.*** Policies that would encourage or prohibit the extraction of domestic oil have not typically included in their benefit-cost analysis the option value of unproduced domestic oil for extraction in the future if an oil disruption caused oil prices to spike. Current models could be modified to include this potential, and the corresponding benefits to GDP from lost or gained future production.
- ***All energy sectors.*** Changes in energy prices create an incentive for consumers to change their consumption of energy. Some decisions made by consumers, such as what vehicle to purchase, where to live and work, and what energy efficiency level is desirable in large appliances, are costly to change if energy prices change again in the near term. A better understanding of the factors that cause consumers to make energy inefficient decisions would help policymakers understand the implications of changes in energy prices.

C. Quantification of Benefits for Energy Supply Diversity and Resiliency

Although some tools exist to model the benefits of diversification and resilience, this review did not identify any approaches to quantifying these benefits in ways that could be used in benefit-cost analyses of energy-related policies and actions.

- ***All energy sectors.*** Diversification indices for oil, gas, and by extension, electricity exist but have not been monetized or linked to effects on GDP or social welfare, and thus they have not been used in benefit-cost analyses of policies that would increase diversification. This includes diversification of sources of fuel, routes of fuel transport, or types of fuel.
- ***Oil and gas sectors.*** The benefits of policies and actions that increase resilience against disruptions have not been quantified in the literature. That is, in part, because it is difficult to forecast the probability that a disruption occurs and the damages resulting from that disruption. Development of methods for quantifying such benefits would improve the efficient investment in resilience and diversification.
- ***Electric power sector.*** Many policymakers talk about fuel diversity, yet monetized estimates of the value of increasing generation or fuel diversity have not been identified. Moreover, not all increases in diversity are likely to have the same effect.

Policies to promote diversity include research and development for new technologies, support for existing nuclear reactors, or renewable portfolio standards. Estimating the value of diversity would enable policymakers to better understand the benefit of these types of policies to weigh against the costs.

D. Quantification of Benefits for Well-Functioning and Competitive Markets

Market operation can often be improved by breaking up monopolies, increasing competition, removing subsidies, lowering trade frictions, removing obstacles to buying and selling a product, reducing transaction costs, and reducing barriers for new firms to enter the marketplace. In many cases, the benefits of more competitive, liquid, and transparent markets can be at least partially estimated using economic models or empirical data. However, most energy models do not currently have the equations and data necessary to quantify the benefits of improvements in market operation.

As a result, the benefits of policies that improve market operation by increasing competitiveness, liquidity, or reducing transaction costs are not often quantified for benefit-cost analysis, even though those benefits can be large. Policymakers would benefit from the development of a consistent approach to benchmarking transaction costs in existing markets and estimating the effects of various types of policies in reducing those transaction costs or increasing competition.

E. Quantification of Benefits for National Security

A significant amount of literature is devoted to estimating the value of avoiding electricity outages, although it is primarily about very short-term outages, and large variation exists in the estimates for any given time period. To generate values that could be used by policymakers in future cost-benefit analysis, additional research is warranted, as follows:

- ***Electric power sector.*** More refinement is needed of methods and data for valuing the direct and indirect costs of long-term electricity supply outages. The wide range of estimates might be reduced if researchers used and further developed best practices with respect to survey and model design. In addition, the effect of adaptation measures available to various sectors on the societal value of an extended outage is not well understood. That is particularly true as it relates to nonlinearities in adaptation strategies that may, for example, provide significant protection to a sector from a week-long outage but much less protection from longer outages.
- ***Electric power sector.*** Some sectors of the economy, such as military, healthcare, and public utilities, are critical lifeline sectors of the economy. Understanding both the resilience of those sectors to outages and the adaptation measures they have adopted or could adopt would enable policymakers to better understand the types of policies that would reduce the cost of extended power outages to the U.S. economy.
- ***Electric power sector.*** The probabilities of various types of outages are not well understood. To estimate the value of any resilience or reliability investment, one

must weigh the costs against expected benefits, which depend on the effect of the investment on the probability of future outages. More research on how policies, technology, and investment change the probability of outage-inducing events for various parts of the country would facilitate better benefit-cost analyses.

- ***Oil and gas sectors.*** We were unable to identify any recent research on the economic cost of a gasoline, diesel, or natural gas outage (i.e., the physical shortage of those products at any price), which is probably because the likelihood of such an outage is low and its duration would be short. Better understanding such outages and the relationship between natural gas and refined petroleum product prices and economic growth would benefit policymakers when, for example, considering additional federally funded storage of these fuels.
- ***Oil sector.*** We identified a limited number of studies that attempted to estimate an optimal SPR size. One such study was the Long-Term Strategic Review of the U.S. SPR, published by DOE in 2016. However, most of the studies about optimal size were conducted more than a decade ago, when domestic production was in a continuous and steady decline. With decreasing U.S. oil imports and new discoveries of domestic oil resources, an update to these studies might be warranted to better understand the value of the SPR to national security.

F. Quantification of Benefits for Environmental Considerations

The National Academies of Sciences, Engineering, and Medicine are currently reviewing the latest research on modeling the economic aspects of climate change to inform future revisions to the SC-CO_2 estimates. While the Academies' review focuses on the SC-CO_2 methodology, recommendations on how to update many of the underlying modeling assumptions will also likely pertain to estimating the social cost of other GHGs, such as SC-CH_4 and SC-N_2O. While the Academies develop their recommendations (expected in early 2017), the Interagency Working Group (IWG) continues to recommend the use of the current social cost of greenhouse gas estimates as the best scientific information on the impacts of climate change available in a form appropriate for regulatory analysis.

A rich literature exists for methods to estimate the value of non-GHG pollution that is emitted from the extraction, transport, and use of energy. These values are not always incorporated into benefit-cost analysis. For example, morbidity and mortality damages stemming from some types of air pollution typically are included in benefit-cost analysis, but the benefits of reduced water use or water pollution are generally not included. Thus two next steps would be as follows:

- ***All energy sectors.*** Benefit-cost analyses do not currently capture the benefits associated with all types of air, water, and solid waste pollution. Nor do they capture the benefits associated with reduced water use, particularly in the arid regions of the country. Benefit-cost analysis would benefit from the development of an inventory of the pollution and other natural resource–related externalities produced from each source of energy during extraction, transport, and use. This could be an expansion of the inventory currently used by EPA. This inventory could be compared with standard benefit-cost analyses to identify which types of pollution or other externalities are not currently captured. The externalities with the largest expected benefits could be identified for inclusion in future cost-benefit analysis.

- ***All energy sectors.*** Some traditional estimates of pollution control benefits are subject to controversy even as the science base improves. A particular area for meaningful analysis would be to evaluate the use of a value of statistical life-year estimate to monetize reduced death risks from energy-related policies and actions instead of using the value of statistical life. Research would be needed to develop credible VSLY estimates.

Prologue: Valuing Energy Security in the United States

Energy security for the United States has historically meant adequacy and diversity of oil supply. Since the energy crisis of the 1970s, this has largely been measured by U.S. oil import dependency. By that measure, the United States has a much stronger energy security position now because it is the top producer of liquid fuels in the world, with shrinking net oil imports. But the factors that affect the energy security of the United States and our allies have become more complex due to the evolving threat to the environment and new global security challenges in various regional settings.

Energy security now includes natural gas supply; electricity generation, transmission, and distribution; the functioning of energy markets; and the ability of the energy system to withstand shocks and disruptions, whether from natural disasters or terrorism. Our energy system is more secure as we move to more sustainable sources of energy supplies and increased energy efficiency. In the past, sustainability was largely associated with not running out of fossil fuel resources, but now a sustainable energy system is one that can produce energy over the long term with minimal environmental consequences. Energy security also needs to reflect the interdependencies between energy systems and sectors of the economy. Non-energy sectors, such as communications and water, have become critical to the operation of energy systems. These interconnections have grown and become more complex. They can compound the effects of energy supply disruptions and make restoration of energy services more difficult.

Energy security for the United States is also a collective responsibility because energy *insecurity* of our allies and partners can raise national security challenges for us, as evidenced by recent actions in Ukraine. Access to energy is central to economic stability, poverty reduction, protection of human rights, and promotion of democracy. The inability to access energy can be destabilizing for developing and developed countries, which can directly affect the security of the United States by creating regional conflicts and drawing on U.S. financial, physical, or military resources for stabilization.

These changes in energy security call for a reassessment of the Nation's energy security goals to reflect our complex and interconnected global and domestic energy markets. Within this new framework, energy security is improved by the modernization of U.S. and global energy infrastructures and supporting systems to enhance resilience, reliability, flexibility, and efficiency. Reflecting this changing perception, the energy ministers of the Group of Seven (G-7) member countries—Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States—agreed in June 2014 to a set of principles that reflect broader ideas of energy security both for individual nations and collectively (G-7 2014). In an effort to articulate a new energy security paradigm, the G-7 endorsed a set of seven energy security principles:

1. Development of flexible, transparent and competitive energy markets, including gas markets.
2. Diversification of energy fuels, sources and routes, and encouragement of indigenous sources of energy supply.

3. Reducing our greenhouse gas emissions, and accelerating the transition to a low carbon economy, as a key contribution to enduring energy security.
4. Enhancing energy efficiency in demand and supply, and demand response management.
5. Promoting deployment of clean and sustainable energy technologies and continued investment in research and innovation.
6. Improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks.
7. Putting in place emergency response systems, including reserves and fuel substitution for importing countries, in case of major energy disruptions.

These principles, with their focus on well-functioning and competitive energy markets, diverse sources and routes of energy supply, environmental protection, efficiency and infrastructure improvements, energy innovation, emergency response, and resilience, are guiding the work currently being done by the Department of Energy (DOE) and our interagency partners. In its 2015 Quadrennial Energy Review (QER), the Administration recommends viewing U.S. energy security and the infrastructures that support it, both physical and geopolitical, in terms of this more comprehensive definition (DOE 2015).

Fully incorporating this new definition of energy security into policymaking requires that appropriate measures be adopted to allow the Federal Government to value energy security contributions. Recognizing this, the Fixing America's Surface Transportation (FAST) Act (Pub. L. No. 114-94, § 61005 (Dec. 4, 2015)) echoes the new G-7 definition and requires the Secretary of Energy, in collaboration with the Secretary of State, to develop a report that will do the following:

- evaluate and define United States energy security to reflect modern domestic and global energy markets and the collective needs of the United States and its allies and partners;
- identify transparent and uniform or coordinated procedures and criteria to ensure that energy-related actions that significantly affect the supply, distribution, or use of energy are evaluated with respect to their potential impact on energy security, including their impact on:
  - consumers and the economy;
  - energy supply diversity and resiliency;
  - well-functioning and competitive energy markets;
  - United States trade balance; and
  - national security objectives; and
- include a recommended implementation strategy that identifies and aims to ensure that the procedures and criteria referred to in [the above bulleted point] are:
  - evaluated consistently across the Federal Government; and
  - weighed appropriately and balanced with environmental considerations required by Federal law.

This report presents an analysis of how energy-related policies and actions are valued, both qualitatively and quantitatively, with respect to their effect on energy security. The report does *not* attempt to assess the extent to which the United States and our allies and partners are energy secure, although it points out several instances where recent developments and policies have contributed to improved energy security. Instead, this report suggests how the United States can consistently value the benefits of policies and actions that increase energy security. The report considers both the domestic and collective aspects of energy security.

Prior to initiating the study, but after the approach was developed, DOE held a public workshop on energy security at DOE's Forrestal Building in Washington, DC, on May 13, 2016. The workshop was announced in the *Federal Register* on May 3, 2016, and a notice was distributed widely via e-mail and posted on the webpage of DOE's Office of Energy Policy and Systems Analysis.[1] The purpose of the workshop was to solicit input from the public on the approach to completing this document adopted by DOE and the expanded definition of energy security. The agenda for this workshop, a summary of key points, and a full transcript are included as Appendix A. In general, attendees and participants applauded the expanded definition of energy security and shared their perspectives on policies that improved energy security according to the new definition.

The report is divided into four chapters. The first two qualitatively discuss the types of energy-related policies and actions in the oil and natural gas sectors (Chapter 1) and the electric power sector (Chapter 2) that affect energy security. Policies and actions are grouped according to the categories defined by the FAST Act, which parallel the G-7 principles: consumers and the economy, energy supply diversity and resilience, well-functioning and competitive energy markets, national security objectives, and environmental objectives. These chapters also examine the energy security posture of U.S. allies and partners according to the same categories.

Chapter 3 examines the current treatment of energy security benefits in benefit-cost analyses conducted by the Federal Government. In principle, a wide range of Federal actions relate to energy security, especially under the broader definition advanced by the FAST Act. In practice, however, only a limited set of Federal energy-related policies or actions have addressed energy security using a quantitative analysis, although a broader group has considered energy security in a qualitative way. This chapter summarizes how energy security is currently incorporated into Federal actions, based on a review of the final Regulatory Impact Analyses (RIAs) prepared by Federal agencies pursuant to Executive Orders 12866 and 13563. It also presents information on the U.S. government's treatment of energy security in other policy contexts, such as permit decisions and energy-related Presidential directives.

[1] 81 Fed. Reg. 26537; the announcement is at http://energy.gov/epsa/articles/upcoming-doe-public-workshop-new-opportunities-and-challenges-us-energy-security (accessed October 20, 2016).

Recognizing that many aspects of energy security are not currently quantified in Federal rulemaking, Chapter 4 then reviews the valuation literature to identify methods and values that could be used to quantify the benefits of energy security in future Federal rulemaking. This chapter also identifies areas for future research to enhance the government's ability to evaluate potential actions that affect energy security in the oil, gas, or electric power sectors.

Chapter 1: Energy Security Policy in the Oil and Natural Gas Sectors

I. Introduction

The United States is home to enormous oil and natural gas deposits, and it has seen a revival in oil and natural gas production over the past decade as a result of advanced technologies, especially horizontal drilling and hydraulic fracturing. Today the United States is the world's largest producer of crude oil and other liquids, the largest producer of natural gas, and the largest producer of refined petroleum products. The United States is a net exporter of refined products and, for the first time in decades, now produces more oil than it imports. In addition, the dramatic growth in domestic natural gas production has lowered U.S. natural gas prices and allowed the United States to begin exporting LNG, which has increased the competitiveness and transparency of international LNG markets.

The United States also maintains one of the most advanced and complex energy infrastructures in the world with an extensive system transporting oil, natural gas, and refined product to consumers: nearly 2.6 million miles of pipelines, 414 natural gas storage facilities, 330 ports handling crude petroleum and refined petroleum products, and more than 140,000 miles of railways and local distribution networks. Industry maintains aboveground storage capacity for more than 600 million barrels of oil and underground storage for natural gas equivalent to nearly 2 months of U.S. consumption. This complex system enables the transport of oil, natural gas, and refined products from sources of supply, refineries, and import terminals to demand centers and export terminals across the Nation.

The U.S. government also controls the world's largest strategic reserve of oil. In the event of a serious oil supply disruption, the prompt release from the U.S. Strategic Petroleum Reserve (SPR), along with reserves held by member countries of the International Energy Agency, can reduce oil-price spikes that would damage both the U.S. and the global economy.

Despite our considerable energy assets, the security of the oil and natural gas sectors remains vulnerable to a growing number of threats. Oil and petroleum products are bought and sold on the world market, which leaves the U.S. economy exposed to supply disruptions anywhere in the world and the ensuing global price volatility. The 2015 QER concluded that in key areas, the country's oil and natural gas infrastructures have not kept pace with changes in the volume and geography of oil and natural gas production. The recent Colonial pipeline disruptions and the Southern California Aliso Canyon gas leaks are prominent examples of the infrastructure challenges faced by the United States in managing a system built decades ago. Sea level rise, severe weather, and storm surges put at risk energy infrastructure, including the 50 percent of U.S. refining capacity located in the Gulf Coast region. Finally, along with greater deployment of information and communication technologies to enhance the operational efficiency of our energy infrastructure, there has been a rise in intentional, malicious cyberattacks to the oil and natural gas sectors.

In the United States, policymakers are keenly aware of the vulnerabilities of the economy with respect to oil and natural gas, as well as many of the vulnerabilities for countries that the United States considers friends and allies. Multiple policies address both domestic and international concerns and seek to enhance national and international energy security.

The following sections assess the energy security of the United States, its partners, and allies in six categories and describe some of the policies that address these vulnerabilities. Those categories are taken from the text of the legislation requesting this report—the Fixing America's Surface Transportation (FAST) Act (Public Law 114-94)—and represent the full breadth of energy security principles adopted in 2014 by the energy ministers of the Group of Seven.

Energy security can be considered in relation to those categories as follows:

Consumers and the economy. Energy security is improved to the extent that consumers, defined as both households and businesses, can reduce their expenditures on fuel when prices for oil, natural gas, or petroleum products rise. That is most likely to occur when consumers are less dependent on any particular energy commodity.

Energy supply diversity and resiliency. Energy security is improved when firms cannot exercise market power with respect to oil or natural gas production, processing and refining, or distribution. Similarly, energy security is improved to the extent that the market can be protected from naturally occurring or human-caused disasters either because firms have taken actions to prevent infrastructure from being affected or because sufficient redundant infrastructure exists.

Well-functioning and competitive energy markets. Energy security is improved when markets are transparent and liquid and have low barriers to entry.

U.S. trade balance. The balance of trade and its effect on exchange rates or investment flows can have economic consequences, but those are unrelated to the G-7 energy security principles. The effect of varying levels of energy imports and exports can affect energy security, but do so primarily through an effect on U.S. GDP, which is discussed in the "Consumers and the economy" category. These factors are further articulated in the brief "U.S. trade balance" section.

National security objectives. Energy security is improved when the U.S. government can take actions during an emergency to reduce the economic effects associated with disruptions in energy markets.

Environmental considerations required by Federal law. Energy security is improved when energy consumption can be increased without posing an increased threat to the environment, from either higher emissions of greenhouse gases (GHGs) or other risks (such as water pollution or seismic activity).

II. Defining and Assessing Oil and Gas Energy Security in the United States

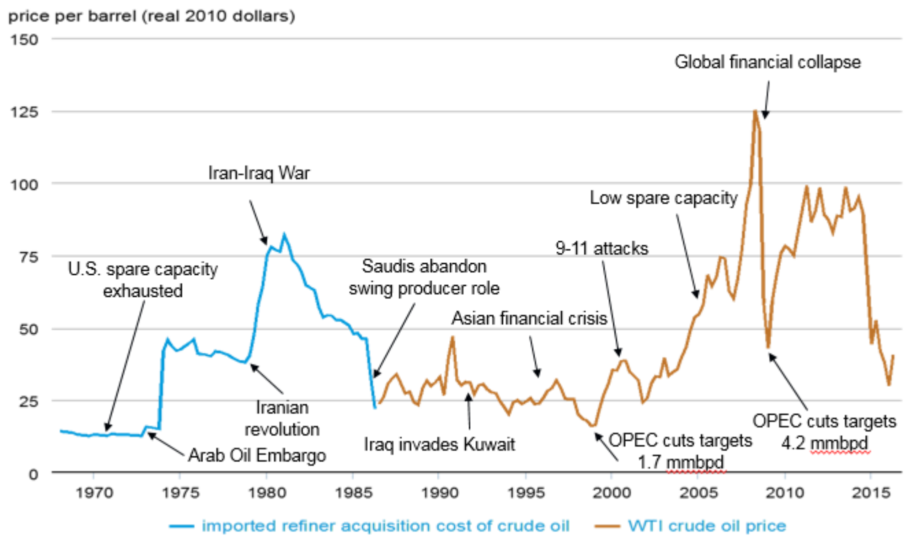
The United States has a reliable supply of oil and gas but faces important vulnerabilities with respect to infrastructure, susceptibility to disruptions of oil anywhere in the world, and the need to mitigate environmental consequences of energy production and consumption (U.S. Chamber of Commerce 2015). The U.S. government has implemented numerous policies and regulations aimed at improving energy security, going as far back as the 1920s and the Federal Power Water Act. Among the Nation's earliest legislative acts affecting oil and gas were the 1938 Natural Gas Act (NGA) and the Energy Policy and Conservation Act of 1975 (EPCA). Other efforts undertaken to improve energy security are explored below, in the context of their benefits for energy security in the oil and natural gas sectors.

A. Consumers and the Economy

Energy security is improved to the extent that consumers, both households and businesses, can reduce their expenditures on fuel when prices rise for oil, natural gas, or refined petroleum products. Consumers are able to reduce their expenditures on fuels either when substitute fuels are available (i.e., high demand elasticity) or when programs are available to reduce the cost of purchasing high-priced fuel (e.g., the Low Income Home Energy Assistance Program, which provides direct support to low-income households). Protecting consumers while enabling strong economic growth are two of the primary goals of policymakers in the United States, and a great number of U.S. energy policies are designed to achieve both goals.

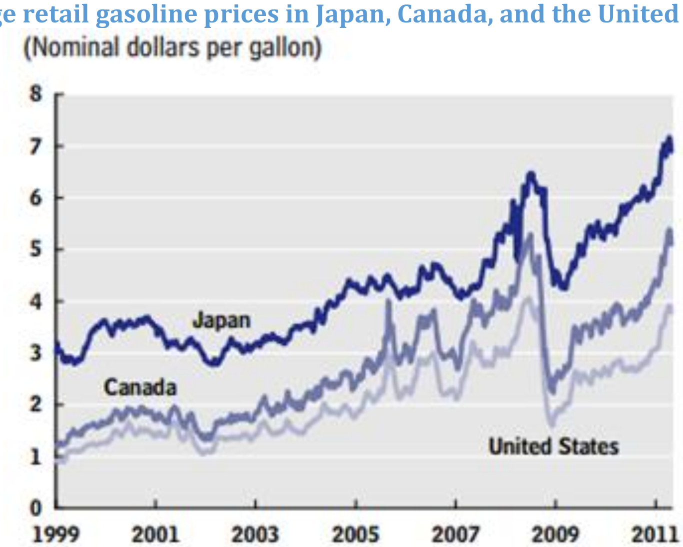
Oil and refined petroleum products. Oil and petroleum products are sold in a global market and priced on the basis of global supply and demand, after accounting for variations in quality and transportation costs to distribution hubs. As a result, a disruption in the supply of oil anywhere in the world would have the same effect on crude oil prices everywhere in the world, regardless of the levels of oil imports for a particular country (e.g., Figure 1.1 shows the price of oil in the United States affected by events all over the world). Similarly, an increase or decrease in demand for oil anywhere in the world affects the price paid by all buyers of crude oil. And the price paid for crude oil directly affects petroleum product prices everywhere in the world (DOE 2015b). That means that prices for gasoline rise for consumers in the United States at the same time that they rise for consumers in Japan and Canada, even though Japan produces no crude oil, Canada is a net exporter of crude oil, and the United States imports less than half of its crude oil demand (Figure 1.2). The global nature of both crude oil and refined petroleum products makes it difficult to insulate the U.S. economy from changes in global oil markets.

Figure 1.1. Crude oil price timeline for U.S. refineries, 1970–2015



Source: **EIA (2016h)**

Figure 1.2. Average retail gasoline prices in Japan, Canada, and the United States, 1999–2011



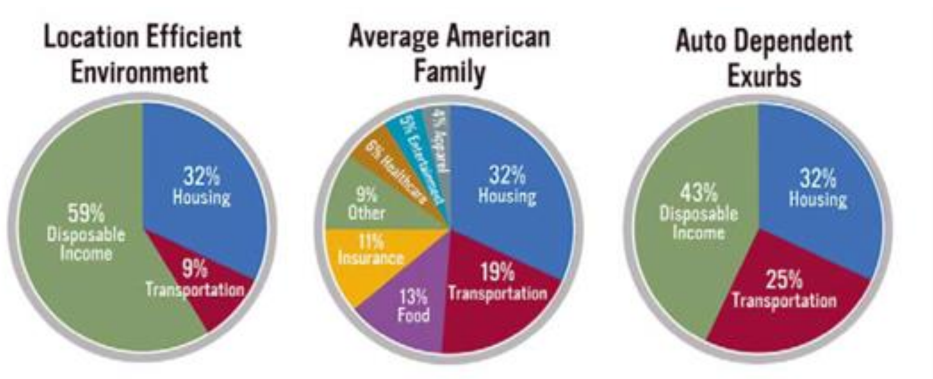
Source: **CBO (2012)**

Volatility in the price of crude oil and petroleum products directly affects the finances of individual consumers and creates indirect costs for the economy overall. When crude oil prices increase, households and businesses pay more for transportation fuels and the other inputs that depend on transportation, all of which constitute the direct costs. As a result of those higher input prices, households and businesses are able to spend less on other goods and services and invest less. Those decisions create indirect costs on the economy, with effects that can last for several quarters. The ability to avoid such costs is measured by the short- and long-term elasticity of demand, which is consumers' ability to reduce their use of crude oil and petroleum products when prices for those commodities rise.

The Federal Highway Administration (FHWA) has found that for many households, transportation is the second-largest expense in their annual budgets, costing as much as 20 to 25 percent of their annual income (DOT 2015b). Petroleum products alone account for 92 percent of globally consumed transportation fuels, with limited substitutions. The Energy Information Administration (EIA) has estimated the short-term price elasticity of gasoline demand to be –0.02 to –0.04:[2] it takes a 25 to 50 percent increase in the price of gasoline to reduce gasoline consumption by 1 percent (EIA 2014b). This means that consumers are unable to make many accommodations over the short term in response to changes in transportation fuel prices.

Although oil price volatility imposes a cost on the economy, low oil prices do not necessarily benefit the economy over the long run if oil prices remain volatile. Boom-and-bust cycles that result in low oil and petroleum product prices can increase demand for larger vehicles and homes farther away from workers' places of employment. This puts consumers in a worse financial situation when oil prices rise: they are locked into transportation options that require greater oil consumption. FHWA has found that households in "location-efficient environments" (close to workplaces and amenities) that require one car (or no car) per home can reduce the share of transportation expenses to as little as 9 percent of income (Figure 1.3). Further, low prices may present a disruption to firms planning investments in next-generation vehicle technologies (IHS Automotive 2015), in turn pushing out the timeline for developing or deploying alternatives to gasoline and diesel as transportation fuels. U.S. policy seeks to reduce harm to consumers and the economy by reducing the oil intensity of the economy, developing advanced engines and alternative fuels, improving fuel efficiency, and providing consumer relief where appropriate. All of these policies are addressed below.

Figure 1.3. Transportation as share of household expenses, by household location



***Source*: DOT (2015)**

[2] This is considerably lower than EIA's previous estimates for gasoline demand elasticity; in the 1990s, elasticity was believed to be –0.08.

Natural gas. Natural gas prices depend on the region of the world in which the gas is produced and consumed, limiting the exposure of any part of the world to disruptions of natural gas supply that occur in other regions of the world. Increased shale gas production in the United States over the past decade has reduced the price of natural gas in the North American natural gas market. Increased domestic supply has also reduced U.S. imports of natural gas and liquefied natural gas (LNG). Within North America, natural gas prices are affected by changes in gas supply and demand, with prices becoming volatile as a result of extreme weather events, infrastructure disruptions, and changes in the price of substitute commodities. Natural gas is used in the United States for electricity generation, in industrial processes, as a home heating and cooking fuel, and as a transportation fuel. For many of these uses, such as home heating and cooking fuels, consumers cannot easily switch to alternative fuels when prices spike because they may have fuel-specific equipment or depend on utilities or local policymakers and regulators who are similarly locked into fuel-specific choices.

Residential consumption of natural gas is believed to be more elastic than the use of petroleum fuels but still relatively inelastic because consumers cannot easily change between gas and electric heating or cooking. Estimates put residential natural gas demand elasticity in the range of –0.12 in the short run and –0.36 in the long run (Bernstein and Griffin 2006). In response to higher natural gas prices, consumers can turn down their heat in the winter. Improving the efficiency of home appliances, both those that directly use natural gas (e.g., air and water heaters, cooking appliances) and those that run on electricity in regions with natural gas–fired electricity generation, may mitigate the effects of volatile natural gas prices on consumers. Further, in the case of the electric power sector, the ability to quickly switch to less-carbon-intensive fuels, whether to address high prices or environmental objectives, is limited by infrastructure and regulation (see Chapter 2).

U.S. policymakers have taken multiple approaches to protecting consumers and shielding the economy from the effect of increasing oil and natural gas prices. Salient policies are addressed below, grouped by policy type.

i. Managing Effects of Price Volatility by Managing Oil Intensity

Given the large role that oil and natural gas play in the U.S. economy, the potential costs of price volatility are significant. One remedy is to reduce the intensity of oil and natural gas use, either by reducing total energy use or by shifting to another energy source with less volatile prices. As Michael Levi of the Council on Foreign Relations has stated, "a fifty-dollar price swing [in the price of oil] is only half as bad if you're using half as much oil" (Levi et al. 2012). This can be achieved through fuel diversification for a given end use (reducing the share of oil and gas in the energy mix) or through demand-side and energy efficiency measures intended to lower energy consumption overall. Consistent with the G-7 principles, the U.S. government has advanced policies for many years aimed at increasing both diversification and efficiency.

a. Diversification of Fuel Supplies

Among the policies intended to encourage diversification away from the use of oil, those aimed at the transportation sector have the greatest effect because that sector is the largest consumer of oil in the United States. Fuel diversification can fall into one of two categories: investment in fuel blend substitutes, such as ethanol, or investment in alternative transportation fuels, like electricity, hydrogen, or natural gas. Gasoline fuel blends like ethanol reduce the gasoline share in the transportation fuel mix and, as a result of that lower demand for gasoline, reduce the average price of gasoline. But the fact that these fuels are blended with gasoline at relatively low percentages and are not substitutes for gasoline means that most consumers cannot choose to use higher volumes of these substitutes when gasoline prices rise, and thus they do little to reduce the effect of gasoline price spikes on consumers. In addition, they can also, to a limited degree, raise the price of gasoline if ethanol prices rise because of, for example, increased corn prices.

Alternative transportation fuels like electricity (for electric-drive vehicles) and natural gas are delinked from global petroleum product markets and could give consumers less expensive alternatives in the event of an oil supply disruption.

Diversity through fuels blended with gasoline or diesel. One policy that increases diversity in the transportation sector is the Renewable Fuel Standard (RFS) program. It was designed to advance renewable biofuels and reduce U.S. dependence on petroleum products by displacing some of the demand for those products. Managed by the Environmental Protection Agency (EPA), the program was authorized by the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007 (EPA 2016h).[3] The RFS requires that a certain volume of fuels (petroleum-based transportation fuel) be replaced or reduced through the use of renewable fuels from one of four categories: biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel. The volume requirements are recalculated by EPA as part of the annual rulemaking process, and the Clean Air Act also allows EPA to waive these requirements "in whole or in part, based on a determination that implementation of the program is causing severe economic or environmental harm, or based on inadequate domestic supply" (EPA 2015). EPA determined that "inadequate domestic supply" of biofuels necessitated a lower RFS volume requirement for 2014–2016 based on the difficulty of distributing more ethanol than can be blended into E10 fuel (10 percent ethanol). Higher-ethanol blends such as E15 and E85 are not widely distributed as a result of limited infrastructure and demand: E15 is approved widely only for vehicles made after 2001, and E85 is used in only a limited number of flex-fuel vehicles, and neither fuel is widely sold in retail outlets. Concerns by EPA about inadequate domestic supply were eliminated from EPA's rationale for the 2017 standards as a result of increasing demand for transportation fuels and ongoing investment in renewable fuel distribution infrastructure (40 CFR § 80).

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[3] For the Energy Policy Act of 2005, see Pub. L. No. 109–58 (Aug. 8, 2005); for the Energy Independence and Security Act of 2007, see Pub. L. No. 110-140 (Dec. 19, 2007); for the Renewable Fuels Standard, see 42 U.S.C. § 7545(o).

The RFS program requires refiners and refined petroleum product importers to demonstrate that particular proportions of nonpetroleum fuels are blended into gasoline or diesel prior to its being sold to consumers. Having been in place since 2007, the program has an observable track record, supplying nearly 18 billion gallons of biofuels (gallons gasoline equivalent). Energy security benefits of this program include a smaller share of petroleum products in the energy mix, reducing U.S. petroleum dependence as renewable fuel use grows. This reduced dependence can marginally protect consumers from the price volatility of crude and product markets; however, as discussed below, it does little to change the very small short-term price elasticity of motor fuel demand. The RFS also encourages continued research and innovation in alternative fuels by providing a guaranteed market for those fuels when they are commercially produced. There are additional opportunities under the RFS program to diversify our transportation energy sources through the recently approved biogas to CNG and biogas to electricity pathways.

The RFS program also reduces GHG emissions from the transportation sector: the Clean Air Act requires that RFS fuels meet a GHG reduction standard compared with a 2005 petroleum baseline, with differing reduction standards for each fuel category. EPA has qualified biofuels for inclusion in the RFS program based on their GHG emissions relative to petroleum-based fuels. Ethanol derived from starch has provided the majority of the fuel required to meet the RFS standard to date. However, the Energy Independence and Security Act of 2007 limits further growth under the program to advanced and cellulosic biofuel categories, which must meet a higher GHG emissions reductions threshold. Cellulosic biofuels do not use food feedstocks and instead can use feedstocks including corn stover, sugar bagasse, or fast-growing trees. The first commercial scale cellulosic biofuel facilities began production in 2015 and are in the process of scaling up production volumes. Production volumes are not at the rate envisioned in 2007 but may become more significant in 2017 and beyond.

The RFS has energy security benefits, as described above, but also presents potential costs and consequences. First, blending biofuels into gasoline or diesel fuel at low levels does not produce an alternative transportation fuel. Biofuels are simply a small component of a standard motor vehicle fuel. As such, even though the policy reduces the relative volume of petroleum used in the transportation sector, biofuels do not provide an alternative to petroleum fuels when oil prices spike or supplies contract: if oil prices spike, the price of E10 is not significantly different than for gasoline with no ethanol. Thus ethanol blended into gasoline at low levels remains subject to price shifts in both global petroleum product markets and feedstock markets, limiting the benefits of the RFS on consumer finances. Additionally, ethanol and biodiesel fuels affect food costs (corn and soybeans), and conversely, biofuel prices may be affected by agricultural markets in years of reduced output or high produce prices due to weather or other factors. DOE's biofuels research agenda is focused on the development and commercialization of "drop-in" cellulosic biofuels that will help realize the objectives of the Energy Independence and Security Act of 2007 with a cost-competitive, low-GHG fuel that does not face distribution restrictions caused by the current ethanol "blend wall."

Diversity through fuels substituted for gasoline or diesel. The use of transportation fuels that are substitutes for and not blended with oil-based fuels insulates consumers' finances from shifts in oil or gasoline prices, thereby improving energy security. Under current law, alternative fuels are defined as "pure methanol, ethanol, and other alcohols; blends of 85 percent or more of alcohol with gasoline; natural gas and liquid fuels domestically produced from natural gas; liquefied petroleum gas (propane); coal-derived liquid fuels; hydrogen; electricity; pure biodiesel (B100); fuels, other than alcohol, derived from biological materials; and P-Series fuels" (42 U.S.C § 13211). These policies improve energy security by making substitute fuels widely available and affordable, but the net energy security benefit is limited by the overall penetration of vehicles using those fuels in the market and the price volatility of the substitute fuels.

The Federal Government has traditionally offered tax credits as a primary mechanism for incentivizing investments in alternative fuels and alternative-fuel vehicles. The Internal Revenue Service manages these tax credits. To cover the cost of fueling equipment for a variety of fuels, including natural gas, liquefied petroleum gas (LPG), and E85, among others, plus charging stations for electric vehicles, the Federal Government offers the Alternative Fuel Infrastructure Tax Credit (DOE 2014a; 26 U.S.C. § 6426). Under this tax credit, "fueling equipment for natural gas, liquefied petroleum gas (propane), liquefied hydrogen, electricity, E85, or diesel fuel blends containing a minimum of 20% biodiesel installed between January 1, 2015, and December 31, 2016, is eligible for a tax credit of 30% of the cost, not to exceed $30,000" (DOE 2014a; 26 U.S.C. § 6426). The Alternative Fuel Excise Tax Credit is a $0.50 per gallon tax credit available for fuels sold for the operation of motor vehicles, available to entities "liable for reporting and paying the Federal excise tax on the sale or use of the fuel in a motor vehicle" (DOE 2014a; 26 U.S.C. § 6426). The Alternative Fuel Tax Exemption is available to eligible entities, including some intercity and local bus fleets and some nonprofit educational organizations, as well as for selected farming purposes and school buses (IRS 2016b). In addition, the U.S. government promotes and funds research, development, and deployment (RD&D) efforts aimed at improving the supply of alternative fuels through several avenues, such as the efforts undertaken by the Bioenergy Technologies Office at DOE in the areas of advanced biofuels derived from sources like cellulosic biomass, algae, and wet waste (DOE 2016a). The U.S. government also has numerous programs aimed at promoting advanced vehicle technologies that do not use refined oil products.

Efforts have also been made to overcome the infrastructure constraints to consumer adoption of alternative-fuel vehicles. As mentioned above, the FAST Act requires the Department of Transportation (DOT) to designate "national alternative fuels corridors" for plug-in electric vehicle charging and hydrogen, propane, and natural gas fueling along major highways by December 2016 (Pub. L. 114-94; 23 U.S.C. § 151). In November 2016, DOT's Federal Highway Administration fulfilled this directive, announcing the establishment of an 85,000-mile "alternative fuel and electric charging" network. The corridor consists of 55 routes, spanning 35 states, and is considered "sign-ready," meaning the routes where alternative fuel stations are currently in operation will be eligible to feature new signs alerting drivers where they can find fuel for their alternative vehicles (DOT 2016a). This work is expected to make it easier and less costly for consumers to adopt new vehicle technologies, which would lower oil intensity and thereby reduce the economic effects of increases in the price of gasoline or diesel. The cost of construction of these corridors could be high, and the corridors will be effective only if alternative-fuel vehicles frequent those areas, but the availability of the fueling stations may encourage investment in such vehicles.

As mentioned above, the total energy security benefits of switching demand from oil-based fuels will depend on the price volatility and supply risks associated with alternative fuels. For some fuels, such as liquid fuels derived by the Fischer-Tropsch process, the lack of an established market and historical data limits predictions about potential price volatility. For other fuels, however, markets do exist that provide insight into potential price impacts. For example, propane, part of a group of hydrocarbons known as LPGs, is currently sold as a fuel for vehicles, space heating, petrochemical use, and use in heavy machinery. LPGs, which are derived from natural gas processing or through oil refining, have traditionally seen their prices shift with both global oil prices and natural gas prices. As a result, LPGs are unlikely to represent a significant improvement over oil-based fuels in terms of price volatility (ICF International 2016). EIA also projects a high degree of price volatility in natural gas markets, as a result of supply restraints and the sensitivity of natural gas demand to shifts in temperature (EIA 2016c). All fuels sold in open markets entail an element of price volatility, but energy security will be improved to the extent that consumers have a variety of transportation options, minimizing the total effect of volatility in one market on consumer finances and the U.S. economy more broadly.

Natural gas vehicles. Under the Energy Policy Act of 1992, both LNG and compressed natural gas (CNG) are considered alternative fuels (42 U.S.C. § 13211). Roughly 150,000 natural gas vehicles (NGVs) are deployed in the United States, a small portion of the 15.2 million NGVs deployed worldwide (DOE 2016j). There are three types of NGVs: dedicated NGVs, which run only on natural gas; bi-fuel NGVs, which have two fuel systems allowing them to run on natural gas or gasoline; and dual-fuel vehicles, which run on natural gas with a diesel fuel ignition assist (generally used only for heavy-duty vehicles). NGVs have proven particularly attractive as a fleet vehicle, such as for delivery vehicles or city buses, because they can take advantage of fueling infrastructure that is concentrated along high-traffic roadways or located in fleet refueling stations.

Several Federal programs encourage the adoption of natural gas as an alternative transportation fuel. For example, there are Federal tax incentives for the use of alternative fuels, including natural gas, and for the construction of the related fueling infrastructure. In addition, the FAST Act establishes a weight exemption for NGVs,[4] allowing them to weigh as much as 82,000 pounds (Pub. L. 114-94; 23 U.S.C. § 127). This exemption is intended to account for "difference of the weight of the natural gas tank and fueling system and the weight of a comparable diesel tank and fueling system" (Pub. L. 114-94; 23 U.S.C. § 127).

[4] Weight limitations are established for vehicles operating on the interstate system; 23 U.S.C. § 127 prohibits overall gross weight from exceeding 80,000 pounds.

Electric vehicles. Another focus of the government has been electric-drive vehicles, a category encompassing hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs). Global demand for electric vehicles is growing, and market analysts project that sales will continue to grow as battery prices fall and the price of electric vehicles trends downward. Analysis by Bloomberg New Energy Finance projects that the price for electric vehicles will be the same as that of internal combustion vehicles by 2022 (Randall 2016). In the United States, approximately 120,000 PHEVs and BEVs were sold in 2014 and 102,600 in 2015 (Hull 2016). By contrast, approximately 444,000 HEVs were sold in 2014 and 384,000 in 2015 (AFDC 2016). Government policies to promote the sale of EVs include tax incentives for purchasing EVs (Pub. L. 112-240 § 403; 26 U.S.C 30D), R&D and deployment assistance for advanced engine and battery technologies through DOE's Vehicles Technologies Office, and the DOE Advanced Technology Vehicles Manufacturing loan program to fund projects in energy storage, electric-drive systems, materials, fuels and lubricants, and advanced combustion. These projects and policies improve energy security by giving consumers substitution options to avoid fossil fuels. Electric vehicles may be particularly attractive when gasoline and diesel prices are high, but the policies are designed to create incentives and opportunities for substitution even when gasoline and diesel prices are low.

The EV Everywhere program at DOE supports the increased deployment of PHEVs and BEVs through RD&D, outreach and education, and partnership building. The program's objective is to make these vehicles as affordable and convenient for the American family as gasoline-powered vehicles by 2022 (DOE 2016a). Other U.S. government initiatives include DOT's Smart City Challenge, which supports city-wide integration of electric vehicles, among other things, and the National Alternative Fuels Corridors effort to develop charging and fueling stations for plug-in, hydrogen, propane, and natural gas vehicles along strategic highways and transport corridors (DOE 2016h).

Another energy security benefit, as defined by the G-7 principles, of advanced vehicle technologies is their relatively lower carbon emissions compared with gasoline-powered vehicles, but this benefit is realized only when the alternative fuel is less carbon intensive. DOE's Alternative Fuels Data Center estimates average annual emissions per vehicle, finding that electric vehicles generally provide major improvements over gasoline vehicles. Whereas gasoline-powered vehicles are estimated to have annual emissions of 11,435 pounds of carbon dioxide (CO_2) equivalent, HEVs and PHEVs are currently estimated, on average across the United States, to emit less than 6,500 pounds per year, and BEVs, as little as 4,815 pounds (DOE 2016d).[5] The total annual emissions per vehicle depends in part on what fuels are used to generate the electricity that powers them: in the United States, roughly 33 percent of the electric power used to charge EVs is generated from coal, 33 percent from natural gas, and 20 percent from nuclear, with the remainder made up of a

[5] Estimates suggest that electric vehicles (BEVs, HEVs, and PHEVs) could reduce emissions by 45 to 58 percent compared with conventional gasoline vehicles, whereas Argonne National Laboratory's GREET model finds that natural gas vehicles emit 6 to 11 percent less emissions than conventional vehicles. Greater emissions savings could be achieved through use of renewable natural gas (biomethane), but supplies are limited (DOE 2016d, 2016i).

combination of renewable power sources (hydro, wind, solar, geothermal), biomass, and oil (DOE 2016d). (The composition of fuels used to generate electricity is likely to change in the future in response to market forces and regulations such as the Clean Power Plan.) The times selected for charging various types of electric vehicles also alter the total emissions benefits. Analysts suggest that enabling workplace charging is likely to encourage greater use of electric vehicles, but charging during off-peak hours is currently likely to use electricity with the lowest emissions (McLaren et al. 2016; ICF International 2014).

Despite the energy security benefits, programs to develop electric vehicle technologies and promote their adoption require upfront capital investments and entail reductions in total tax receipts—that is, tax expenditures—with no guarantees that a large enough market will develop to support the capital investments.

Hydrogen fuel cell vehicles. Hydrogen, defined as an alternative fuel under the Energy Policy Act of 1992, powers fuel cell electric vehicles (FCEVs), which combine hydrogen and oxygen to produce electricity (DOE 2015c). FCEVs are zero-emissions vehicles that are two to three times more efficient than a gasoline-powered internal combustion engine (EIA n.d.a). Although there are only three commercially-available FCEV models currently in production, about 1000 FCEVs are on the road in the United States (EIA 2015c). Since 2007, the cost of fuel cells has fallen by half while their durability has quadrupled, in part due to financial support from DOE's Fuel Cell Technologies Office for RD&D (DOE 2015c). Through partnerships with companies, universities, and national laboratories, DOE-funded projects have produced more than 500 patents, 45 commercial hydrogen and fuel cell technologies, and 65 emerging technologies (DOE 2016b).

Federal programs also create incentives for consumers to adopt FCEVs. The Alternative Fuel Excise Tax Credit provides a $0.50 tax credit per gallon for alternative fuels, while the Alternative Fuel Infrastructure Tax Credit offers a 30% tax credit for fueling equipment (up to a maximum credit of $30,000) (DOE 2016f).

A number of automobile manufacturers now offer commercially available FCEVs. Hyundai and Toyota began to sell or lease FCEVs in 2015, and Honda announced the introduction of its new Clarity FCEV in 2017. To encourage deployment, the state of California and a number of countries have implemented programs to support the buildout of hydrogen fueling infrastructure. As of 2016, California has more than 20 commercial fueling stations and approximately 30 additional stations planned for 2017, which will support more than 10,000 FCEVs (CEC/CARB 2015). The most significant long-term benefits of FCEVs are realized when hydrogen is produced from renewable or low-carbon sources. Current technologies produce hydrogen from natural gas because it can be sold at a cost that is competitive with gasoline (DOE 2015a). Even though this is not a long-term solution, FCEVs using hydrogen produced from natural gas can achieve substantial CO_2 emissions reductions compared with vehicles running on gasoline (DOE 2013b).

b. Better Fuel Efficiency for Gas and Diesel Vehicles

Energy security is improved when consumers can reduce their use of fossil fuels. Corporate Average Fuel Economy (CAFE) and GHG emissions standards for light-, medium-, and heavy-duty vehicles are likely the most well-known of the policies to promote fuel efficiency. Developed by EPA and the National Highway Traffic Safety Administration (NHTSA), these standards set the average fuel economy for new passenger vehicles. Standards were set in 2010 that mandate fuel economy of 34.1 miles per gallon (mpg) for model year 2016; a 2012 rule mandates average fuel economy and GHG emissions of up to 54.5 mpg for model year 2025 if achieved exclusively through fuel economy improvements (77 Fed. Reg. 62624 (Oct. 15, 2012)). New fuel economy mandates for medium- and heavy-duty vehicles were finalized in 2016 (EIA 2016b). Vehicle efficiency standards improve energy security by ensuring that future vehicles will use less gasoline or diesel per mile driven than the current fleet, reducing the oil intensity of the transportation sector over time and thus consumers' financial exposure to volatile oil prices. EPA and NHTSA estimate fuel savings from the new standards to be around 4 billion barrels of oil, and 2 billion metric tons of GHG emissions, over the lifetime of the vehicles covered (EPA 2016g).

The CAFE and GHG emissions standards require vehicle manufacturers to invest in efficiency through advanced engine technologies, lighter vehicles, or other changes, whose costs are often passed on to customers in the form of higher automobile prices. In addition, not all of the efficiency gain is captured by consumers when prices rise. On average, vehicles that are more efficient reduce the cost of driving and thus create an incentive for owners to drive more. This "rebound effect" suggests that a 1 percent increase in fuel efficiency may increase driving by as much as 0.2 to 0.4 percent (Linn 2013).[6]

c. Alternatives to Personal Vehicles

Public transportation gives consumers an alternative to owning or operating a personal vehicle and may reduce the vulnerability of U.S. consumers to both temporary and long-term increases in oil prices (CBO 2012). In addition to providing alternative transportation when prices for gasoline or diesel (or alternative transportation fuels such as E-85 or natural gas) are high, public transportation can also be a permanent alternative to personal vehicle ownership in some areas. Public transportation options include metro and subway systems, light rail or streetcars, and city bus systems. These public systems provide relatively low-cost alternatives to owning private vehicles and often run on alternative fuels (electricity for metro, light rail, buses, and streetcar systems, sometimes LNG or CNG for bus systems). Federal support is available for some public transportation systems. For example, states and cities can receive low-interest financing (direct loans, loan guarantees, or standby lines of credit) for infrastructure projects (including public transportation) through the Transportation Infrastructure Finance and Innovation Act (TIFIA) (DOT 2016d). As of March 2016, 61 projects have been approved through TIFIA, including public transportation options such as a light rail line in Seattle and a Denver project that combines multiple public transport components (a regional bus terminal, light rail station, and commuter rail station) into one facility (DOT 2016b).

[6] The rebound effect may have other consequences that could reduce the overall benefits of fuel efficiency standards, although they are not directly related to energy security. Most notably, an increase in overall miles driven may contribute to road congestion and wear.

Public transportation can also provide environmental benefits. The Federal Transit Administration reports that public transportation emits fewer GHGs per passenger mile traveled than single-occupancy vehicles, with heavy rail producing, on average, 76 percent less emissions per passenger mile, light rail 62 percent less, and bus transit 33 percent less (DOT 2016c). Public transportation options that do not run on refined oil products (such as electric light rail or bus fleets powered by electricity, CNG, or LNG) may have higher energy security benefits, by both insulating consumers from refined oil product price increases and producing lower GHG emissions. The costs of public transportation can be high, however, in the form of infrastructure construction, maintenance, and system operation. In the event that ridership does not cover the full cost of these systems, taxpayers are generally responsible for the remaining costs (often at the state and local level, but funding through programs like TIFIA come from the Federal Treasury).

Some states and localities promote carpooling, or ridesharing, as an option for reducing emissions and traffic congestion, particularly during peak travel hours, through the use of high-occupancy vehicle lanes and carpool programs. Technology to facilitate ridesharing has improved such that apps like UberPool and Lyft Line can match consumer location and travel time needs in real time and introduce riders to drivers using rating systems. Increasingly, private businesses are giving consumers mobility options without the financial cost and responsibilities of owning a private vehicle. Companies like Zipcar and Enterprise CarShare give subscribers access to a vehicle as needed, on an hourly or daily basis, with more flexibility than traditional car rentals. In North America, the number of car-share program members grew from fewer than 120,000 in 2006 to more than 1,600,000 in 2014 (Shaheen and Cohen 2016). Bike-share programs have a similar effect, allowing consumers to choose an environmentally friendly alternative to both public transportation and individual vehicle ownership or operation, helping insulate them from financial harm when prices rise. The net energy security benefits of these programs are limited by the extent that they are used, and in the case of car-sharing businesses in particular, it can be difficult to calculate the exact benefits, given the difficulty of predicting what consumer activity would look like in the absence of such programs. One recent analysis of these programs estimated that changes in fuel consumption ranged from more than 90 percent fuel savings to more than 150 percent increase in energy use (Stephens et al. 2016).

ii. Managing Effects on Consumers' Finances

Energy expenditures, for oil in particular, are a significant factor for individual consumers. According to the Bureau of Labor Statistics' Consumer Expenditure survey, the average U.S. household spent 4.9 percent of its annual income on gasoline and motor oil for transportation in 2013–2014 (BLS 2015). This represents a significant portion of household income, and it can vary depending on fuel prices. To reduce the effect on consumers' finances, the government has public programs and policies that help low-income consumers (generally households rather than firms) unable to otherwise change their energy consumption patterns when prices rise.

The Federal Government does not have many programs to help consumers offset higher transportation costs in the event of an oil price spikes. Some Federal programs such as the establishment of lower speed limits reduce transportation costs at all times and not just during an oil price spike.[7] However, price spikes with respect to oil also influence the finances of consumers who rely on oil for heating their homes. A notable example of a program designed to mitigate the income impacts of energy prices is the Low Income Home Energy Assistance Program (LIHEAP). A Federal program run by the Department of Health and Human Services and managed by individual states, territories, and tribes, LIHEAP helps low-income consumers with electricity bills, natural gas bills, and expenses for refined oil products, to the extent that their homes directly use electricity or natural gas to power home appliances or use oil products for home heating (as in the Northeast). The program not only provides federally funded assistance directly to families to pay home energy bills but also offers assistance for consumers in an energy crisis (generally defined as consumers without utility service or who have received a 10-day shut-off notice) and subsidizes weatherization and energy-related minor home repairs. LIHEAP improves energy security by providing direct financial support to households that would otherwise struggle to pay for vital services like home heating. LIHEAP is operated at the state and local levels, so the application of the program may not be consistent across the Nation.

DOE also operates the Weatherization Assistance Program (WAP), which is designed to lower consumers' energy bills. Through WAP, low-income households are eligible for funds to improve the energy efficiency of their homes. Like the LIHEAP program, WAP is operated locally by states, territories, and tribes. WAP funds "are used to improve the energy efficiency of low-income homes using the most advanced technologies and testing protocols available in the housing industry" (WAP n.d.). Since 1976, more than 7 million homes have received WAP assistance, reducing households' energy consumption by an average of 35 percent and shaving approximately $400 off their energy bills annually (WAP n.d.). Both LIHEAP and WAP improve energy security by funding efficiency and weatherization measures that help households lower their overall energy consumption.

B. Oil and Natural Gas Supply Diversity and Resiliency

The United States has access to diversified sources of oil and natural gas across the country. In addition to being the world's largest combined producer of oil and natural gas, the United States has access to imports of oil and gas by pipeline from Canada and Mexico and to shipments of oil and petroleum products from all over the world. The Nation also has significant volumes of LNG import capacity (though many of these terminals are being repurposed to export U.S. LNG). The U.S. refining system is made up of 141 operable refineries (EIA 2016g) that span the entire Nation but are concentrated most heavily in the Gulf Coast and the Midwest, with additional facilities in the Northeast, on the Pacific Coast and limited facilities in Alaska and Hawaii (EIA n.d.g). Ensuring diversity of supply, thereby limiting overdependence of the U.S. economy on energy from a small number of overseas suppliers, has been a policy priority since the 1973 oil embargo. In 2015, the United States imported more than 3.4 billion barrels of crude oil and products, representing almost 50

[7] The Government Accountability Office states that the establishment in 1974 of a national speed limit of 55 mph decreased fuel consumption in the United States by 0.2 percent to 3 percent, which DOE estimated saved 175,000 to 275,000 barrels of oil per day (GAO 2008).

percent of total U.S. consumption, from some 70 countries (EIA 2016h, 2016i). By contrast, in the same year, the United States imported less than 10 percent of its total annual natural gas consumption (EIA n.d.c., 2016f), and more than 96 percent of those imports came by pipeline from Canada, with small volumes of pipeline imports from Mexico and LNG imports from Canada, Norway, Trinidad, and Yemen making up the remaining 4 percent (EIA 2016e). EIA (2015i) projects that the United States will become a net exporter of natural gas by 2017.

Supply diversity reduces the likelihood that disruptions to supply or threats to production areas, trade, or distribution routes—whether caused by weather, terrorism, or geopolitics—significantly disrupt U.S. access to physical energy supplies. A diversity in supply sources enables the United States to replace disrupted supplies with energy from other producers or strategic stocks. Disruptions in energy supply will increase the price of the disrupted energy, but increased supply diversity reduces the effect on price that any disruption can cause. Today, definitions of energy supply security incorporate concerns beyond political disruptions and encompass such threats as cybersecurity and extreme weather events.

Energy security is improved to the extent that firms cannot exercise market power with respect to oil or natural gas production, processing and refining, or distribution in ways that run counter to the best interests of U.S. consumers. Similarly, energy security is improved to the extent that the market can be protected from naturally occurring or human-caused disasters either because firms have taken actions to safeguard infrastructure or because sufficient redundant infrastructure exists. DOE's 2015 QER found that "ensuring the resilience, reliability, safety, and security of [transmission, storage, and distribution] infrastructure is a national priority and vital to American competitiveness, jobs, energy security, and a clean energy future" (DOE 2015b) The G-7 identifies both of these topics as priorities: "diversification of energy fuels, sources and routes, and encouragement of indigenous sources of energy supply" and "improving energy systems resilience by promoting infrastructure modernization and supply and demand policies that help withstand systemic shocks."

The Nation's extensive infrastructure for transporting oil and gas contributes to improving energy security by enabling the movement of energy products from diverse sources to demand centers across the country. The G-7 identified diversification of energy routes as an important energy security principle. The first installment of the QER (DOE 2015b) identified 12 such elements of oil and gas infrastructure: natural gas gathering lines; transmission pipelines; natural gas storage facilities; processing facilities; distribution pipelines and systems; LNG production and storage facilities (including export terminals); crude oil pipelines; crude oil and products import and export terminals; rail, truck, barge transport; oil refineries; Strategic Petroleum Reserve (SPR) and Regional Petroleum Product Reserves; and CO_2 pipelines (including for enhanced oil recovery).

The Nation's robust infrastructure system serves to support the objectives of improving diversity of supply (Table 1.1). First, the availability of multidirectional energy pipelines, cross-border pipelines, waterways, railroads, and highway transport options allows the transport of oil and gas from points of production and import to centers of demand. The U.S. refining system is capable of processing large volumes of crude oil in excess of domestic demand. Consequently, refined petroleum products are an important U.S. export commodity. The availability of LNG export and import facilities gives the United States flexibility that enhances the Nation's energy security, making it possible to import LNG purchased on the spot market if necessary.

Table 1.1. Components of U.S. transportation, storage, and distribution infrastructure

Fuel/Energy Carrier	TS&D Infrastructure Element/System
Electricity	Transmission lines and substations
	Distribution lines and distributed generation
	Electricity storage
	Other electric grid-related infrastructure
Natural Gas	Natural gas gathering lines
	Transmission pipelines
	Natural gas storage facilities
	Processing facilities
	Distribution pipelines and systems
	LNG production/storage facilities (including export terminals)
Coal	Rail, truck, barge transport
	Export terminals
Crude Oil/ Petroleum Products	Crude oil pipelines
	Crude oil and products import and export terminals
	Rail, truck, barge transport
	Oil refineries
	Strategic Petroleum Reserve & Regional Petroleum Product Reserves
	CO_2 pipelines (including for enhanced oil recovery)
Biofuels	Transport of feedstock and derived products, biorefineries

***Source*: DOE (2015b)**

Crude oil and petroleum products. Diversity of oil supply has long been a primary focus of policymakers seeking to address energy security. In the United States, the Arab Organization of the Petroleum Exporting Countries (OPEC) oil embargo of 1973 highlighted the importance of cultivating oil supply from numerous suppliers, given the role that oil and refined oil products play in the U.S. economy. According to data collected by EIA, the United States imported crude oil and refined oil products from more than 80 countries in 2015 (albeit in very small volumes from some of them), with the largest single supplier (by far) being Canada (EIA 2016i). The United States has also increased its domestic production of oil, further limiting its need to rely on imported oil and limiting the ability of foreign entities to manipulate oil markets, and thereby oil prices. Despite this diversity of supply, the global nature of oil markets means that the United States cannot insulate itself from external actions even by becoming entirely self-sufficient in supply. However, actions taken by the U.S. government can ensure that U.S. consumers always have access to oil, albeit at prices determined by the market, following disruptive actions that affect oil supplies.

Infrastructure for crude oil and refined products is also subject to disruption by natural disasters or physical attacks. Hurricanes Katrina and Rita in 2005 and Hurricanes Gustav and Ike in 2008 disrupted the operations of refineries and loading docks on the Gulf Coast, and Hurricane Sandy in 2012 interrupted deliveries of refined products to major centers of demand in the Northeast. Cybersecurity has increasingly become a concern for the oil and gas industry, particularly following the Stuxnet attack on an Iranian nuclear facility. No successful cyberattacks affecting the operation of physical infrastructure, such as refineries or pipelines, have been publicly identified in the United States, although multiple attempts of cyberattacks for the purpose of gathering sensitive or proprietary information have been reported (Clayton and Segal 2013). Hardening infrastructure against attack and building emergency gasoline and diesel fuel stocks for use in case of interruption of supplies can help limit the effects of crises on energy security.

***Natural gas**.* Natural gas faces different energy security challenges than do crude oil and petroleum products in terms of supply diversity, but it shares many of the same challenges with regard to infrastructure resilience. The U.S. natural gas market has numerous choices for sources of supply, nearly all of which are domestic or North American: domestic sources via pipeline and imports from Canada or Mexico by pipeline. The United States also imports some LNG, mostly from Trinidad. To the extent that there are abundant natural gas resources and no supply disruptions in North America, the lack of global diversity in supplies of natural gas is not a liability for energy security. But in a regional market, like that for natural gas in North America, a disruption to supply (e.g., loss of important pipeline infrastructure or production field) can have a large effect on natural gas prices because supply chains and infrastructure do not exist to quickly replace lost North American supplies with supply from elsewhere in the world. As a point of comparison, the long reduction in crude oil production that occurred in the United States between 1998 and 2008 had little effect on the domestic price of crude oil; a similar reduction in natural gas production would probably have a significant effect on domestic natural gas prices. The recent expansion in LNG trade between regional markets has contributing to a narrowing price difference between gas markets in North America, Europe, and Asia.

Natural gas infrastructure faces vulnerabilities that are similar to those of all physical infrastructure, including damage or disruption from natural disasters and physical or cyberattack. Disruptions in natural gas supply raise risks of electric power blackouts or brownouts and may affect fuel supply for home heating or transportation (primarily a risk for fleet vehicles, which are currently the biggest transportation demand sources for LNG or CNG). The majority of natural gas used domestically is transported by pipeline from domestic U.S. producers and from Mexico and Canada, making pipeline infrastructure vital to maintaining supply security and resilience.

i. Enhancing Supply Diversification

Supply diversity is maintained through the large number of countries from which the United States is able to import oil and refined products today and through the growing interconnection of North American energy markets. This interconnection is characterized by high volumes of bidirectional energy trade with Canada and Mexico. Total energy trade between the United States and Canada was close to $140 billion in 2013, and energy trade with Mexico in 2012 exceeded $65 billion (DOE 2015b). The QER found that the energy sectors of the United States and Canada are often considered a single market (DOE 2015b). The United States promotes supply diversification and resilience through numerous policies, including permitting of interstate and cross-border pipelines and facilities, regulating safety of energy infrastructure, encouraging the modernization of aging infrastructure, supporting the safe and transparent production of supply in other nations, leasing Federal lands for energy production, and investing in RD&D of energy-producing technology.

a. Robust Infrastructure

The United States' robust infrastructure system enhances energy supply diversity because supply can be taken from multiple sources (e.g., domestic production, import terminals, pipelines) and transported to demand centers across the Nation. In addition, the United States oversees and issues Federal permits for cross-border and interstate infrastructure, such as pipelines. DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) oversees the safety of the Nation's transport systems for oil and natural gas, including railways and pipelines. The U.S. government is also responsible for the maintenance, upkeep, and modernization of inland waterways, including ports, canals, shipping channels, and locks.

Rail transport of oil and gas expanded significantly between 2010 and 2015, with particular growth in rail transport of crude oil from Canada into the United States and from new oil fields in North Dakota to refining centers in the Midwest and on the East Coast. The U.S. government promotes the operation and safety of the rail transport system through data collection by EIA (2016f) and the Surface Transportation Board (STB), the promulgation and enforcement of safety regulations at DOT and PHMSA, and analysis of traffic flow and congestion conditions by DOE, STB, and the Federal Energy Regulatory Commission (FERC). STB (2016) also established the Rail Energy Transportation Advisory Committee in 2007 to provide guidance and serve as a discussion forum for energy-related rail issues.

The increasing volume of waterborne transport of energy commodities affects the performance of the energy transportation system. The government manages many aspects of the inland waterway system, including investments in maintenance and operations: "the Federal Government is authorized to pay 100 percent of the cost of eligible operations and maintenance at coastal ports for all work at depths up to 50 feet depth. For channels at coastal ports, the Federal Government provides a 50 percent to 90 percent cost share for new construction (this varies by channel depth needs and contributions by sponsors)" (DOE 2015b, 5-17). The U.S. government also seeks to enhance industry's ability to deliver oil and products to consumers during a national emergency or when it is in the interest of national security by offering Jones Act waivers, allowing shipping companies to move oil or products between U.S. ports even if no Jones Act–compliant ships are available.[8]

[8] The Merchant Marine Act, Public Law 66-261, commonly known as the Jones Act, mandates that vessels making shipments between U.S. ports be built in the United States, be 100 percent owned by U.S. citizens, be

Yet gaps in infrastructure coverage and operation do exist, and they can limit the ability of the Nation to access and use energy. As domestic oil and gas production has increased significantly over the past decade, the infrastructure system has not always kept up with some changing market dynamics and new areas of oil and gas production. The QER notes that the oil and natural gas infrastructure system poses both aging and obsolescence concerns, highlighting overdue repairs and modernization efforts (DOE 2015b). Roughly 59 percent of the Nation's natural gas transmission and gathering lines were built before 1970. Private sector responses to the gap between available infrastructure and energy supplies have included "expanding pipeline capacity where it can; reversing flow direction on other pipelines; converting natural gas lines to oil; and seeking new 'workaround' solutions to transportation bottlenecks by moving increasing amounts of oil by truck, barge, and rail" (DOE 2015b, 1-5). These efforts are critical to maintaining access to diverse oil and gas supplies and ensuring the resilience required by modern market conditions (see below for additional information on resilience). Infrastructure expansion and modernization improve energy security by ensuring that energy supplies can be moved to demand centers regardless of their place of origin (domestic or foreign), but there are associated costs: the efforts can be costly, and if the modernization efforts are the responsibility of the infrastructure operator, their costs can be passed on to consumers through price increases.

b. Help for Emerging Oil- and Gas-Producing Countries

Energy security is improved when new reserves located around the world enter the global market because they diversify supplies of oil and gas, add resilience to the aggregate productive base, and reduce the ability of existing producers to disrupt the market for non-market reasons—effectively muting the market power of major producers by reducing their share of the total market. Recent history demonstrates how new producers can improve global energy security. Oil prices increased from $104 per barrel in February 2011 to $126 per barrel in April after the Libya uprising disrupted more than 1.6 million barrels per day (b/d), prompting the IEA to coordinate a collective response. The United States contributed by drawing down the SPR. However, the shock would have been even more acute but for production growth from emerging producers Brazil, Canada, and Iraq, which added a combined 4.2 million b/d in production from 1995 to 2010 (EIA n.d.d).

The United States has programs to assist emerging oil and gas producers, including DOE engagement programs worldwide, which include technical and regulatory assistance. The DOE's Office of Fossil Energy works with government and industry in numerous countries to share technology advances and best practices in safety and environmental protection in the development of offshore oil and gas resources and onshore unconventional resources. Specific examples include the U.S.-China Oil and Gas Industry Forum, which meets annually to promote technology and environmental solutions for Chinese oil and gas development, technical workshops with Brazil, Argentina, and Colombia on oil and gas development, and support of the Power Africa initiative through intense consultation for emerging African

maintained in the United States, and operate with a U.S. flag and U.S. crew. This policy, designed to protect the U.S. shipping industry, can raise the cost of shipping between U.S. ports significantly.

natural gas producers on LNG development. DOE also works with Canada, India, Japan, and Korea on gas hydrate research, a frontier area for natural gas development.

Other programs are led by the Department of State's Bureau of Energy Resources (ENR), which was launched in 2011 and tasked with helping "boost international energy security, steer the world's energy mix toward a more sustainable path, and emphasize the U.S.'s continuing commitment to transparency and good governance, in order to ensure that each nation's natural wealth translates into increased prosperity for its citizens" (DOS 2011). Specific programs include the Energy Governance and Capacity Initiative, which provides technical and capacity-building assistance to developing countries with the potential to join the world's next generation of oil and gas producers. Agencies from the Departments of Interior, Treasury, and Commerce are among those that provide assistance under this initiative (DOS n.d.a). Other State Department–led programs include the Unconventional Gas Technical Engagement Program, which focuses on providing assistance to help countries develop their unconventional natural gas resources (DOS n.d.b, 2010). The U.S. Agency for International Development (USAID) has led efforts to develop and implement programs that support policy, legal, regulatory, and commercial reforms to improve energy sector performance while accelerating private sector participation and investment (USAID 2015). In cases where the U.S. private sector is involved in helping improve the energy systems of other countries, the Overseas Private Investment Corporation, the Ex-Im Bank, and the U.S. Trade and Development Agency facilitate the flow of U.S. goods and services by providing incentives to both domestic companies and foreign governments.

The programs listed above improve energy security both by helping increase the overall global supply of oil and gas and by limiting the market power of individual countries or large nationalized oil companies. A larger, more diversified supply in the market means that actors seeking to disrupt the global market by withholding their own supply (individually or as a collective action) will have less effect. It also improves the energy security of U.S. allies and partners abroad (see Section III), benefiting U.S. foreign policy objectives in addition to the Nation's energy security. Additionally, capacity-building programs, many of which help countries that would seek to develop their resources even without assistance from the United States, can have indirect benefits, both in enhanced transparency, since the United States promotes participation in the Extractive Industries Transparency Initiative (DOI n.d.), and in advanced environmental protections. The United States also encourages countries to implement the rule of law, allow foreign investments through trade and investment framework agreements, and participate in open markets. With U.S. training, capacity building, and regulatory assistance, the new producing nations may be able to develop better environmental regulations and more competitive market structures. The energy security benefits of these competitive markets and environmental regulations are addressed further in subsequent sections of this chapter.

There may also be unintended consequences of encouraging foreign production. The energy security benefits of enhanced global production may be tempered if the country that hosts the new production is unstable or actively engages with other countries to manipulate energy markets—for example, by joining OPEC. To the extent that new foreign production increases oil supply without a corresponding increase in global oil demand, the new production would reduce global oil prices, which would reduce the income to U.S. producers of oil. International natural gas developments are currently less likely to have such an effect because of the mostly regional nature of gas markets; however the growing trade in LNG between regional markets over the last decade has contributed to reducing the price differences between markets. Similarly, new oil production could be offset by reduced oil production by other producing countries, resulting in an efficiency loss if higher-cost production replaces lower-cost production. With respect to the environment, GHG emissions could increase if the new production has higher emissions than the production it replaces.

c. Support for Domestic Oil and Gas RD&D and Production

The United States has multiple policies that promote domestic oil and gas development, including leasing of Federal lands under attractive fiscal terms, a history of investment in RD&D for advanced oil and gas production technologies, and tax incentives. Greater domestic production of oil and gas benefits the U.S. economy and is consistent with the objective of having a diverse and stable source of supply.

In the United States, oil and gas production takes place on both public and private lands. Whereas the leasing, management, and taxation of oil and gas development on private lands is largely the responsibility of individual landowners and local and state officials, the Federal Government, through the Department of Interior (DOI), is responsible for permitting, regulating, and setting contractual terms for production on Federal lands and the Outer Continental Shelf (OCS).

Oil and gas production in the United States has increased significantly since 2008, largely as a result of advances in hydraulic fracturing and horizontal drilling technologies that have allowed the production of oil and gas from shale and other reserves that were previously considered uneconomic to tap. Since 2008, U.S. production of natural gas from shale has grown from less than 5 billion cubic feet per day (bcf/d) to more than 40 bcf/d, while oil production from shale and other tight formations has grown from less than 0.5 million barrels per day (mmb/d) to approximately 4.5 mmb/d (Sieminski 2015, 2). That represents an eightfold increase in shale gas production and a ninefold increase in oil production from shale and tight formations, not including production from conventional oil and gas formations. Production on Federal lands onshore accounts for 11 percent of U.S. natural gas production and 5 percent of U.S. oil production (BLM 2016b); leased acreage in the OCS accounts for roughly 5 percent of U.S. natural gas production and 16 percent of U.S. oil production (BOEM n.d.b).

Federal leasing and regulatory authority for oil and gas production on Federal lands is primarily managed by DOI. The Bureau of Ocean Energy Management (BOEM) has responsibility for managing OCS oil and gas development (as well as offshore renewable electricity generation), the Bureau of Land Management (BLM) oversees onshore Federal production (as well as onshore production of coal and electricity from renewable energy sources on Federal lands), and the Bureau of Safety and Environmental Enforcement (BSEE) is responsible for safety and environmental protection regulations for OCS production.

These agencies all carry out multiple functional activities to promote the safe production of abundant U.S. energy resources. BOEM is responsible not only for developing leasing plans through the creation of the Five-Year OCS Oil and Natural Gas Leasing Program, identifying what areas will be available for lease in a given 5-year period, but also for holding the lease sales, conducting environmental reviews for all stages of offshore energy development, and conducting and overseeing environmental studies that inform policy decisions relating to OCS energy development (BOEM n.d.a). BLM has numerous responsibilities for managing Federal lands that extend far beyond energy production: it manages some 245 million surface acres plus 700 million subsurface acres of mineral estate (BLM 2016a). BLM is responsible for holding lease sales for onshore drilling and overseeing the environmental review and permitting process under the National Environmental Policy Act (NEPA) (BLM 2009).

To maximize the energy security benefits of increased production, domestic oil and natural gas production must be done in a safe, environmentally responsible manner. The primary responsibility for safety and environmental protection in oil and gas development on non-Federal lands lies with the states. EPA has collateral responsibility for the effects of production on air and water under various laws, including the Clean Air Act and the Safe Water Drinking Act. DOE provides support on best practices for safe production; these efforts have included the work of the Secretary of Energy Advisory Board's former Natural Gas Subcommittee and DOE support for hydraulic fracturing fluid disclosure through the FracFocus program.

The United States offers attractive contractual terms for oil and gas production carried out on Federal lands, well-established rule of law (including contract sanctity), and political stability, all of which incent oil and gas companies to develop resources in the United States rather than abroad (CBO 2016). Since its establishment in 2010, DOI's Office of Natural Resources Revenue has been responsible for managing and ensuring "full payment of revenues owed for the development of the Nation's energy and natural resources on the Outer Continental Shelf and onshore Federal and Indian lands" (DOI 2016a). At present, the Federal onshore royalty rate, set by BLM, is 12.5 percent, although lower rates do exist for qualifying leases (BLM n.d.). This is lower than royalty rates charged by most states and private landowners. DOI is currently undertaking a review of onshore royalty rates to determine "whether the American taxpayer is getting the right return for the development of oil and gas resources on public lands" (BLM 2015). The royalty rates for offshore oil and gas development are 18.75 percent for leases issued after March 2008, although leases issued before March 2008 were subject to differentiated rates for shallow offshore leases (less than 400 meters deep) and deep offshore leases (400-plus meters deep) (BOEM 2012). BOEM also offers royalty relief for qualifying leases (BOEM n.d.c). Outside the United States, royalty rates and other contractual terms for offshore development vary significantly and can be higher or lower than those in the United States (Agalliu 2011). For example, the Nigerian royalty rate for onshore production is 20 percent, and Canada assesses a royalty rate that is the greater of 30 percent of net profits or 5 percent of gross revenues (LC 2015).

The U.S. government has long invested in the technology of finding and developing energy resources through R&D incentives and tax incentives. The resulting technologies have improved seismic analysis and deepwater discovery and drilling. At DOE, the Office of Fossil Energy's Unconventional Oil and Natural Gas Program is now focusing on research and development that contributes to safe and environmentally sustainable supplies of natural gas, including efforts in the following areas: water quality and availability; induced seismicity; methane emissions; subsurface science; footprint reduction; and transportation and storage. The Unconventional Oil and Natural Gas Program is undertaken with the support and collaboration of state and local governments, other government agencies, nongovernmental organizations, and the National Labs. Of the National Labs, the National Energy Technology Laboratory is noteworthy for its capabilities that support the efficient recovery of our nation's oil and natural gas resources in an environmentally safe manner, which includes research on advanced oil recovery, deepwater production technologies, methane emissions, methane hydrates, and natural gas "technologies that reduce the cost, increase the efficiency, and minimize the environmental risk of finding and producing natural gas in unconventional reservoirs, most importantly in fractured shale" (NETL n.d.). The Office of Fossil Energy at DOE recently completed the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research Program, a public-private partnership established by the Energy Policy Act of 2005, with the stated objective of "developing technologies to increase America's domestic oil and gas production and reduce the Nation's dependency on foreign imports" (Pub. L. No. 109-58, Aug. 8, 2005; DOE 2016m).

The Energy and Minerals Mission area of the U.S. Geological Survey (USGS) is responsible for "research and assessments that focus on the location, quantity, and quality of mineral and energy resources, including the economic and environmental effects of resource extraction and use" (USGS 2016). This is a broad mandate, and accordingly, USGS works with the private sector to develop seismic surveys and other geology-based assessment methodology to create resource assessments that are widely used by both the U.S. government and the energy industry. The USGS assessments are an important tool for industry and policymakers alike, as they seek to better understand the resources available in the United States (and abroad, to the extent that USGS carries out global assessments).

Tax incentives for oil and gas production include the domestic manufacturing tax credit (I.R.C. § 199) and intangible drilling costs (IDC). Section 199, the domestic production activities deduction, is an incentive for domestic production that allows businesses to deduct 9 percent of the lesser of "the qualified production activities income of the taxpayer for the taxable year, or taxable income (determined without regard to this section) for the taxable year" (6 percent for oil-related qualified production activities income) (26 U.S.C. § 199). This tax incentive may encourage investment in the United States over similar opportunities abroad. The Internal Revenue Service also allows entities that hold an operating or working interest for oil, gas, or geothermal steam or hot water to deduct costs for drilling or preparing a well for production. Costs that can be deducted include "wages, fuel, repairs, hauling and supplies related to drilling wells and preparing them for production"; some payments to contractors developing the well and the cost of exploratory drilling to "determine the location and delineation of offshore hydrocarbon deposits if the shaft is capable of conducting hydrocarbons to the surface on completion" are also deductible (IRS 2016a). The IDC allows companies to take deductions for these investments immediately, rather than spreading them over the lifespan of the well, as would typically be the case for capital expenditures. The IDC may be particularly attractive to small, independent oil producers, which have been important in the development of onshore oil and gas resources.

Since the 1970s, U.S. energy policy has been predicated on the basis that domestic production of oil and gas, and thus greater self-sufficiency in energy needs, offers multiple advantages. That policy stemmed from concern that countries or specific oil producers could limit U.S. access to oil. Today's global oil market greatly diminishes that concern. But there are still energy security benefits associated with domestic production of oil and natural gas. First, production of domestic oil and natural gas puts downward pressure on global oil prices and North American natural gas prices, benefiting consumers. Second, that additional production, in particular of natural gas, attracts businesses that rely on natural gas as a feedstock or for fuel (Kaskey 2013; Birnbaum 2013). Third, the U.S. oil and gas industry is regulated under U.S. environmental regulations and business standards, which may be more stringent or effective at achieving societal goals than those in other producing nations. Fourth, the U.S. oil and gas industry is privately held, characterized by numerous firms of varying sizes and specialties, and under the jurisdiction of U.S. antitrust and collusion laws, all of which help ensure a competitive market that is more responsive to market forces than might occur in a marketplace where the United States was not a major producer. Fifth, domestic shale oil and gas production has a shorter response time from exploration to production, in some cases as short as a few months,[9] compared with the years required for deepwater production, for example. As a result, shale production increases the responsiveness of U.S. supply and, in turn, the elasticity of global oil supply.

There are also some limits to the energy security benefits of U.S. oil and natural gas production, however, as well as potential costs and disadvantages. First, the ability of Federal policies to encourage incremental production is limited because current production of oil and gas is already significant and determined by market prices. As a result, the financial support for domestic production in the form of attractive contractual terms, tax expenditures, and RD&D subsidies might be more efficiently used elsewhere. Second, although growing domestic production increases global supply and puts downward pressure on prices, which may benefit consumers financially, that downward pressure may discourage decisions to reduce consumption of oil or natural gas products,

[9] Several characteristics of the shale oil and gas industry contribute to its ability to ramp production up and down quickly. First, and most recent, is the proliferation of drilled but uncompleted wells (DUCs). These DUCs are wells (usually several on a single pad site) that the operator has fully drilled but chosen not to "complete"; that is, the well bore and laterals have not yet been hydraulically fractured to allow for production. Completion on a drilled well generally takes 10 to 15 days. Second, the shale oil and gas industry has seen significant improvements in drilling productivity since 2008. Today it is possible to complete drilling in less than 20 days after a well has been fully permitted (some analysts suggest that drilling time is even shorter—as little as 7.7 days, on average, for wells in the Eagleford) (see Braziel 2016). With an estimated 10–15 days for full completion, it is reasonable for a permitted well site to be producing within 30–40 days of the start of drilling.

making consumers more vulnerable to future price spikes. Third, increasing domestic production may come at the cost of environmental considerations. Fourth, increased domestic production cannot prevent disruptions in oil supply abroad or be ramped up quickly enough to completely offset large disruptions. Fifth, increased domestic production today comes at the cost of reduced ability to produce oil and gas in the future, possibly when oil and gas are more valuable commodities. Finally, an increase in production in the United States may not always result in greater price stability. As experience in recent years has shown, other producers may choose to respond to increased U.S. oil production by increasing or decreasing their own production of oil. They might increase production to further lower global oil prices with the hope of driving U.S. firms out of business; many analysts suggest this is the rationale behind Saudi Arabia's late-2015 pledge to increase in production (Economist 2016b). Or they might decrease production because production is no longer profitable or with the intent of maintaining higher oil prices. This type of behavior can lead to increased oil price volatility, harming U.S. energy production-related income, potentially stranding energy production or transportation infrastructure, and aggravating political relations between the United States and other energy producers, or among other energy producers themselves.

ii. Enhancing Supply Resiliency

The resilience of the infrastructure system is central to energy security, and improvements in the form of infrastructure hardening or the construction of redundant infrastructure serve to improve energy security. The QER says the transportation, storage, and distribution system "must handle a diverse and evolving mix of energy sources and energy products; link sources, processors, and users across immense distances; match demands that vary on multiple time scales; co-exist with competing uses of the same systems (e.g., ports and railways); and perform 24 hours a day, 365 days a year with high reliability, which in turn requires both low susceptibility to disruptions and the resilience to recover quickly from whatever disruptions nonetheless occur" (DOE 2015b, 1-3).

The United States has taken several approaches to ensuring the resilience of the Nation's infrastructure. A primary component of U.S. policy is directing Federal agencies to collect data and information on the risks faced by the infrastructure system and make recommendations to ameliorate them. A second component is to communicate with the owners and operators of private infrastructure to identify best practices in infrastructure hardening and crisis response. Finally, Federal policy propagates the coordination of activities and knowledge across the Federal Government.

In 2013, Presidential Policy Directive 21, Critical Infrastructure Security and Resilience (PPD-21), identified the importance of resilience, identifying energy as a designated critical infrastructure sector and DOE as the sector-specific agency (SSA) with responsibility for "evaluating the need for and approving changes to critical infrastructure" (White House 2013). PPD-21 also identifies the Department of Homeland Security (DHS) as the agency overseeing implementation of the strategy, providing strategic guidance and day-to-day engagement with the SSAs. The second strategic imperative underlying PPD-21 is to "enable effective information exchange by identifying baseline data and systems requirements for the Federal Government" (White House 2013). DOE has already collected considerable information about energy sector resilience for the QER, and DHS collects information related to resilience through the Enhanced Critical Infrastructure Protection (ECIP) initiative via site visits and surveys (DHS 2016a). Multiple agencies use this information to identify vulnerabilities and risks.

DHS also runs the Regional Resiliency Assistance Program, a “cooperative assessment of specific critical infrastructure within a designated geographic area and a regional analysis of the surrounding infrastructure” (DHS 2016b). Through this program, DHS coordinates with other Federal agencies, the owners and operators of private infrastructure, law enforcement and first responders, and academics and subject matter experts. Projects can overlap with other DHS resilience efforts, such as the ECIP initiative, and include facility surveys, interviews, workshops, tabletop exercises, and more. (DHS 2016b). DOE launched the Partnership for Energy Sector Climate Resilience with 17 electric utility companies in April 2015 with the goals of identifying vulnerabilities, identifying and pursuing resilience strategies, and sharing the experiences of the organizations involved (DOE 2016k). Finally, DOE’s Office of Electricity Delivery and Energy Reliability oversees numerous efforts related to infrastructure resilience, including the development of tools to help organizations and industry better understand cyber risks, such as the Electricity Subsector Cybersecurity Capability Maturity Model (DOE 2016c); running public-private partnerships such as the Cybersecurity Risk Information Sharing Program (DOE 2015d); and funding advanced R&D in cyber technologies (DOE 2016e).

Another example of Federal coordination of policy is the tasking of multiple agencies with responsibility for cyber threats, including threats to energy infrastructure. The Center for Integrated Resiliency Analyses at Argonne National Laboratory is an example of an organization within the DOE network undertaking such analysis, considering disruptions from multiple sources including natural hazards, accidents or terrorist attacks. The Cybersecurity Framework, launched by the Obama Administration in 2014, “consists of standards, guidelines, and practices to promote the protection of critical infrastructure,” and DHS hosts the Critical Infrastructure Cyber Community C^3 Voluntary Program to help owners and operators integrate the framework, manage and understand cyber risks. Further discussion of cybersecurity appears in Chapter 2. The energy security value of understanding and preventing the risks of cyber and physical attack comes both from maintaining the resilience of the energy sector and limiting the national security risks of such attacks through preventive measures. Understanding and preventing attacks requires continued attention and investment in research and preventive measures because of the continually evolving nature of these risks. In addition, Presidential Policy Directive 41, United States Cyber Incident Coordination (PPD-41), was issued in July 2016 to better coordinate Federal responses to cyber incidents through the creation of a Cyber Response Group (CRG) responsible to the National Security Council (NSC) to manage the development and implementation of U.S. policy and strategy (White House 2016b). PPD-41 also establishes the Cyber Unified Coordination Group as the primary method of communication among Federal Government agencies in the event of a cyber incident; it will be formed at the discretion of the NSC principals or the CRG, or on request of two agencies that participate in the CRG (White House 2016b).

Beyond data collection and ongoing efforts to improve resilience, the QER makes several recommendations for improving U.S. energy security, such as establishing a "competitive program to accelerate pipeline replacement and enhance maintenance programs for natural gas distribution systems," supporting updates and expansion of state energy assurance plans, establishing a "competitive grant program to promote innovative solutions," analyzing the need for new or expanded regional product reserves, and determining the need for a single trigger to release products from all of the regional petroleum product reserves (see section II.E) (DOE 2015b). These QER recommendations are being further studied and implemented and are expected to have energy security benefits.

C. Well-Functioning and Competitive Energy Markets

Open, transparent, and competitive energy markets advance energy security in the United States and globally by increasing market liquidity and reducing market power for any specific agent in the market. Energy security is improved when sellers can easily observe the value of the energy commodities they produce and identify buyers, and when buyers can easily identify the price and availability of energy commodities. Opening markets to barrier-free trade allows prices to be determined by supply and demand. Trade flows are unpredictable, but open markets allow flexible trade through which market forces determine the most efficient means of distribution. The North American market for natural gas and the global market for oil and petroleum products are already highly transparent, liquid, and competitive. The value of this openness was demonstrated in the aftermath of Hurricanes Katrina and Rita in 2005, when roughly one-third of U.S. refining capacity was shut down, and some crude and product pipelines also experienced disruptions. As a result of open markets and a coordinated emergency response initiated by the International Energy Agency (IEA), however, crude oil and products were made available to affected regions within 2 weeks. Jones Act waivers further supported the shipment of refined products between U.S. ports. However, several southeastern states that depended on deliveries of petroleum products from the Colonial and Plantation pipelines experienced very long truck deliveries from coastal ports.

Oil and refined products. Crude oil and refined products today are sold in open, globally connected markets. Many of these products traverse the globe by pipeline, barge, cargo ships, and railcars, and prices are largely set in the global market as a result.[10] Additionally, crude oil and refined products can be imported at a lower capital cost than some other fuels, such as LNG, reducing barriers to importing crude oil. As a result, consumers and importers of crude oil and refined products have numerous options for purchasing oil from competitive markets.

Natural gas. Worldwide, natural gas markets have traditionally been less open and competitive than those for oil and refined oil products. Natural gas is transported by

[10] Local or regional prices for oil and refined products may vary, but even in those circumstances, movements in regional and local prices for these goods tend to reflect price shifts on the global market, simply at a different level.

pipeline or by tanker in the form of LNG and is not as easily moved by truck or barge as oil and refined products. The need for dedicated infrastructure makes regional pricing for natural gas prevalent.

The availability of floating storage and regasification units is lowering the cost of market entry for smaller-scale LNG consumers, and floating LNG terminals may reduce siting issues as well. As more LNG suppliers and consumers have entered the market, raising competition, LNG prices have converged slightly between markets, but regional pricing for natural gas remains prevalent. The transition to market-based pricing will drive competition and further enhance price discovery in regional gas markets. Gas supply contracts linked to market-based gas hub prices will provide buyers with leverage over oil-linked sellers because of the inherent transparency, lower upfront costs, and contract flexibility of the relatively liquid hub markets.

i. Ensuring Open Markets

The United States operates under a policy of open, transparent markets, allowing imports from suppliers all around the globe (except where legal restrictions, such as sanctions, may apply). The market mechanisms are uncomplicated, designed without artificial barriers to entry, and subject to free trade rules, such as those identified by the World Trade Organization, allowing for competition among suppliers and prices that reflect supply and demand worldwide. As a result of these open market policies, the United States is able to import oil, petroleum products, and natural gas from international suppliers as needed, ensuring that supply diversity is maximized.

a. Exports of Oil and Gas from the United States

Supporting trade of oil and gas between domestic producers and foreign consumers by reducing or eliminating export restrictions improves energy security by increasing the liquidity and competitiveness of international energy markets. This benefits the United States and its allies and partners by providing more sources from which oil and gas can be purchased.

U.S. policy toward crude oil exports was updated legislatively in December 2015. Prior to the passage of the Consolidated Appropriations Act of 2016, exports of crude oil had been restricted under the Energy Policy Act of 1975 for more than 40 years.[11] EPCA granted the President the authority to restrict exports of crude oil, natural gas, petroleum products, petrochemical feedstocks, and coal, but in 2015, only the restrictions on crude oil remained. Exports of crude oil were permitted in limited circumstances—notably, exports to Canada and exports from Alaska's North Slope. As a result of the omnibus budget deal in December 2015, crude oil and condensate can now be exported without need for a permit or license, putting crude oil on the same footing as petroleum products, although exports are restricted to certain nations under U.S. sanctions and exports can be restricted by the Secretary of Commerce and the President in the event of a national security emergency. Exports of crude oil are likely to increase and to some extent be offset by imports of crude

[11] Consolidated Appropriations Act of 2016, Pub. L. No. 114-113; Energy Policy Act of 1975, Pub. L. No. 94-163; 42 U.S.C. § 6212

oil better suited to U.S. refineries. That occurs when there is a freight advantage to fill tankers importing heavy crude oils with light crude oils for export; in so doing, importers and exporters pay only one-way shipping costs instead of round-trip. If the production of light crude oil from shale increases to the point that U.S. refineries cannot process the volume produced, allowing exports of U.S. crude oil will increase the value of U.S. light crudes because they can be sold to foreign refineries.

Natural gas imports and exports are regulated by DOE under the 1938 Natural Gas Act (NGA), as amended in 1992 and 2005(Pub. L. No. 75-688; 15 U.S.C. 717). Under the NGA, applications to import and export natural gas to nations that have a free trade agreement (FTA) with the United States, such as Canada and Mexico (pursuant to the North American Free Trade Agreement (NAFTA)), and imports of LNG from any country, are deemed to be in the public interest and must be approved by DOE without modification or delay. The NGA also directs DOE to authorize applications to export natural gas to non-FTA countries unless it finds those exports are inconsistent with the public interest. DOE conducts a full public interest review and takes final action on non-FTA applications only after the environmental review required under the National Environmental Policy Act (NEPA) is complete. As of November 16, 2016DOE has approved a total of 19 non-FTA LNG export applications totaling the equivalent of 15.22 billion cubic feet per day (Bcf/d) of (DOE 2016g) natural gas. The first LNG tanker export from the Lower 48 states left Cheniere's Sabine Pass terminal in Louisiana in late February 2016, and increasing volumes of LNG will be available for export over the next few years.

Energy security is affected by oil and natural gas exports in a variety of ways. First, demand from foreign buyers creates an incentive to produce additional oil and natural gas domestically, which could be made available to meet domestic demand during peak demand periods. As a second example, U.S. LNG export contracts are offered without destination clauses, which gives customers maximum flexibility to resell the LNG on the spot market, increasing market liquidity. In addition, the natural gas price that underlies U.S. LNG contracts is set by the competitive and transparent Henry Hub market and not pegged to the price of oil, as with many European and Asian LNG contracts. These innovations have put pressure on other sellers of LNG to adopt a similar contract structure and have caused a much greater share of LNG to be traded through short-term contracts. This increased liquidity in global LNG markets also has energy security benefits for our allies and partners (see section III) and is helping reduce price variability among regions. Given the regional nature of natural gas markets today, prices in the United States are unlikely to be significantly affected by prices outside North America. Additionally, the United States will always have a natural gas price advantage compared to the delivered price of U.S.-produced LNG because domestically-produced and consumed natural gas does not require liquefaction and regasification.

Studies show that increasing exports are unlikely to have a significant effect on domestic natural gas prices because of the high long-term price elasticity of U.S. natural gas supplies and the abundant resource base (Deloitte Center for Energy Solutions 2011).

b. Free Transit of Energy through Sea Lines of Communication
To ensure the competitiveness of global markets, the United States has undertaken efforts to protect markets and shipping through its worldwide naval presence. The United States has long espoused the international legal norm of freedom of navigation using both diplomatic and military channels, including for disputed areas such as the South China Sea. This topic is crucial for global energy trade. Sea lines of communication are among the highest-volume shipping channels. At least 17 million b/d of oil and 3.7 trillion cubic feet per year (tcf/year) of LNG pass through the Strait of Hormuz, for example, and at least 15.2 million b/d of oil and 4.2 tcf/year of gas pass through the Strait of Malacca (EIA 2014c). Such deliveries include critical supplies to the United States' Asian partners in the Organisation for Economic Co-operation and Development (OECD), and disruptions can raise prices and force use of alternative routes, adding thousands of miles in transit (EIA 2014c). The U.S. Navy carries out regular freedom-of-navigation exercises in these disputed areas to demonstrate its commitment to this principle, challenges maritime claims that the United States considers excessive under international law, and makes clear that U.S. vessels, and by extension those of other nations, maintain unrestricted access to their maritime rights (Glaser et al. 2015). Maritime security was among the preeminent areas of focus at the February 2016 US-ASEAN Summit in California, as the parties affirmed the importance of ensuring maritime freedom of navigation and unimpeded lawful maritime commerce consistent with the UN Convention on the Law of the Sea, while committing to address common challenges in the maritime domain. Additionally, at the most recent G-7 Leaders' Meeting in June 2015, the Leaders' Declaration expressed concerns with ongoing tensions in the East and South China Seas, noted opposition to efforts to change the status quo (e.g., large-scale land reclamation), and reiterated the principles of the G-7 Foreign Ministers' Declaration on Maritime Security, released in April 2015 (G-7 2015a, 2015b). The United States supports freedom of navigation and maintains a worldwide naval presence for multiple reasons, including freedom of trade in all goods, safety of navigation from piracy, and deterrence of coercion by hostile powers (CFR 2006). These commitments have significant costs, can expose the U.S. military and Coast Guard to physical risk, and involve the United States in geopolitical tensions in multiple regions.

ii. Providing Transparency in Data about Market Fundamentals
The United States has improved transparency in global energy markets by supporting the availability of high-quality data and analysis on energy production, consumption, trade flows, and prices, as well as forecasting future trends on those same topics. These data allow consumers, firms, and government agencies to make calculated, informed decisions about investments, energy use, and purchases of homes, buildings, vehicles, equipment, and machinery.

Domestically, EIA plays the primary role in collection and analysis of energy data and the creation and publication of energy forecasts (both domestic and international). EIA is continually enhancing its reports to make them more relevant to policymakers; its Drilling Productivity Report and dashboard are examples of innovations to enhance the depth and timeliness of energy data. Other government agencies also collect and publish data; for example, USGS assesses the size and type of energy resources that remain below ground. For international energy analysis, IEA, an OECD agency, operates with the support of all of the OECD nations, including the United States. It works not only with the OECD member nations but also with OECD's partner countries and groups, including China, India, and OPEC. IEA provides an annual review of coal, natural gas, and oil markets; participates on in-depth energy sector surveys; holds topical workshops on energy-related issues; hosts technology collaboration programs; and holds "training and capacity-building activities to spread best practices in energy policy and energy statistics" (IEA 2016a). IEA was one of the six founding members of the Joint Organizations Data Initiative, with the primary goal of raising "awareness among oil market players about the need for more transparency in oil market data" (JODI 2016). Recently, IEA has been mandated by the G-7 Energy Ministers to examine ways to enhance its data collection on natural gas (G-7 2016a). All of these organizations contribute to maintaining open and transparent markets.

Both EIA and IEA have some limitations on the types of data that they can collect and how they can use or publish those data, which requires balancing the goals of transparency and privacy protection. Collecting and disseminating data are costly and time-consuming tasks, and some data are protected or proprietary. Both organizations rely on their sources to provide high-quality data; many are reliable and verifiable, some less so, particularly in the realm of self-reported data in international markets.

iii. Improving Transparency and Efficiency in Infrastructure Permitting

The permitting of energy infrastructure in the United States often requires a rigorous analysis of the project by Federal, state, and/or local regulatory agencies; transparency is a major component of that process. The infrastructure system is important for the operation of the entire energy system and the ability of the Nation to access and diversify its energy supply. It also represents a large public investment with significant fiscal, employment, and environmental effects.

Infrastructure that crosses national borders requires a Presidential Permit. The authority to grant Presidential Permits is derived from the constitutional power of the President to conduct foreign relations of the United States. This authority is distinct from the authority granted in certain regulatory statutes to permit facilities used in the import, export, and interstate transportation of energy commodities, including petroleum, petroleum products, natural gas, and electricity, and statutes regulating the importation and exportation of those energy commodities.

a. Permitting Oil and Refined Petroleum Product Infrastructure

Permitting authority for various types of infrastructure related to oil and refined petroleum products are as follows:

Cross-border facilities. Executive Order 11423, issued in 1968, provided the State Department with authority to issue Presidential Permits for cross-border pipelines moving petroleum and petroleum products into or out of the United States. Executive Order 13337, issued in April 2004, directs the Secretary of State to authorize cross-border petroleum and petroleum product facilities that the Secretary has determined would serve the national interest.

Deepwater ports. The U.S. Maritime Administration, in partnership with the U.S. Coast Guard, regulates deepwater port facilities that will be used for imports or exports of oil. The Deepwater Port Act of 1974 sets out conditions that deepwater port license applicants must meet, including minimization of adverse impact on the marine environment and submission of detailed plans for construction, operation and decommissioning of deepwater ports.

Interstate transportation facilities. The Pipeline Hazardous and Materials Safety Administration (PHMSA) within the Department of Transportation has jurisdiction over the safety of interstate pipelines moving liquids, including petroleum and petroleum products.

Commodity imports and exports. Imports of petroleum and petroleum products are not regulated by Federal statute although informational filings are required by the Energy Information Administration. Until 2015, exports of petroleum and petroleum products were restricted by a number of federal statutes. However, pursuant to the Consolidated Appropriations Act, 2016, enacted December 18, 2015, Federal officials may no longer restrict exports of crude oil.

b. Permitting Natural Gas Infrastructure

Permitting authority for various types of infrastructure related to natural gas are as follows:

Cross-border facilities. Executive Order 10485, issued in 1953, designated the FERC's predecessor, the Federal Power Commission (FPC), to review Presidential Permit applications for cross-border natural gas facilities. The FPC was to grant such applications if the FPC determined that the proposed facilities were consistent with the public interest. Following the creation of the Department of Energy in 1977, the President delegated Presidential Permit authority for cross-border natural gas and electric transmission facilities to the Secretary of Energy in Executive Order 12038. Pursuant to a series of delegation orders, DOE has transferred authority to issue Presidential Permits for cross-border natural gas facilities to FERC.

Natural gas import and export terminals. The regulation of natural gas (including LNG) import and export facilities was transferred to DOE in the DOE Organization Act. However, DOE has delegated that authority to FERC. Additionally, the 2005 amendment of the NGA in the Energy Policy Act of 2005 designated FERC as the lead agency of environmental reviews of natural gas import and export terminals. FERC thus oversees the permitting of the physical terminal, undertaking the environmental review of the terminal required by NEPA. In an attempt to accelerate the environmental review process for LNG projects (for import or export), FERC recommends that companies take full advantage of the prefiling process, during which the company and FERC staff can discuss concerns and potential areas of delay. FERC maintains that addressing issues prior to official filing of the application helps expedite the formal review.

Deepwater ports. The U.S. Maritime Administration regulates deepwater port facilities that will be used for imports or exports of natural gas.

Interstate transportation facilities. Pursuant to Section 7 of the NGA, FERC regulates the construction of interstate natural gas pipelines. FERC works with other Federal agencies, including PHMSA, to ensure safety and security. FERC has expedited the certification of natural gas pipelines by having its staff engage stakeholders during the prefiling process to identify and resolve their concerns (FERC 2015).

Commodity imports and exports. Pursuant to Section 3 of the NGA, authorizations for imports and exports of natural gas are issued by the Office of Fossil Energy at DOE. In 2014, DOE introduced changes to its public interest determination policy, seeking to expedite the process by considering projects only after they had received their facilities authorization under NEPA from FERC or, in cases involving deepwater port facilities, the U.S. Maritime Administration.

c. Other Permitting Regulations

The NEPA process has been called a "transparency statute" (DOE 2011b). Infrastructure projects going through the permitting process are published in the *Federal Register*, public comment periods are required, public hearings are held as relevant, and documentation is posted throughout on the permitting agency's website. The NEPA process also incorporates interagency cooperation: multiple agencies are involved in most permitting processes, with one agency identified as primary. The process allows for numerous stakeholders, not limited to the company submitting the application and the affected government agencies, to have their concerns and opinions heard and considered. This allows local communities, other businesses that may be affected, and nongovernmental organizations, such as environmental organizations or unions, to have a voice in the proceedings and gather information about the proposed projects. The costs and time involved in the NEPA process, however, can be extensive, resulting in project delays or increased costs to the project developers. Further, Federal agencies may approach the NEPA process in slightly different ways, meaning that decisions may not be entirely uniform across the government.

Efforts are under way to modernize the infrastructure permitting process by addressing some of those concerns. Section 41 of the FAST Act seeks to improve the Federal permitting process in two primary ways: by establishing the Federal Permitting Improvement Steering Council, and by adding major infrastructure projects (including energy projects) to the online Federal permitting dashboard (Pub. L. No. 114-94; 42 U.S.C. 4370m). With the goal of making the process more efficient, the FAST Act directs the Federal Permitting Improvement Steering Council to "develop recommended performance schedules, including intermediate and final completion dates, for environmental reviews and authorizations most commonly required for each category of covered projects," within one year of enactment of the legislation (Pub. L. No. 114-94; 42 U.S.C. 4370m). The permitting dashboard for Federal infrastructure projects, an online platform that allows members of the public and the government to track the progress of complex infrastructure projects through the permitting and review processes, is "one element of a larger, government-wide effort to streamline the Federal permitting and review process while increasing transparency, in addition to improving environmental and community outcomes" (Permitting Dashboard 2016). Many Federal energy projects will now be included on the dashboard. Because these transparency efforts have yet to be completed, it is difficult to assess their overall effect on energy security, but they are intended to streamline a complex permitting system that can be difficult for both industries and the public to understand and navigate.

iv. Allowing Third-Party Access to Infrastructure

Open access, or third-party access, to interstate oil and gas pipelines guarantees that owners of energy infrastructure cannot form a monopoly in transportation of oil and gas and ensures that fair rates are charged for access to that infrastructure. Open access typically requires that owners of infrastructure offer terms of use for that infrastructure to individual consumers or distribution companies in return for payment, to the extent that capacity is available.

The United States has various types of open access regulations for interstate oil and natural gas pipelines, as well as for oil and gas pipelines transporting oil or gas from the Outer Continental Shelf. FERC oversees the access requirements for the natural gas pipeline system. Under FERC Order 636 (1992), interstate pipelines were required to unbundle sales and transportation services and offer open access to pipelines (BOEM 2011). Order 636 built on FERC's 1985 Order 436, which recommended open access to interstate natural gas pipelines, and following the issuance of these two orders, numerous states also began to establish open access requirements for intrastate gas pipelines as well (EIA 2008). This means that gas pipelines are contract carriers, and if private parties contract for capacity and use all of it, they can turn away other shippers. The Outer Continental Shelf Lands Act (43 U.S.C., Ch 29, Subch III) requires that "every permit, license, easement, right-of-way, or other grant of authority for the transportation by pipeline on or across the outer Continental Shelf of oil or gas … provide open and nondiscriminatory access to both owner and non-owner shippers" for all pipelines traversing the OCS. Since DOI's reorganization in 2008, BSEE has authority over all OCS pipeline issues, including open access regulations and appeal procedures (BOEM 2011).

Oil pipelines in the United States, by contrast are "common carriers" under the Interstate Commerce Act and "must provide transportation service to any party that reasonably requests service (76 FERC P 61286 (1996)). This means that if an oil pipeline is constrained and a new customer asks for transportation service, the oil pipeline's capacity must be allocated among its customers—including the new customer—and the existing customers all lose some of the capacity they otherwise would have had" (Lewis and Morgan 2011). Railways also operate under common carrier conditions, at least in some cases, such as in the case of hazardous materials (Eby 2008).

D. U.S. Trade Balance

The trade balance of the United States is determined by complex economic factors. The fact that the U.S. dollar acts as the global reserve currency allows the dollar to react differently than the currencies of other nations; a trade deficit (when the value of imports exceeds that of exports) is often accompanied by net foreign investment into the United States. That occurs because U.S. firms purchase the imports with U.S. dollars, and the largest markets in which to spend those dollars are U.S. markets, such as Treasury markets, equities markets, or land markets. Although U.S. economic policy must account for a variety of indicators, trade deficits do not necessarily indicate a problem for the Nation's energy security.

Table 1.2. Energy trade as a share of U.S. trade balance (billions of dollars)

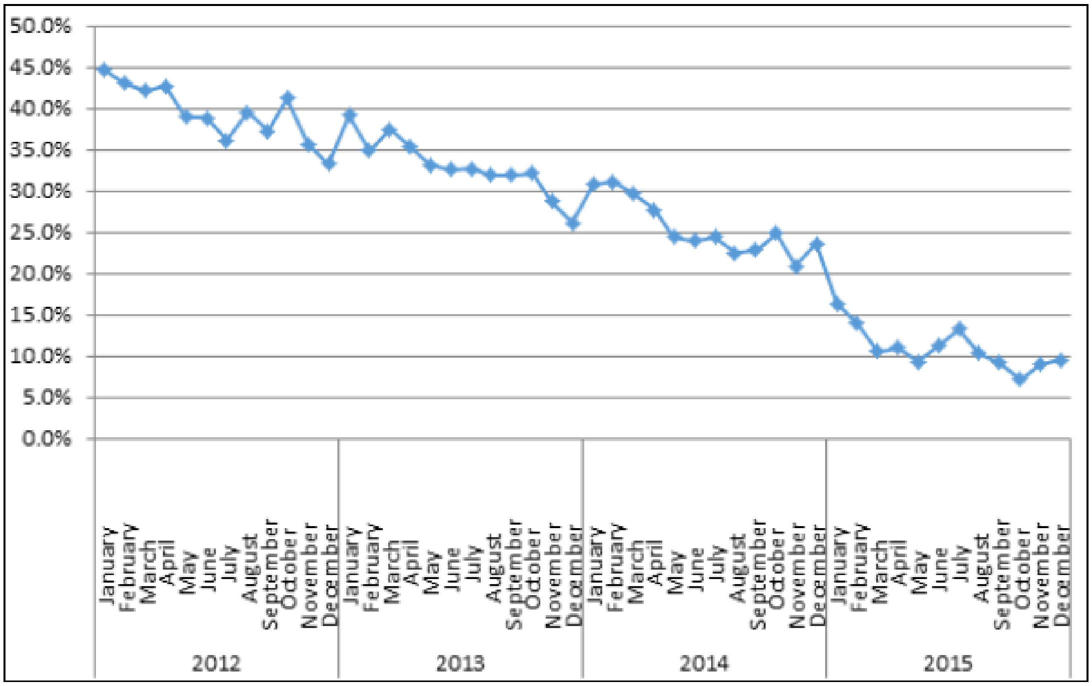
	Imports			Exports			Trade Balance		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Total Oil	254	336	439	49	71	113	(205)	(265)	(327)
Crude Oil	189	252	332	1	1	2	(188)	(251)	(330)
Other Oil	65	84	108	48	70	111	(17)	(14)	3
Natural Gas	16	17	15	3	5	6	(13)	(12)	(9)
Electricity	2	2	2	1	1	0	(2)	(1)	(2)
Nuclear fuel	5	6	6	2	2	3	(3)	(4)	(3)
Coal	2	2	3	7	10	17	4	8	14
Total Energy	279	363	465	62	89	139	(218)	(275)	(326)
Total Goods and Services	1,956	2,338	2,661	1,575	1,838	2,103	(381)	(500)	(558)
Energy Share	14%	16%	17%	4%	5%	7%	57%	55%	58%
Oil Share	13%	14%	17%	3%	4%	5%	54%	53%	59%

Source: *U.S. International Trade in Goods and Services (FT900)*, reports for December 2011 (February 12, 2012) and 2010 Annual Revisions (June 9, 2011), U.S. Census Bureau and U.S. Bureau of Economic Analysis, http://www.census.gov/foreign-trade/data/index.html.

Notes: Other oil includes Petroleum Products, other; Fuel oil; natural gas liquids (for import data), and liquefied petroleum gases (for export data). Coal includes Coal and related fuels and metallurgical grade coal (for export data).

***Source*: Nerurkar (2012)**

Figure 1.4. Reduction in energy share of U.S. merchandise trade deficit since 2012 due to lower oil prices and lower oil imports



Source: Department of Commerce.

***Source*: Jackson (2016)**

The United States has historically been a net importer of energy products, including crude oil, petroleum products, and natural gas. EIA has noted that "crude oil and petroleum products play a significant role in the balance of U.S. trade accounts," (Table 1.2) although the current trade deficit would exist "even if the United States did not import oil" (McManmon and Tarver 2014). EIA reported that in 2013, "energy accounted for 15% of gross U.S. goods imports … while energy exports, which have grown significantly in recent years, accounted for 7% of overall U.S. goods exports" (McManmon and Ford 2014), dominated by crude oil and then petroleum products (Houser and Mohan 2014). Although the United States has also historically been a net importer of natural gas, LNG exports have now begun from Cheniere's Sabine Pass terminal, with additional projects in the planning phase or under construction. EIA expects the United States to become a net exporter of natural gas by 2017 (Sieminski 2015, 2). The increase in oil and gas production has reduced oil import quantities and contributed to lower global oil prices, both of which lower the value of imports and improve the Nation's trade balance (Figure 1.4). Unlike other countries that experience rapid increases in energy resource production, the United States has a diversified economy in which energy represents a relatively small share of GDP, and the dollar is used as the global reserve currency; consequently, analysts have argued, the recent increase in oil and gas production does not pose a threat to the competitiveness of other exports (Vostroknutova et al. 2010; Houser and Mohan 2014).

E. National Security Objectives

The national security of a country depends not only on its national defense (military, Coast Guard, border controls, etc.) but also on the extent to which it can continue normal operations when an emergency occurs. Emergencies can take numerous forms—severe weather events, natural disasters, political disruptions, or cyber or physical attacks, among others—and are often associated with disruptions in the flow of energy. Emergencies can also involve the disruption in supply of critical materials, necessary for the production or use of energy (see Appendix B for a discussion of critical materials). Disruption in the supply of energy is often associated with price increases. The United States has several policies available to reduce the economic effect of high prices caused by a disruption in the flow of oil and gas to U.S. and international markets.

Oil and refined products. Because few alternatives to oil and refined products exist, high levels of dependence on a single supplier, or a single organized group of suppliers, can make a nation vulnerable to disruptions in energy markets, compromising its national security. Given the ability of the United States and other countries to purchase oil and refined products from the global market, most countries are not significantly vulnerable to physical loss of supply due to political pressure or coercion. And particularly for the United States, the strong global market—combined with access to oil and gas supplies from within the United States, from friendly neighboring countries in North America through pipelines, and from a vast array of international suppliers—limits the influence of any single supplier. However, this has not always been the case. The 1973 Arab OPEC oil embargo is the most famous example of an attempt to change U.S. behavior through coercion, but it is not the only example: threats have been made in the intervening years to withhold oil supply during tight markets.[12]

The U.S. National Security Strategy issued in 2010 identifies factors that support U.S. leadership and national security, including "sturdy alliances, an unmatched military, the world's largest economy, a strong and evolving democracy, and a dynamic citizenry," and "recognizes the fundamental connection between our national security, our national competitiveness, resilience, and moral example" (White House 2010). The ability of the United States to leverage these factors, particularly its alliances, improves U.S. national security with respect to oil and petroleum products.

Natural gas. The regional nature of the North American natural gas market comes with benefits and risks from a national security perspective. As a benefit, the North American natural gas market is largely insulated from disruptions to the supply of natural gas that occur outside North America; that stands in contrast to the global oil market, where disruptions anywhere in the world affect the price paid for oil by the United States.

The risk of a regional market, however, is that the United States is more exposed to disruptions to the flow of natural gas within North America than it might be to domestic

[12] For example, Iran has issued regular threats to close the Strait of Hormuz and withhold oil supplies, as recently as spring 2016, following the signing of the Joint Comprehensive Plan of Action nuclear deal (Al Jazeera 2016).

disruptions in the supply of oil and refined product. That is because the United States has significant infrastructure for importing and exporting oil and refined products to respond to domestic disruptions in those markets, but the same infrastructure does not currently exist for natural gas. Oil and refined products can be moved by pipeline, rail, barge, tanker, or truck, whereas natural gas can be moved only by pipeline or in liquefied form. The geographically concentrated nature of natural gas trade makes natural gas markets particularly susceptible to outages that affect a particular area. For example, a hurricane in the Southeast that disrupts natural gas pipelines can affect flows of natural gas in the region until the disruption is resolved. Other pipeline or LNG imports cannot be easily rerouted to resolve the disruptions.

i. Maintaining Emergency Response Mechanisms

Policies exist to reduce the effect of supply disruptions on energy prices and the availability of oil and natural gas, most notably in the form of buffer stocks of crude oil, petroleum products, and natural gas. Once released, those stocks can supplement commercial stocks and lower energy prices to mitigate severe economic harm from energy price shocks.

a. U.S. Strategic Petroleum Reserve

The largest and best-known emergency response system for addressing disruptions in the crude oil market in the United States is the Strategic Petroleum Reserve (SPR), maintained and overseen by DOE's Office of Fossil Energy. The SPR was established under the authority of EPCA in 1975, following the oil market disruptions caused by the Arab OPEC oil embargo. The SPR is designed such that oil can be distributed via competitive sales in the event of an energy supply emergency. As of August 2016, the SPR held 695.1 million barrels of crude oil (DOE 2016l), equivalent to 148 days of U.S. net imports (based on 2015 net import levels) (DOE n.d.d). This volume will be reduced following sales of up to 124 million barrels of crude oil from the SPR that were mandated by section 403 of the Bipartisan Budget Act of 2015, and Section 32204 of the FAST Act, which would reduce the reserve to 571.1 million barrels unless future authorizations are made to refill it.

As pointed out in the 2015 Quadrennial Energy Review, the renaissance of U.S. oil production and rising crude oil imports from Canada have resulted in well-supplied inland refineries, making SPR distribution in the event of a global disruption most valuable to U.S. coastal refineries (DOE 2015b). However, congestion in the Gulf of Mexico during an oil supply emergency has reduced the ability of the SPR to replace lost world-market oil supplies through Gulf terminals. Consequently, section 404 of the Bipartisan Budget Act of 2015 authorized DOE to raise up to $2 billion through additional sales of SPR crude oil to modernize SPR infrastructure and build dedicated marine terminals to increase the system's distribution capacity. According to the authorizing legislation, the modernization sales must occur between fiscal years 2017 and 2020. As a result of these sales, as well as the sales that were directed by section 403 of the Bipartisan Budget Act of 2015 and section 32204 of the FAST Act, the SPR size will drop from 695.1 million barrels to about 536 million barrels (rough estimate), and the waterborne (marine) distribution capacity will increase significantly from 1–2 million barrels per day to 3–4 million barrels per day (again, rough estimates).

Participants in a 2015 DOE workshop on the SPR suggested that “geopolitical risks on the horizon justify the maintenance of a robust SPR to help mitigate the economic losses caused by any catastrophic and/or severe oil disruptions that do occur” (GGS 2015). In addition, the workshop participants found it unlikely that any disruption would last long enough to require an extended period of SPR releases to the extent that a reserve of even

Box 1. SPR Drawdown Triggers

Releases of crude oil from the Strategic Petroleum are governed by the Energy Policy and Conservation Act (EPCA) (42 U.S.C. § 6241). Following is a full description of the circumstances under which a drawdown can be authorized:

Generally, there are three possible types of drawdowns envisioned in the Act:

Full drawdown: The President can order a full drawdown of the Reserve to counter a “severe energy supply interruption.” EPCA defines this as “a national energy supply shortage which the President determines -
(A) is, or is likely to be, of significant scope and duration, and of an emergency nature
(B) may cause major adverse impact on national safety or the national economy; and
(C) results, or is likely to result, from (i) an interruption in the supply of imported petroleum products, (ii) an interruption in the supply of domestic petroleum products, or (iii) sabotage, an act of terrorism, or an act of God.

EPCA also states that a severe energy supply interruption “shall be deemed to exist if the President determines that -
(A) an emergency situation exists and there is a significant reduction in supply which is of significant scope and duration;
(B) a severe increase in the price of petroleum products has resulted from such emergency situation; and
(C) such price increase is likely to cause a major adverse impact on the national economy.”

Limited drawdown: If the President finds that -
(A) a circumstance, other than those described [above] exists that constitutes, or is likely to become, a domestic or international energy supply shortage of significant scope or duration; and
(B) action taken … would assist directly and significantly in preventing or reducing the adverse impact of such shortage” then the Secretary may drawdown and distribute the Strategic Petroleum Reserve, although in no case:
“(1) in excess of an aggregate of 30,000,000 barrels …
(2) for more than 60 days …
(3) if there are fewer than 500,000,000 barrels … stored in the Reserve.”

Test Sale or Exchange: The Secretary of Energy is authorized to carry out test drawdowns and sale or exchange of petroleum products from the Reserve. If any such test drawdown includes the sale or exchange of crude oil, “then the aggregate quantity of crude oil withdrawn from the Reserve may not exceed 5,000,000 barrels during any such test drawdown and sale or exchange.”

550 million barrels would run out. Instead, participants stressed the need for a rapid and large initial release of SPR oil to keep world oil prices from spiking soon after an international supply disruption. The EPCA authorization authority for an SPR release requires that a "severe energy supply disruption" result in increases in domestic petroleum prices sufficient to cause a "major adverse impact on the U.S. economy."

Only two international oil supply disruptions have triggered releases from the SPR, in 1991 and 2011, and they each illustrate the difficulty in deciding whether and when to use the reserve. Four important questions delayed a quick response to a supply outage in both instances: (1) whether the supply disruption was of sufficient magnitude to justify the use of the SPR; (2) whether the SPR should be held in reserve lest the disruption becomes more severe; (3) whether the release of strategic stocks would discourage deployment of OPEC spare production capacity; and (4) whether IEA member countries could reach a consensus to undertake a coordinated drawdown. Although these issues delayed previous releases, they need not delay a future use of the SPR in response to an oil supply emergency because (1) the principles laid out in the QER emphasize the value of quickly replacing lost world oil market supplies; (2) OPEC spare capacity is likely a less important factor in today's oil market than previously; and (3) the volume of oil in the SPR far exceeds the United States' IEA obligations to hold emergency petroleum stocks. Consequently, the United States could unilaterally release emergency oil supplies before IEA consensus is achieved. Nonetheless, the ability of the SPR to serve as a loss absorber (mitigating the economic harm of a supply disruption) or as a deterrent (discouraging attempts to disrupt supply by firms or countries) depends on the predictability and credibility of U.S. policy for using the SPR and on the ability of the SPR to deliver physical supply to the market to offset any severe disruption. It will be important to continue current plans to add dedicated marine loading dock capacity as well as other upgrades that increase the distribution capacity of the SPR in an emergency (DOE 2015b).

b. U.S. Regional Petroleum Product Reserves

The U.S. government also maintains petroleum product reserves. The Northeast Home Heating Oil Reserve holds a total of 1 million barrels of ultralow-sulfur distillate (diesel) at two sites designed to provide heating fuel to northeastern homes and businesses in the event of a supply disruption (DOE n.d.a). The Northeast Gasoline Supply Reserve holds a total of 1 million barrels of gasoline across three locations in the Northeast; it was established after Hurricane Sandy limited access to gasoline supplies in 2012 (DOE n.d.b). Hurricane Sandy affected New York Harbor regional gasoline prices: the usual price differential between New York and the U.S. Gulf Coast prices, largely a result of transportation costs, more than doubled after Hurricane Sandy, from $0.18 per gallon to $0.46 per gallon (DOE 2013a). That price differential, on top of the gasoline shortages that affected more than 20 percent of retailers for at least 11 days after the storm made landfall (EIA 2012), demonstrated the need for a regional gasoline reserve. Because they are small, these petroleum product reserves provide limited protection to consumers and the economy, but they do ensure that some energy supplies will be available in an emergency.

Larger petroleum product reserves would seek to protect consumers from petroleum product price shocks and/or physical fuel shortages, but would differ somewhat from the

SPR in their use, form, and advantages and disadvantages. The 2015 QER recommended an analysis of the costs and benefits of additional or expanded regional refined product reserves. DOE has developed cost-benefit analyses for all regions of the United States identified as vulnerable to fuel supply disruptions. In general, product reserves must be carefully designed to meet regional needs. Different regions of the country have different gasoline and diesel formulation requirements, complicating decisions about the location and fuel type held by the reserve. In addition, in some parts of the United States, the private sector holds large quantities of reserves, which could reduce the benefits of U.S. government product reserves. The costs of maintaining product reserves are high because they would likely stored be in aboveground terminals, unlike the SPR, which is stored in below-ground salt caverns. In addition, petroleum products have a short shelf life and must be rotated and replaced with new product on regular intervals. As with the SPR, efficacy of the reserves depends on sufficient supplies, predictable drawdown policies, and the ability to remove stocks from the facilities. And the same circumstances that caused the shortage could also inhibit distribution of the reserve supply. To be effective, then, these reserves must be located near the demand centers that they seek to serve, but also above floodplains and outside areas likely to be affected by severe weather.

ii. Energy Diplomacy

Through energy diplomacy, the Department of State and DOE seek to ensure that energy resources are used to promote global economic growth and stability, and to advance global integration of renewable and cleaner energy sources in support of U.S. climate change goals. How countries use and produce energy, and their ability to access sustainable energy to support economic growth, cuts across the entirety of U.S. foreign policy interests. Energy policy is central to global economic growth and poverty reduction, climate change policy, political stability, democracy promotion, and the protection of human rights. Energy trade plays a critical role in how countries relate to one another. Given the critical intersection of energy policy and U.S. national security, the Department of State's Quadrennial Diplomatic and Development Review recommended the creation of ENR to engage producer and consumer economies, bilaterally and multilaterally, on current energy supply questions, to set the world on a more secure and sustainable energy path, and to address energy governance and transparency issues. By managing the geopolitics of today's energy economy through reinvigorated energy diplomacy with major producers and consumers of energy, ENR is working to ensure that all of our diplomatic relationships advance the interests of the United States and broader global community through access to secure, reliable, and ever-cleaner sources of energy.

ENR's portfolio has grown since its inception and along with DOE, serves as a focal point for U.S. energy efforts internationally. The White House sought ENR's leadership to support the President's Clean Energy Plan, the U.S.–Caribbean–Central American Energy Task Force, and the Counter–ISIL Finance line of effort. The Secretary of State asked ENR to promote the significant climate change portion of the QDDR. Examples of State Department's global engagement on energy include, but are not limited to:

- ***European energy security.*** ENR is strongly committed to helping advance European energy security by supporting the efforts of the European Union as well as the European Energy Community and individual member states to advance a secure, stable, transparent and integrated energy market with a diversity of energy types, sources, and delivery routes. We are convinced that such a common market will improve regional security, economic prosperity, and sustainability. With our partners, allies, and the International Financial Institutions, ENR is working to assist countries whose energy sourcing depends on Russia to invest in alternative energy sources and seek new energy providers, and with the EU and individual member states to support critical infrastructure projects. Such projects include the pipelines that comprise the Southern Gas Corridor, interconnector projects (such as the Bulgaria-Greece interconnector), and floating gas storage and regasification units in areas that will facilitate energy diversification.

- ***Counter ISIL.*** ENR plays a major role in diplomatic efforts to defeat ISIL by working across the interagency to inhibit the group's ability to exploit energy resources under its control. The Bureau is also monitoring the effects that low oil prices are having in oil producing countries in the developing world in order to counter the threat of social instability.

- ***Caribbean energy security.*** ENR leads implementation of the Caribbean Energy Security Initiative (CESI), which was launched by Vice President Biden, and aims to boost energy security and sustainable economic growth in the region by attracting investment in clean energy, chiefly by promoting and facilitating improved governance, increased access to finance, and strengthened coordination among donors, governments and stakeholders.

- ***Nigerian stability.*** ENR helps promote Nigerian stability by encouraging dialogue with representatives from the Niger Delta's oil producing region on development issues, providing tools to crack down on oil theft that undermines government revenues, and addressing other concerns that currently inhibit additional investment in the region. ENR further encourages renewable energy projects in Northern Nigeria to increase energy access and economic growth in the region threatened by Boko Haram. Along with USAID, ENR is also working with Nigerian authorities on policies to enable greater use of natural gas for power generation.

iii. Imposing Sanctions on Major Oil Producers

Although the United States has never sanctioned a foreign country for seeking to manipulate energy markets, sanctions have been placed on major energy-producing countries that have the potential to alter the Nation's energy security by altering global energy supplies. The United States has long been willing to bear the burden of economic risks to support its national security, supporting both unilateral and multilateral sanctions against major oil and gas suppliers while seeking to mitigate the potential economic damage to the United States and its allies and partners. Examples include current and past sanctions against Iran, Iraq, Libya, Sudan, and Russia (Department of Treasury 2016). The multilateral sanctions imposed on Iran's oil and gas sector are a particularly good example: the sanctions restricted Iran's exports and greatly reduced its overall production of both crude oil and natural gas. To guarantee the effectiveness of the sanctions, the United States and its European allies undertook extensive diplomatic negotiations to allow nations dependent on Iranian oil and gas supplies to shift their demand to alternative sources and, for major importers of Iranian oil that were unable to shift their demand, provided waivers to mitigate the economic effects. Sanctions remain a primary component of the suite of national security policy options available to U.S. policymakers, and policymakers can address energy security implications through waivers and other complementary policies.

F. Environmental Considerations

Energy security is improved to the extent that energy consumption can be increased without posing an increased threat to the environment, from either increased emissions of GHGs or other risks (such as water pollution or seismic activity). Environmental pollution in the form of GHGs and other air emissions from fossil fuel use is significant and poses a threat to the health and safety of U.S. residents. EPA reports that fossil fuel combustion was responsible for 76 percent of global warming potential-weighted (GWP) emissions in 2014. Although production of natural gas and oil accounts for less than 0.05 percent of GWP-weighted emissions (EPA 2016d), production from unconventional resources, such as shale, can result in considerable demand for water, and the wastewater may require special disposal or treatment measures, including recycling for reuse and removal of normally occurring radioactive materials. That can strain the availability of water in shale-producing areas of the United States, particularly during times of drought. The G-7 highlighted the importance of reducing the environmental impact of the energy sector by reducing GHG emissions and accelerating the transition to a low-carbon economy as a major contributor to energy security.

i. Reducing Demand for High-GHG Fuels

GHG emissions are generated primarily from the burning of fossil fuels, including oil, natural gas, and coal. (Other sources of GHGs, like cement and steel manufacturing and agriculture, are small by comparison.) In 2014, the electric power sector was responsible for 30 percent of GHG emissions, followed by the transportation sector, accounting for approximately 26 percent of carbon dioxide emissions (EPA 2016b). As a result, policies that reduce demand for oil and increase the use of alternative fuels such as natural gas and electricity for transportation also have environmental benefits. Policies such as mobile-source GHG and CAFE standards improve fuel efficiency in vehicles, thereby reducing emissions per mile traveled and the demand for oil.[13] Fuel efficiency standards have the added benefit of not requiring a significant transformation of the existing transportation infrastructure. Alternatively, Federal policies to encourage the use of electric vehicles or natural gas vehicles reduce emissions from the transportation sector as long as the new vehicles replace vehicles that run on oil products. Other policies that promote the use of alternatives to oil and increase the supply of alternatives are the Renewable Fuel Standard program and R&D support for biofuels and other advanced transportation technologies.

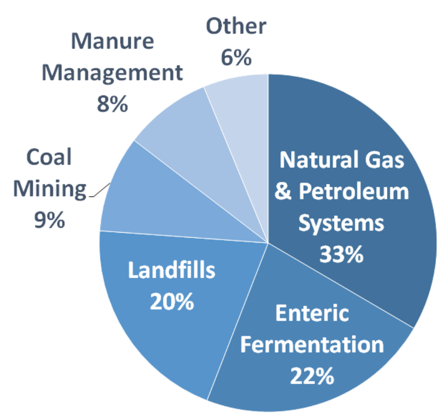
[13] The White House (2014b) reports that the fuel efficiency standards "finalized after 2008 have already saved nearly a billion gallons of fuel and avoided more than 10 million tons of carbon dioxide emissions."

ii. Improving Environmental Performance of the Energy Sector

a. Emissions of Methane

Methane, recognized by EPA as the second most prevalent GHG emitted in the United States (EPA 2016a), represents 11 percent of domestic GHG emissions (EPA 2016a). It has a shorter life cycle than carbon dioxide but is more efficient at trapping radiation inside the atmosphere and therefore has a bigger effect on the climate in the short run. EPA estimates that roughly 33 percent of methane emissions (EPA 2016a) in the United States come from the oil and natural gas industry (Figure 1.5).[14] Numerous efforts are under way to mitigate methane emissions in the oil and gas sector, both at the Federal level and in the private sector. To the extent that U.S. policies can reduce methane emissions while maintaining production, energy security is enhanced.

Figure 1.5. U.S. methane emissions, by source



***Source*: EPA (2016a)**

The Obama Administration's Climate Action Plan: Strategy to Reduce Methane Emissions, released in March 2014, aims to reduce methane emissions from oil and gas by 40–45 percent by 2025 relative to 2012 levels. In March 2016, the Obama Administration, joined by the Canadian government, recommitted to that goal; the Mexican government committed to this goal in June 2016. Since 1993, EPA has been running a voluntary program, called Natural Gas STAR, to reduce methane emissions in the oil and gas sector through the adoption of cost-effective technologies and practices that improve operational efficiency. Similarly, in the absence of regulations, the Natural Gas STAR program enables the Federal Government to work directly with companies to reduce methane emissions. Through the Natural Gas STAR program, EPA estimates that its domestic industry partners have reduced their methane emissions by more than 1.2 Tcf through the use of roughly 150 technologies and practices (EPA 2016c). In 2006, the Natural Gas STAR program was expanded and Natural Gas STAR International was created, allowing for the inclusion of

[14] EPA (2016e) defines the oil and gas industry to include "a wide range of operations and equipment, from wells to natural gas gathering lines and processing facilities, to storage tanks, and transmission and distribution pipelines."

global oil and gas companies. Natural Gas STAR International partners have reduced their methane emissions by 105 bcf (EPA 2016c). In 2016, EPA launched the Natural Gas STAR Methane Challenge Program, a public-private partnership in which founding members from industry "made a commitment to implement a suite of best management practices across their operations within five years" (EPA 2016c). The energy security benefits of voluntary methane emissions reduction programs are limited to the extent of their adoption by private industry and by the availability of technologies to measure fugitive methane emissions and verification methods.

The United States has also taken strides to limit methane emissions through regulation. In 2015, EPA introduced draft New Source Performance Standards (NSPS) for methane and volatile organic compound (VOC) emissions from new and modified oil and gas wells. Once finalized, this regulation will significantly reduce emissions from the oil and gas sector as part of the Obama Administration's methane strategy. The NSPS relies on many of the technologies identified through the Natural Gas STAR program, and particularly on the use of "green completion," or reduced emissions completion, as the best technology currently available (EPA 2012, 2016f). Building on the NSPS, on November 10, 2016, EPA requested material from the oil and gas sector on "monitoring, detection of fugitive emissions, and alternative mitigation approaches in the oil and natural gas sector."[15] Finally, in January 2016, DOI (2016b) proposed regulations to reduce methane emissions by reducing venting and flaring from oil and gas production on Federal and tribal lands. Once finalized, compliance would require the adoption of best available technologies and periodic inspection of equipment for leaks. These regulations require investments on the part of the private sector, but the costs are limited to companies that have not already adopted green completion,[16] or other methane emissions reduction technologies voluntarily or as a result of state regulations (ANGA 2012).

b. Advanced Oil and Gas Production Technologies

Efforts are also under way to reduce the use of water in the production of oil and gas from shale and other unconventional formations, with R&D investments coming from both private and government sources. Advanced technologies for hydraulic fracturing include reusing water instead of only using fresh water and using carbon dioxide instead of water (a practice already under way in Wyoming) (Bullis 2013). DOE's Office of Fossil Energy in conjunction with the national laboratories are working to better understand the risks of seismicity and reduce the use of fresh water in hydraulic fracturing. Those efforts have led to the development of new technologies for treating wastewater for reuse and improved well design to protect water resources. Continuing RD&D efforts include efforts to establish seismic monitoring networks and develop tools to assess seismic risks (DOE n.d.c). These efforts are intended to improve the availability of advanced technologies and operating practices that will enhance environmental performance and energy security at the same time.

[15] 81 Fed. Reg. 46670–72 (July 13, 2016).

[16] In comments to EPA regarding the proposed NSPS regulations, a natural gas industry trade association suggested that green completion technologies were already being used in as much as 90 percent of well completions (ANGA 2012).

III. Assessing Energy Security for U.S. Allies and Partners

For this report, U.S. allies and partners are defined as those countries in the OECD, European Union, and IEA. These allies and partners face many of the same energy security challenges as the United States but also have some unique challenges and concerns. For example, Mexico nationalized its oil and gas sector almost 80 years ago but is now implementing landmark energy reforms to bring in private sector investment and technological expertise and reverse several consecutive years of annual production declines. As another example, some European countries have long been dependent on natural gas from Russia. High monopolistic prices for Russian gas and concerns about supply security have prompted the development of greater connections with international markets, including the build-out of additional LNG terminals, gas storage facilities, and gas pipeline interconnectors to create a more integrated market. Finally, allies and partners in Asia face diverse opportunities and challenges ranging from Australia's position of resource wealth to Japan's and Korea's almost complete dependence on the import of seaborne oil and LNG. Both Japan and Korea have worked to mitigate energy security risks by creating open, transparent markets allowing them to contract supplies worldwide and enacting policies to incentivize greater deployment of indigenous renewable energy capacity.

This section is not intended to be a comprehensive discussion of the energy security situation for U.S. allies and partners; rather, it highlights major policies adopted by other countries that affect their energy security. All monetary values are expressed in current U.S. dollars.

A. North America

Canada and Mexico increasingly participate with the United States in a fully integrated North American energy market. Market forces have driven much of this integration, but the heads of state advanced integration efforts with the 2014 North American Leaders' Summit by creating a framework for regular meetings of their energy ministers (DOE 2014c). Subsequent engagements have led to collaboration in three major strategic areas: 1) collaborating on energy data, statistics, and mapping; 2) crafting responsible and sustainable best practices for the development of unconventional oil and natural gas; and 3) ensuring modern, resilient physical and institutional regional energy infrastructure (DOE 2014c).

i. Canada

Canada's oil and natural gas trade with the United States is significant. Even as U.S. domestic crude oil production increased over the past decade, imports of Canadian crude and product grew by 58 percent (EIA 2015b). These imports flow through an extensive pipeline system owned and operated by private companies, including the Enbridge Mainline, Kinder Morgan Trans Mountain, Spectra Express, and TransCanada Keystone pipelines. In addition, about 3 percent of oil imports reach the United States by rail (EIA 2015a). Much of the flow of Canadian oil to the United States is a result of the suitability of U.S. Gulf Coast refineries for processing western Canadian heavy crude grades and the limited number of pipelines running from Canada's oil-producing regions to its east and west coasts. Pipeline and rail infrastructure has, at times, been insufficient to transport the large volume of Canadian crude to the Gulf Coast during peak production periods. To alleviate such concerns, Canada's National Energy Board provided conditional approval for the expansion of Kinder Morgan's Trans Mountain pipeline, which is Canada's only oil pipeline from Alberta to Canada's Pacific coast, in May 2016. The project is undergoing additional review, and Prime Minister Trudeau's government is expected to render a final decision by the end of 2016. Canada's National Energy Board has conducted public hearings pertaining to the Energy East pipeline to carry crude to the Atlantic coast, but it is not required to render a recommendation to the Federal Government until 2018 (Globe and Mail 2016). Prime Minister Trudeau has repeatedly stated his opposition to the construction of the Northern Gateway Pipeline to transport crude to Canada's west coast, and in November 2015, President Obama rejected the Keystone XL pipeline, which would bring larger volumes of crude from Alberta to the U.S. Gulf Coast.

Canada is the world's fifth-largest producer of dry natural gas, and virtually all its exports are sent to the United States via pipeline. Cross-border pipeline infrastructure capacity is closely integrated with the U.S. pipeline system and owned and operated by private companies, including TransCanada, Spectra, Enbridge, and Veresen. Canadian natural gas exports to the United States reached 2.6 tcf/year in 2014, or approximately 97 percent of total U.S. natural gas imports (EIA 2015b). U.S. piped natural gas exports to Canada have also increased, from just under 400 bcf in 2004 to nearly 770 bcf in 2014 (EIA 2016k).

Canada is seeking to improve the resilience of its energy infrastructure against natural disasters and other catastrophic events. The government issued its revised National Strategy for Critical Infrastructure in 2010. This strategy established a framework for action among federal, provincial, territorial, and private sector actors to coordinate emergency management for 10 critical sectors, including energy. The strategy espouses an all-hazards risk management approach, which takes into account accidental, intentional, and natural hazards (Public Safety Canada 2009). Since 2010, the government has established sector-specific networks, the National Cross Sector Forum, and the Critical Infrastructure Gateway to enable governments and private sector actors to better undertake a range of activities to address both sector-specific concerns and cross-sectoral interdependencies (Public Safety Canada 2014). Canada and the United States also issued a revised bilateral critical infrastructure plan in 2010 to establish a joint, cross-border critical infrastructure emergency management plan. This plan shores up a framework for bilateral coordination and assistance when necessary, better integrates response and relief efforts for cross-border incidents, and enhances cross-border information sharing. Energy infrastructure, including refineries, cross-border pipelines, and nuclear plants, is within its scope. The bilateral risk management approach is based on the assumed need for continual improvement in "setting protection and resiliency goals, identifying critical infrastructure and key dependencies, assessing and prioritizing risks, developing and executing plans and programs to address the identified risks and dependencies, and measuring the effectiveness of the plans and programs" (Government of Canada and Government of the United States of America 2010).

The Canadian federal, provincial, territorial, and municipal governments implement many policies to manage price volatility. Canadian fuel consumption taxes have two basic elements. The first is a series of fixed taxes imposed by the federal, provincial, and in select cases, municipal governments. The Federal Government levies a $0.28 per gallon tax on gasoline and a $0.11 per gallon tax on diesel applied nationwide (in the United States, the Federal gasoline tax is $0.184 cents per gallon, and the Federal tax on diesel is $0.244 cents per gallon) (NRC 2016c; EIA 2016a). Provincial taxes vary by jurisdiction. Municipal taxes are not universal or uniform. The municipal government of Vancouver charges a tax of $0.32 per gallon of gasoline and diesel, for example, and Victoria and Montreal impose taxes of $0.10 and $0.09 cents per gallon, respectively (NRC 2015). The second element of the tax regime is the sales tax. In most jurisdictions, this is assessed as a federal goods-and-services tax totaling 5 percent of the retail gasoline or diesel price. British Columbia's additional fuel consumption tax is an exception; it is applied as a carbon tax of $23/per ton of CO_2 emitted. Several academic studies conclude that British Columbia's carbon tax, which totals approximately $0.20 per gallon on gasoline and $0.23 per gallon on diesel, has reduced per capita fuel sales by as much as 18.8 percent (Murray and Rivers 2015). British Columbia's carbon tax is revenue neutral, and the provincial government has cut income and corporate taxes to account for increased revenues accrued through the carbon tax (Economist 2014). Alberta is planning to implement its own revenue-neutral carbon tax beginning at a rate of approximately $15 per ton of CO_2 emitted in January 2017. It will reach parity with British Columbia's $23 per ton of CO_2 emitted one year later (Bakx 2016).

Canada began to calibrate fuel efficiency standards to manage transportation fuels consumption in 1973 following the Arab OPEC oil embargo. The Canadian standards were harmonized with U.S. CAFE standards for light-, medium-, and heavy-duty vehicles. However, the Canadian standards were voluntary until 2007, when the Federal Government shifted to a mandatory approach (ICCT and Diesel Net 2016). Canada's standards for 2011–2016 model-year passenger automobiles and light trucks represent a 20 percent reduction in new car and light truck emissions relative to the new vehicle fleet sold in 2007. Emissions standards for 2017–2025 model-year passenger automobiles and light trucks were adopted in 2014 (ICCT and Diesel Net 2016). Although standards for passenger automobiles and light trucks are not identical and the fuel efficiency of individual vehicle models varies (ICCT 2015), these regulations mean that 2025 model-year motor vehicles will consume as much as 50 percent less fuel than the 2008 fleet (Government of Canada 2014). Canada finalized separate fuel efficiency standards for medium- and heavy-duty vehicles in 2013, which went into effect the following year and are required to be fully phased in by 2018 (ICCT and Diesel Net 2014). As a result of these regulations, Canada forecasts that CO_2 emissions from 2018 model-year heavy-duty vehicles will be reduced by up to 23 percent from those sold in 2010, depending on vehicle model (ICCT and Diesel Net 2014). Canada has also worked to manage fuel demand through robust investments in public transportation infrastructure. Public transit ridership totaled a record 2.05 billion trips nationwide in 2013 (CUTA 2015). Investment is especially evident in provinces with higher population density and thus greater opportunity to realize value from public transit. Among the clearest examples is the Ontario government's 12-year, $121 billion "Moving Ontario Forward" infrastructure plan, which allocates $22 billion for transportation infrastructure, including public transport (CUTA 2015).

Canada is also applying additional incentives for renewable energy deployment. The country is already a world leader in renewable energy generation, with hydropower alone providing more than 59 percent of the country's power (Natural Resources Canada 2016a). Ontario is working to phase out coal plants and replace them with natural gas, wind, and solar generation. In addition, hydropower is increasingly replacing oil-fired electricity generation in Newfoundland, while Nova Scotia is seeking to diversify from coal-, oil-, and natural gas–fired facilities and generate more power from renewable energy (CEA n.d.). Transitions to clean and renewable energy will better insulate these provinces from oil price volatility while benefiting the climate. Wind and solar photovoltaic energy are the fastest-growing electricity sources in Canada (Natural Resources Canada 2016b). The Federal Government is leveraging provincial and territorial government efforts to develop a pan-Canadian framework for clean growth and climate change (McDiarmid 2016b). This work, as encapsulated in the March 2016 Vancouver Declaration, calls for collaboration between Ottawa and the provincial governments in developing flexible, province-supported carbon pricing nationwide. The government also created the Low Carbon Economy Trust to finance projects that will "materially" reduce carbon emissions and allocated $1.5 billion over two years for the trust in the 2016 budget (Government of Canada 2016a). In addition, Canada is doubling investments in clean energy research and development over the next 5 years (Prime Minister of Canada 2016). New investments include those in the transportation sector: Canada is leveraging alternative energy sources to lower the carbon footprint of its public transportation services and increase its resilience to a major hydrocarbon supply disruption. Technologies that have already been deployed at scale with some success include biodiesel and diesel-electric buses (CUTA 2015).

In December 2014, Canada passed the Extractive Sector Transparency Measures Act (ESTMA) (S.C. 2014 c. 39 § 376). This law complements the amended EU Transparency and Accounting Directives and requires extractive companies operating in Canada to report their payments to the governments of all jurisdictions where they operate. To streamline industry reporting requirements, the law authorizes companies subject to both EU and Canadian jurisdiction to meet their reporting obligations through implementation of the EU directives (Natural Resources Canada 2016e). Canada is welcoming to foreign investment, and several foreign companies are invested in the country's oil and gas sector. The country's Investment Canada Act outlines the process through which the government reviews foreign investment in cases where there is "reasonable grounds to believe that the investment would be injurious to national security" or where a foreign company acquires a Canadian business valued at $250 million or greater (Alini 2012). This is roughly equivalent to the Committee on Foreign Investment in the United States.

The Canadian government, through its National Energy Board, maintains an online portal that includes extensive energy data relevant to the interests of both the general public and current and prospective private sector actors. In addition to basic aggregate production and consumption data, the portal displays detailed information on the volume and value of

Canadian hydrocarbons exports by type, destination, and means of export, and extensive analysis of the potential of conventional and unconventional Canadian oil and gas reserves (National Energy Board 2016a). Canadian pipeline companies are required to operate according to the principle of open access (NEB 2016b).

Canada's INDC, as submitted by the previous Harper government, committed Canada to reduce GHG emissions to 30 percent below 2005 levels by 2030. However, the Harper government was replaced by a Liberal Party government following the October 2015 federal elections. In March 2016, Prime Minister Justin Trudeau established four working groups to collaborate with Canada's provincial leaders to develop recommendations for how Canada should move forward on four energy-related areas: "clean technology, innovation, and jobs; carbon pricing mechanisms; specific mitigation opportunities; and, adaptation and climate resilience." The working groups' recommendations, due in October 2016, will form the basis of efforts to develop a pan-Canadian framework for clean growth and climate change (Prime Minister of Canada 2016). Through this process, the Trudeau government appears likely to forge targets that exceed the Harper government's INDC (McDiarmid 2016a).

ii. Mexico

Mexico is also linked to the U.S. energy infrastructure, although to a lesser extent than Canada (Osborne 2015). Natural gas exports to Mexico from the United States have increased from around 333 bcf in 2010 to nearly 1.1 tcf in 2015 (EIA 2016l). Wood MacKenzie has projected that 2015 volumes could nearly double by 2020 (Osborne 2015). Cross-border pipelines are owned and operated by private U.S. firms, including Kinder Morgan, Energy Transfer Partners, and Howard Energy Partners. Crude oil imports to the United States from Mexico have dropped because Mexican production has decreased and heavy crude markets elsewhere in the world are using Mexican oil that would have otherwise gone to the United States.

The Mexican economy has become less vulnerable to oil and natural gas price spikes. Financial difficulties at Pemex, a long legacy of state control over the oil and gas sector, and natural field decline rates have all contributed to declines in Mexico's oil production and increased oil imports. Imports have also increased to supply a growing transportation sector. At the same time, however, NAFTA has helped diversify the Mexican economy (Webber 2016; Harrup 2016b). Oil exports accounted for nearly 80 percent of total dollar income for Mexico's economy prior to NAFTA but currently total less than 20 percent, as manufacturing exports have emerged as Mexico's leading source of foreign income (AP 2016). In addition, the move by the United States to lift the crude oil export ban in December 2015 provided Mexico with an important source of light oil that is well suited for Mexico's refineries. In addition, the very low sulfur content of U.S. tight oil and limited desulfurization capacity by some Mexican refineries have probably helped reduce air pollution in Mexico City and other major cities. The potential for the two countries to enjoy extensive energy trade was evidenced by the U.S. Department of Commerce's work to issue a license for Pemex to import limited volumes of U.S. light oil even before the crude oil export ban was rescinded.

In the longer term, Mexico's oil dependence should shrink further as it converts its fuel oil and diesel-fired power plants to natural gas. These conversions are contributing to the emergence of a more liquid North American natural gas market while increasing Mexico's dependence on U.S. piped natural gas. Conversions will also help diversify Mexico's electricity generation mix, erode remaining dependence on fuel oil, and improve the resilience of the country's infrastructure by facilitating the further build-out of a cross-border export pipeline network with the United States. As noted above, Mexico's policy has already led to a surge of new cross-border natural gas pipelines.

Mexico's efforts to increase the resilience of its infrastructure have faced some challenges in recent years. The current government initially sought to increase infrastructure spending more broadly and introduced a $590 billion infrastructure plan for the years 2014 to 2018 (Harrup 2016a). However, because of reduced government revenues and resulting austerity budgets, Mexico will look to implementation of its energy reforms, which allow private sector investment in strategic infrastructure, to improve the resilience of its facilities. Mexico's energy reforms have created a new, autonomous, and independently funded regulator, the National Industrial Safety and Environmental Protection Agency. This dedicated, focused entity should enhance the country's capacity to mitigate disaster risk and better ensure infrastructure resilience, provided it is well-resourced and collaborates with sister agencies around the world to absorb international best practices and build capacity.

Mexico has a different approach than Canada to enhancing consumer energy security and protecting its economy from shocks originating from a major oil and gas supply disruption. It is the only OECD country that does not directly tax gasoline and diesel consumption. At the same time, its energy reforms, specifically the government's move on April 1, 2016, to sunset a long-held monopoly of Petróleos Mexicanos (Pemex), Mexico's state-owned oil and gas company, will permit the import of gasoline and diesel into the country, which will improve security of supply for consumers (Guthrie and Montes 2016). Pemex will no longer face the burden of importing sufficient volumes and maintaining attendant storage and transportation infrastructure to meet the entirety of Mexican oil and gas demand. The monopoly's end will also introduce more competition in retail fuel markets. This will contribute to downward price pressure, to the benefit of consumers. In addition, Pemex will be able to partner on more attractive terms with other oil companies, enhancing Pemex's productivity and Mexico's oil supply.

Mexico's approach to transportation policy is similar to those in Canada and the United States. Following passage of the General Law on Climate Change in 2012, Mexico promulgated fuel efficiency standards for passenger vehicles for the first time in 2013. Like the Canadian standards, these measures are patterned on the U.S. CAFE standards. The Mexican government projects that implementation of fuel economy standards will reduce consumption by 710 million barrels of oil nationwide by 2032 (ICCT 2013). Mexico has managed fuels consumption in urban areas by maintaining mass transit systems Mexico City, Monterrey, and Guadalajara. The government announced a multibillion-dollar plan to revitalize passenger rail throughout Mexico in 2012 (Miroff 2013). However, several projects have been stymied by tendering issues or budget cuts. A railway to link Mexico

City with Toluca, the capital of the subnational state of Mexico that borders the Mexico City federal district, has survived the budget cuts and is proceeding (Alonso 2016).

Mexico's comprehensive energy reforms also seek to add substitution options to shield the economy from an oil or natural gas price spike. Unlike the United States and Canada, Mexico relies on oil for a significant share of power generation (EIA 2015f). Mexico is diversifying its generation mix by converting power plants from fuel oil to natural gas and introducing greater shares of renewables. Seven fuel oil power plants near the U.S. border are being converted to gas-fired facilities and will be fueled by piped U.S. gas imported across the border (Zeng 2015). The 2012 General Law on Climate Change stipulates a national target of producing 35 percent of Mexico's energy from clean sources by 2024. Mexico held its first power auction for private sector investors under the energy reforms in March 2016; 1,720 MW were awarded exclusively to solar and wind energy projects (Dezem and Williams 2016). No contracts were awarded to competing technologies (Anand 2016). Mexican officials note that wind and solar projects are growing increasingly competitive relative to fossil fuels. Indeed, the costs associated with the Clean Energy Certificates program, which was developed under the reforms to incentivize renewable energy development, are much lower than the government initially forecasted.[17]

As part of its transparency drive under the energy reform framework, Mexico is working to join EITI (EITI 2015). In the past, Pemex was given a monopoly in the national upstream sector, but the Mexican energy reforms are intended to eliminate that monopoly and bring transparency to the sector. Joining the EITI would obligate companies operating in the country to publicly report their payments to the Mexican state and make them comprehensible to the general public through the issuance of annual reports.

Mexico's energy reforms are doing many things to enhance energy market competitiveness. Most importantly, the reforms eliminate the monopoly held by Pemex and open up the country's oil and gas resources to foreign companies through a process of auctioning leases. Also, like Canada, Mexico has established open access principles for pipelines, as the Energy Regulatory Commission is tasked with enforcing open access of all oil, product, and natural gas pipelines (Goldwyn et al. 2014). They also require the country's Energy Regulatory Commission to issue more detailed statistical data, including the number of permits issued, volumes of transported and stored natural gas, used and available capacity in the facilities and pipelines of permit holders, and other "statistics relating to the transport, storage, distribution, and retailing to the public of natural gas, petroleum products, and petrochemicals, at a national level (Obeso 2016). Additional work on data transparency and collection is carried out by both Mexico and Canada through the following agenda set in regular meetings of the North American energy ministers:

- Systematically comparing respective import and export information on energy flows to validate publicly available data and improve data quality;

[17] This information was derived from conversations between Goldwyn Global Strategies staff and Mexican officials on April 20, 2016.

- Sharing publicly accessible geospatial information relating to utility infrastructure, such as pipelines, transmission lines, power plants (fossil, nuclear, and renewable), refineries, and oil and natural gas wells;
- Exchanging views and projections for cross-border flows of natural gas, electricity, crude oil, and refined products; and
- Developing a cross reference for terminology commonly used in the energy sector with a view toward harmonization of terms, concepts, and definitions for energy products and flows, or understanding their differences.
  (Government of Canada 2016b).

Mexico exercised noteworthy global leadership by acting as the first developing country to release an INDC. Its INDC includes an unconditional commitment to reduce GHGs and short-lived climate pollutants by 25 percent relative to business as usual in 2030. Under such a target, Mexico's net emissions would peak in 2026. This target enables Mexico to decouple GHG emissions from economic growth, since emissions intensity per unit of GDP would decline by around 40 percent from 2013 to 2030. Mexico's emissions reduction commitment could increase from 25 percent to as much as 40 percent subject to several conditions, including "access to low-cost financial resources and technology transfer, all at a scale commensurate to the challenge of global climate change" (Government of Mexico n.d.).

B. Europe

Most of Europe already enjoys a diverse supply of oil. Diversifying natural gas supply sources and routes represents an opportunity for Europe to improve its energy security. The continent faces a declining outlook for both oil and gas production in the coming years and decades. It imports about 90 percent of its oil and 66 percent of its natural gas, but because of comparatively less dependence on imported nuclear fuel and solid fuel, energy imports account for only about 50 percent of total energy demand (EC 2014b).

Europe is highly integrated into global oil markets. The continent has several major points of entry, owned and operated by a large number of public and private sector actors, including the port of Rotterdam in the Netherlands, Marseille and Le Havre in France, and the port of Trieste in Italy. Around 2 million barrels of crude oil enters Rotterdam each day, mainly from the Middle East, the North Sea, and Russia, to be refined on site (Port of Rotterdam n.d.). Oil also enters Europe through an extensive pipeline network from Rotterdam to refineries in Belgium, Germany, and elsewhere in the Netherlands (Port of Rotterdam n.d.). As with the ports of entry, no single public or private sector actor maintains requisite control of the cross-border pipelines and refineries to leverage market power to extract concessions from the state. For example, in Germany several major international companies, including Shell, BP, ConocoPhillips, and Total, have significant refinery stakes. In addition, all four of Germany's cross-border oil pipelines are owned and operated by private companies and transport oil from four sources: Russia, the Netherlands, France, and Italy (IEA 2012). Nevertheless, Europe depends on Russia and the OPEC states for around 60 percent of its oil supply, with Russia alone accounting for about 30 percent. The completion of the Baku-Tbilisi-Ceyhan (BTC) pipeline in 2006 has enabled

Kazakhstan and Azerbaijan to emerge as important new suppliers of crude to Europe. Their combined market share totals around 10 percent (Eurostat 2016).

Despite Europe's diversity of oil sources, some countries in Central and Eastern Europe depend on one or two suppliers because crude and petroleum products are not able to easily flow east through pipelines. Western European refineries are typically supplied by pipelines coming from major ports, including Rotterdam and Marseille, giving them access to world supplies. Yet Central and Eastern European refineries are generally directly supplied by Russia's Druzhba pipeline (EC 2014a). In the Czech Republic, roughly two-thirds of domestic oil demand is met by imports transited through Druzhba (IEA 2014). The European Union has made note of this vulnerability and unveiled several "projects of common interest" (PCIs) that promote greater security of oil supply at Eastern European refineries (EC n.d.e). Because transportation costs for oil are low, Europe could leverage its extensive network of inland waterways, railways, short sea shipping vessels, and road networks to transport crude and product in the event of a supply disruption. Another potential vulnerability of the European oil supply security is the decline of EU refining capacity by 1.8 million b/d from 2008 to 2014; current capacity totals around 15 million b/d (EC 2016b). The decline is due to the limited global competitiveness of the European refining industry and successful efforts by Russian companies to purchase assets that other companies are seeking to off-load (EC 2014a, 2014b; EurActiv with Reuters 2014).

Since around 2008, Europe's natural gas market has become more diversified, improving the energy security of EU countries, particularly those in Eastern Europe, largely because of two major developments. First, the UK National Balancing Point has become the spot price of natural gas in northwestern Europe and is trading below the oil-indexed price of traditional long-term natural gas contracts. This lower price reflects rapid growth in availability of global LNG; the build-out of new LNG terminals in the United Kingdom, France, the Netherlands, and Italy; and significant Western European LNG import growth at a time of limited or even falling demand growth in the region. Diverse private sector operators maintain stakes in these terminals. For example, Enagas, SAGGAS, BBG, and Reganosa all have ownership of at least one LNG import terminal in Spain, which has the largest regasification capacity in Europe (Gas Infrastructure Europe 2015). Second, the availability of spot-priced gas in the Western European market has proliferated. This reflects several factors, including increased will among national regulators in Western Europe to implement EU rules on open access for pipelines, in effect allowing more suppliers to secure pipeline capacity from pipelines owned and operated by others; and the interrelated build-out of interconnection capacity across national borders (Noel 2013).

Gas producers in the United States are among those supplying LNG to Europe, with the Portuguese firm Galp Energia's purchase of a cargo from Cheniere's Sabine Pass in April 2016 marking the first of such transactions (Kantchev and Malek 2016). Even before exports began, the U.S. shale boom enhanced Europe's energy security by contributing to global gas supplies, in effect allowing LNG cargoes initially destined for the United States to supply other markets. Increased LNG supplies in turn forced Gazprom, either through negotiations or as a result of arbitration awards, to provide several concessions and/or rebates to individual buyers to protect its own market share (Rogers 2015). The extent to which LNG exports, including those from the United States, exert further pressure on Russian supplies in the coming years is subject to several difficult-to-forecast variables. These include how fast LNG demand grows in both Asian and European markets and whether Gazprom chooses to leverage its ample spare production capacity to sell excess supplies directly onto European hubs and keep prices sufficiently low to limit LNG market share growth (Rogers 2015).

Whereas Western Europe successfully connected to international natural gas markets, large areas of Eastern Europe continue to lack access to natural gas trading hubs or LNG import terminals. In recent years, Russia has accounted for around 40 percent of total EU natural gas imports, with six EU member states depending exclusively on Russia for their natural gas needs (EC 2014a, 2014b). Although the unbundling provisions of the European Union's Third Energy Package have improved security of supply for these countries, significant dependence on Russia remains an issue of foremost concern. Estonia's parliament waived an EU exemption that would have allowed it to delay unbundling, which the European Union defines as "the separation of energy supply and generation from the operation of transmission networks" (EC n.d.d). In effect, these provisions prevent a single company from controlling both the upstream production of an energy project and the associated transmission network so that it cannot obstruct competitors' access to infrastructure (EC n.d.d). This has required Gazprom and a Russia-based investment group, which own a combined 47 percent stake in Estonia's strategic natural gas transmission and distribution infrastructure, to sell their shares, which has introduced competition to Estonia's natural gas market and improved its energy security (Eesti Gaas 2016). Countries are also beginning to break their dependence on pipelines originating in Russia, although efforts are in a relatively early stage. Lithuania's Klaipėda LNG terminal began operating in late 2014, breaking Gazprom's gas export monopoly in the Baltic states. Lithuania subsequently began exporting gas to Estonia, inaugurating the first semblance of a diversified Baltic gas market. Construction of Poland's Świnoujście LNG terminal was completed in 2015. Poland and Lithuania are collaborating in the construction of the Gas Interconnector Poland Lithuania, which will serve as the first major interconnection between the Central European and Baltic State natural gas markets. This construction is being co-financed with $332 million in grants from the Connecting Europe Facility, an EU financing mechanism intended in part to help finance strategic regional energy infrastructure that enhances regional energy market integration (Jegelevicius 2015).

In addition to facilitating greater diversity of supply, the European Union has taken steps to harden Europe's oil and gas infrastructure against natural disasters, including those brought about by climate change. The European Commission encourages member states to adopt comprehensive adaptation strategies and provides financing to help them build their adaptation capacities (EC 2013). The European Commission plans to assess member states' progress in 2017 and, if necessary, propose a legally binding instrument to accelerate work. The strategy promotes adaptation in vulnerable sectors, including energy. The commission tasked European standardization organizations to identify energy industry standards that will need to be revised to better reflect adaptation considerations; these efforts are ongoing (ECS n.d.). The European Union is also giving greater consideration to climate change adaption through its structural and investment funds. It allocated $8.4 billion in financing from 2014 to 2020 to bolster disaster resilience against both climate and nonclimate disasters (EC 2015a). This work is consistent with European regulations on guidelines for trans-European energy infrastructure, which mandate consideration of disaster resilience in the cost-benefit analysis of PCIs (Official Journal of the European Union 2013).

Despite the continent's declining oil and gas production (EIA n.d.e), Europe has shown success in protecting both its consumers and its broader economy from oil and gas price volatility originating from a major supply disruption. Similar to Canada and to a lesser extent Mexico, Europe has employed a combination of fossil fuel consumption taxes, efficiency measures, public transportation investments, and measures promoting renewable energy deployment.

High taxes on petroleum products in Europe's transportation sector has raised gasoline prices and reduced consumption, thereby limiting the potential economic costs in the event of an oil price spike. For example, between September 2010 and September 2013, the price per liter of Euro-Super 95 increased by 40 percent without considering taxes, but with taxes, this spike represented only a 22 percent real cost increase for consumers (EEA 2015c). Such taxes in Europe (which typically include excise taxes and a value-added tax, VAT) range from an equivalent of about $2 to more than $4 per gallon (DOE 2011a). Although petroleum product taxes likely played a role in mitigating demand growth in the transportation sector, final energy consumption in the sector still increased by 23 percent over the same period (EEA 2015b). Freight transportation in particular accounts for the upswing.

Fuel taxes are generally not high enough to seriously limit demand growth. Other means, including vehicle efficiency regulations, have therefore been leveraged to offset demand growth (EEA 2015c). The European Union's rigorous fuel efficiency standards appear to have had a greater effect on the continent's fuel consumption than petroleum product taxation. Indeed, energy efficiency in the transportation sector increased by nearly 20 percent from 1990 to 2013 (EEA 2016).

The increases in fuel efficiency have had a commensurate effect on CO_2 emissions. The average emissions level of a new car sold in the European Union in 2014 was 123.4 g CO_2/km, equivalent to a fuel efficiency rate of about 44 miles per gallon (mpg) of gasoline. The level exceeded the European Union's approximately 42 mpg binding target in place for new cars by 2015. An updated standard requires a target of around 57 mpg by 2021 (EC 2016c). Several mechanisms, including eco-innovation emissions credits, super-low-emitting vehicle credits, the ability for manufacturers to group together to meet their emissions reduction obligations, and less stringent requirements for smaller manufacturers, have allowed for flexibility to the automobile industry in meeting fuel economy and CO_2 targets (EC 2016c). Similarly ambitious targets have been set for new vans. Yet there are no binding EU standards for heavy trucks, which account for 30 percent of on-road EU emissions. The fuel efficiency of heavy European trucks has not improved in a decade. Heavy European trucks may soon be outperformed by heavy U.S. trucks, which have recently become subject to mandatory targets (Muncrief and Sharpe 2015; Transport & Environment 2015).

Europe, in contrast to the United States, has also proven successful at limiting petroleum product consumer demand by investing in and maintaining world-class public transportation infrastructure. Although roughly 30 percent of daily trips in both Europe and the United States are less than one mile, Americans completed roughly 70 percent of such trips by driving, while Europeans made 70 percent of such trips on public transportation, bicycle, or foot (Buehler 2014). One significant factor is Europe's greater population density, which raises occupancy rates and improves the economics of mass transit (World Bank n.d.a).Another factor is European zoning laws. Europe generally allows for more mixed-use development in residential zones, in effect enabling citizens to live close to commercial services. Still another factor is the earlier onset of mass motorization in the United States, where assembly-line production capacity and greater personal wealth were more prevalent, especially after World War II; the effects include sprawl and low gasoline taxes (Buehler 2014; Pomerleau 2015).

Annual EU investment in public transport totals approximately U.S. $44 billion. There are around 60 billion total passenger journeys on public transportation in the European Union each year and an additional 1 billion journeys on long-distance rail —more than the total for commercial aviation, at 800 million (IAPT 2014). Use of public transportation limits energy demand because European cars consume four times more energy per passenger than public transportation. The most recently available data suggest that public transportation has increased its market share in major EU countries, including the United Kingdom, France, and Germany. However, the share of public transport in total passenger traffic actually declined from 23 percent in 1990 to 17 percent in 2009 (EEA 2015a).

The aforementioned policies focus on curbing demand for petroleum products and lowering greenhouse gases in Europe's transportation sector. Additional policies create incentives for the deployment of renewable energy. The Renewable Energy Directive requires the European Union to meet 20 percent of its total energy demand with renewable resources by 2020. It specifies separate national renewable energy targets to enable each member state to contribute to this aggregate goal. Precise deployment incentives are set at the member state level, but the EU directive encourages cooperative mechanisms, such as statistical transfers of renewable energy, joint renewable energy targets, and joint renewable energy support schemes, to help countries reach their targets (EC n.d.f). Some EU member states have already exceeded their 2020 targets, and the European Union as a whole currently satisfies around 15 percent of total energy demand with renewable sources (EC n.d.c).

The European Union obligates member states to adhere to common standards to ensure nondiscriminatory access to the exploration and production of hydrocarbons. The intent of these standards, laid out in EU Directive 94/22/EC, is "to prevent a single entity from having exclusive rights for an area whose prospection, exploration and production can be carried out more effectively by several entities." The directive requires EU member states to grant authorizations through either an open-door system or a licensing round. In both cases, notice is published in the Official Journal of the European Union. In addition, tendering procedures must comply with the transparency and nondiscrimination principles laid out in EU public procurement legislation (EUR-Lex 2007).

The European Union has also played a global leadership role in anticorruption legislation requiring companies to report their government payments. In 2013, it amended the EU Accounting and Transparency Directives to complement a law already in place in Norway that requires European extractive companies to report their payments, including production entitlements, royalties, taxes, and dividends, to governments in all countries where they operate (Publish What You Pay 2013). Some European countries, including the United Kingdom and France, are taking the additional step of implementing EITI, which is already in place in Norway (Kråkenes 2013).

Data transparency in Europe is abundant. Information is frequently available in several languages (European Commission policy gives citizens the right to access EU documents in its official languages; EC 2016a). However, EU policymakers acknowledge the need to make available more adequate and timely data on oil, gas, and coal stocks. This will better inform contingency planning efforts, including those that take place among IEA member states, necessary to calibrate effective responses to both intentional and unintentional supply disruptions. Among the publicly available sources of information today is the European Union's Eurostat database, which has energy production, consumption, and other data, such as electricity and natural gas prices data (EUR-Lex 2007). Detailed information is also available on the European Commission's Energy Portal (EC n.d.a) and the Energy Statistical Pocketbook (EC n.d.b). The latter two sources have information pertaining to EU energy imports by country of origin, and analysis of issues, such as enhancing the bargaining power of EU buyers in wholesale natural gas markets and the potential of unconventional gas in Europe. Still further information is available through IEA, which keeps statistics and publishes regular reports on the energy security of EU member states; other topics include energy market reform policies and efforts to adopt clean energy technologies (IEA n.d.).

The EU INDC commits member states to achieving an aggregate GHG emissions reduction totaling 40 percent by 2030 relative to 1990 levels. The European Union notes that this target is consistent with its fair share of international efforts to reduce global temperature increase below 2°C, adding that it is "consistent with the Intergovernmental Panel on Climate Change (IPCC)'s assessment of the reductions required from developed countries as a group, to reduce emissions by 80–95 percent compared to 1990 levels by 2050" (EC 2015b). The EU INDC is comprehensive and includes economy-wide emissions reduction goals (Climate Action Tracker 2016).

C. Asia

Select U.S. allies in Asia, including Australia, New Zealand, Japan and Korea, face diverse circumstances that range from significant resource wealth to complete import dependence. These countries have all worked hard to create open, transparent domestic energy markets allowing them to buy and sell supplies worldwide.

i. Australia and New Zealand

Australia's upstream sector is liberalized and open to private investors, which include leading major international companies such as Chevron, Shell, ExxonMobil, ConocoPhillips, Inpex (Japan), Total, BHP Billiton, and Apache Energy. These companies have capacity to increase production if new fields are discovered or if oil prices recover sufficiently to encourage foreign investment in deepwater fields (EIA 2014a). Australia also maintains domestic oil pipeline and refinery networks that are privately owned and operated by Epic Energy, Santos, Esso, BP, Shell, and other companies (EIA 2014a). The country's refinery infrastructure is located near several populated areas throughout Australia's east and south coasts, rendering it unlikely that a single weather event could disrupt the entire system. However, refining throughput met less than 50 percent of Australian domestic demand in 2015, since rising labor and operating costs and new environmental standards have led several refineries to close in recent years. Australia appears likely to grow progressively more dependent on the larger, newer, and more profitable refineries that are emerging throughout Asia (EIA 2014a). Australia imports significant volumes of crude oil and petroleum products from a variety of sources. The country's import requirements will increase in the coming years; production has already declined from 828,000 b/d in 2000 to 416,000 b/d in 2015 (Office of the Chief Economist 2015). By comparison, New Zealand produces some sweet crude domestically, but the country's only refinery is calibrated for sour crude, requiring it to export its sweet crude oil and import sour crude to meet domestic demand (IEA 2010).

Australia is among the world's top 10 producers of dry natural gas and is the world's second largest exporter of LNG. Production has increased substantially in recent years, growing from 1.2 tcf/year in 2000 to 2.3 tcf/year in 2015 (BP 2011, 2016). As with oil, private firms, including Santos, Woodside, Chevron, ConocoPhillips, ExxonMobil, Origin Energy, Apache Corporation, INPEX Corporation, Total, Shell, and Statoil, participate in upstream activities. The diversity in private sector participation forecloses any reasonable possibility that a single actor could leverage market power for coercive purposes. Australia's gas pipeline transmission network has expanded significantly since 2000 because of increased investment inflows (EIA 2014a). Efforts to interconnect the remote states of Western Australia and the Northern Territory into the national transmission network are ongoing. The Asian conglomerate Jemena won a tender to build an interconnector from the Northern Territory to Queensland in Eastern Australia in November 2015 (ABC 2015). Low natural gas prices are affecting forecasted rents secured by private sector actors and could put significant downward pressure on future gas production. Expectations that global LNG markets will be more than adequately supplied in the coming years have reduced investment in the country's LNG export projects. Among the relevant examples is cancellation of the $20 billion Browse LNG project in Western Australia in March 2016 (Kennedy 2016; IAPT 2014). New Zealand lacks an LNG import terminal or any cross-border gas pipelines, leaving its gas market isolated from the rest of the world. The country thus meets local demand entirely through domestic production, which totaled 190 bcf in 2015 (MBIE 2016a).

Australia's government continues to address risks associated with critical infrastructure resilience through the Trusted Information Sharing Network for Critical Infrastructure

Resilience. In this forum, business and government leaders share information on hazards and vulnerabilities and identify mitigation strategies to address them. Energy sector collaboration is focused within the network's Energy Sector Group, which also engages in cross-sector collaboration with the banking, finance, communications, and other sectors to identify interdependencies and find means to work together (DIIS n.d.b). The government has signaled that it will continue to pursue a productive business-government partnership in addressing critical infrastructure risks rather than take a regulatory approach. This reflects the government's view that owners and operators of critical infrastructure are best positioned to assess risks to their operations and decide the most appropriate mitigation strategies (Government of Australia 2015b). New Zealand's efforts to bolster the resilience of its energy infrastructure are spelled out in the National Infrastructure Plans (National Infrastructure Unit 2015).

Allies and partners of the United States in Asia exhibit a variety of energy security settings. Australia, the world's second-largest exporter of LNG as of 2015, satisfies more than one-third of its total oil demand with domestic production (EIA 2014a). New Zealand imports a majority of its oil but is self-sufficient in natural gas. Japan and Korea depend almost entirely on imported hydrocarbons. However, given both the nature of the global oil market and an Asian gas market that is increasingly integrated with Europe's gas market, all four countries are undertaking similar policies to protect their consumers from the macroeconomic costs of a major price shock.

Australia's gasoline and diesel tax regime includes a fuel excise tax, assessed by the Federal Government on a per liter basis. The fuel excise tax was frozen from 2001 until 2015, when the government agreed to new measures allowing for the excise to increase twice each year corresponding with inflation (OECD 2014; Conifer 2015). The government delegated all funds from increased excises to finance transportation infrastructure; businesses can secure fuel excise tax exemptions or rebates under certain circumstances (Conifer 2015). The Federal Government also assesses a 10 percent goods-and-services tax on both gasoline and diesel (AIP n.d.). Subnational governments do not levy additional consumption taxes (ATO 2015).

Both Australia and New Zealand lack binding fuel efficiency standards comparable to those in place throughout North America and Europe. However, Australia's current government is convening a ministerial forum that will explore whether such standards are needed (Ministers and Assistant Ministers for DIIS 2015). Australian public transportation projects have in recent history been largely the provenance of state governments, but an ongoing debate concerns whether the Federal Government should play a more significant financing role. Some argue that it needs to give Australian citizens substitute transportation options in emergencies, given the country's limited storage capacity for petroleum products (Medhora 2015). Passenger rail was ubiquitous in Australia in the mid-20th century. However, its role in the transportation sector has since declined because expansions have not corresponded to population growth and dispersed suburbs around major cities (BITRE 2013).

Australia and New Zealand are also engaged in calibrating incentives to expand renewable energy to decrease the total share of fossil fuels in their energy mixes and minimize price volatility emerging from any major global supply disruption. The Australian government's main policy mechanism is the Renewable Energy Target, with two instruments: the Large-Scale Renewable Energy Target and the Small-Scale Renewable Energy Scheme. The former creates financial incentives to establish or expand utility-scale renewable energy power stations by legislating demand for large-scale generation certificates. Electricity retailers must in turn acquire these certificates to meet the scheme's annual targets. Separately, the latter instrument creates financial incentives for households, small businesses, and community groups to install small-scale renewable energy systems (Department of the Environment and Energy 2015). The Australian government launched a $760 million clean energy innovation fund in July 2016 (Parker 2016). New Zealand has a robust renewable energy resource endowment and a mature market: 80 percent of electricity generation already comes from renewable sources, and New Zealand is seeking to increase this share to 90 percent by 2025 (Frykberg 2016).

Australia has not passed legislation equivalent to the EU Accounting and Transparency Directives or Canada's ESTMA, although such measures have been proposed in the past (Ashurst Australia 2014). Australia carried out an EITI pilot in 2011 and announced that it would join EITI in May 2016 (Bartlett 2016). Transparency legislation requiring extractive companies in Korea and Japan to report their payments has not taken hold. This is because both countries manage extremely small upstream sectors that contribute only marginally to overall oil and gas consumption.

Australia does provide extensive energy sector data through the Department of Industry, Innovation, and Science's official Australian Energy Statistics Dataset. This serves as the government's official energy report and is used for the country's international reporting obligations. The dataset is comprehensive and includes extensive information about Australia's energy consumption, production, and trade (DIIS n.d.a). Additional details are available through the Australian Energy Regulator, which publishes, among other analyses, annual state-of-the-market reports offering a deep dive on the country's gas and electricity markets (Australian Energy Regulator 2016). New Zealand's government provides statistical information through the Ministry of Innovation, Business, and Employment and Statistics New Zealand (Statistics New Zealand n.d.; MBIE 2016b).

Australia's INDC aims to reduce GHG emissions to 26 to 28 percent below 2005 levels by 2030. In meeting its target, Australia plans to leverage its nearly $2 billion Emissions Reduction Fund, which offers a suite of incentives for businesses to reduce their carbon emissions. According to the Australian government, this program has already brought about 47 million tons of emissions reductions. Australia plans to further calibrate its target policy framework in 2017 and 2018 (Government of Australia 2015a). New Zealand's INDC targets a GHG emissions reduction of 30 percent below 2005 levels by 2020. The government plans to reach this target "through a mix of domestic emission reductions, the removal of carbon dioxide by forests, and participation in international carbon markets" (Ministry for the Environment 2016).

ii. Korea and Japan

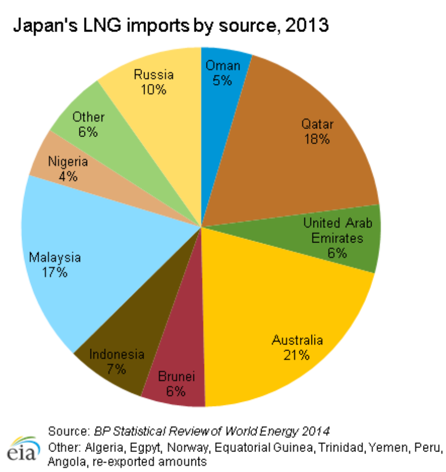
Korea and Japan must pursue a fundamentally different approach to ensure oil and gas supply diversity and resilience. Both are extremely reliant on the Middle East for their crude oil supplies (EIA 2015d, 2015e). Both are among the world's four largest destinations for oil transiting the Strait of Hormuz (Cordesman 2015), which Iran has threatened to close on occasion even after the consummation of the Joint Comprehensive Plan of Action nuclear deal in January 2016 (Johnson 2016). And both rely on the free flow of oil from the Strait of Malacca, the shortest sea route between Middle East suppliers and Asian consumers. Malaysia, one of the strait's three littoral states, has competing claims with China in the nearby South China Sea (Deutsch and Sterling 2016). Additionally, Chinese bilateral ties with Indonesia, another littoral state, are deteriorating over tensions stemming from Chinese maritime claims that overlap with Indonesia's offshore exclusive economic zone (Economist 2016a). Japan and Korea import approximately 6.7 million b/d combined, or nearly 7 percent of total global oil demand (EIA 2015d, 2015e). Dependence on these geopolitically risky chokepoints leaves both countries vulnerable to supply shortages in the short term or higher transport prices if a major disruption forces them to buy scarce supply from more distant producers.

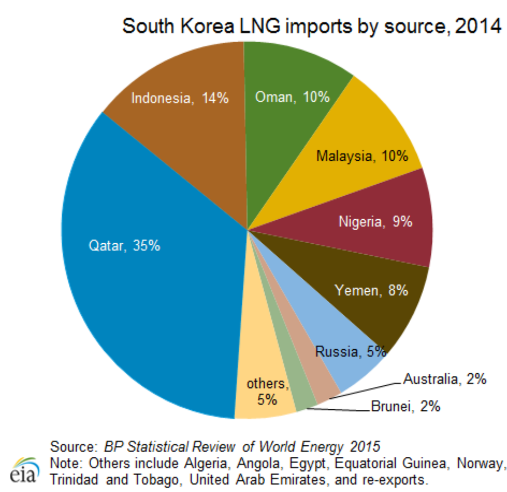
Both Korea and Japan have therefore enrolled state-owned firms to engage in overseas oil and gas projects to help maintain access to stable sources of supply. This has brought about particular difficulties in Korea. The Korean National Oil Corporation and Korea Gas Corporation are selling off their stakes in foreign projects amid allegations of corruption, heavy losses incurred by overseas investment projects, and government efforts to cut the debt-to-equity ratios in state-owned energy companies (Lee 2014). On the positive side, the repeal of the U.S. crude oil export ban in December 2015 promotes liquidity in global oil markets and offers an opportunity for Korea and Japan to diversify their sources of supply. Korea has carried out exemplary efforts to attract private sector investment to build and maintain a world-class refining infrastructure. Refining capacity currently totals nearly 3 million b/d, and major private sector actors include Hyundai and GS Caltex (EIA 2015d). This has enabled Korea to become one of Asia's exporters of refined products, with other U.S. allies and partners, such as Japan, as buyers.

Japan and Korea are, respectively, the world's first- and second-largest importers of LNG. Both have access to several suppliers, reflecting the status of their domestic consumers of LNG as well capitalized and credit worthy (see Figures 1.6 and 1.7). Japan especially enjoys significant supply diversity: it has contracted considerable volumes outside the Middle East and is a major Australian client. Yet both countries are still major clients of Qatar, which transits LNG through the Strait of Hormuz, and rely on the Strait of Malacca as a transit route for their supplies from both the Gulf and Africa. Qatar provided nearly one-third of the world's LNG supply in 2015 (International Gas Union 2015). Both countries expect to benefit from the availability of U.S. LNG exports, which will increase the diversity of their LNG supply. Korean Gas signed a contract in 2012 to purchase 3.5 million mt/year over a 20-year period from Cheniere's Sabine Pass project, which began exports in 2016 (Klump and Katakey 2012). Tokyo Gas and other Japanese firms have signed contracts to purchase gas from Dominion Resources' Cove Point LNG terminal, which is expected to be completed in 2017 (Humber 2012). For this terminal in particular, the completion of the new, wider Panama Canal makes purchasing gas from such a distant supplier affordable.

Like Canada, Australia, and New Zealand, Korea seeks to make its energy infrastructure more resilient against disasters through an integrated approach comprising all relevant economic sectors. Planning is carried out largely through Korea's National Comprehensive Plan on Climate Change Adaptation 2009–2030 and shorter-term climate change adaptation plans forged every 5 years (Ministry of Environment 2015). Efforts include deploying technologies and best practices to make energy infrastructure more physically resilient and developing better early warning systems to maximize disaster preparedness (Myeong n.d.). In 2014, Japan issued its first Strategic Energy Plan after the 2011 earthquake (Agency for Natural Resources and Energy 2014). The plan includes attention to strengthening safety and resilience by building a multilayered and diversified energy demand-supply structure, reinforcing hydrocarbons storage systems infrastructure, and enhancing the disaster response capabilities of refineries, service stations, and other mid- and downstream facilities. Public and private sector resilience spending in Japan includes infrastructure hardening and promoting renewable energy-fueled distributed generation systems to alleviate dependence on centralized power infrastructure. Spending totaled $210 billion in 2013 and is expected to increase further in the coming years (DeWit 2016).

Figures 1.6 and 1.7. LNG imports by source, Japan and South Korea





Both Korea and Japan also impose gasoline taxes. Levies are equivalent to just over $2.50 per gallon, higher than the U.S. gasoline tax but somewhat lower than similar taxes levied in Europe (DOE 2011a). Gasoline demand in Korea is expected to reach around 77 million barrels in 2016, an increase from 73.5 million barrels in 2015 (Lee 2015). Demand for gasoline has declined in Japan, largely because of the country's aging population and status as a global leader in fuel economy standards (Inajima and Suzuki 2015). To determine its fuel economy standards, Japan's Ministry of Economy, Trade, and Industry (METI) employs the "Top Runner" program, in which standards are determined on the basis of the most fuel-efficient vehicle in each weight class. This approach, coupled with financial incentives offered to manufacturers, has allowed Japan to set some of the world's most ambitious fuel efficiency standards (ICCT and Diesel Net 2013). Japan met its 2015 regulatory targets by 2010 and is now pursuing its 2020 target, which stipulates an average across vehicle classes of around 48 mpg—a 24.1 percent efficiency increase from the 2010 standard and far above U.S. standards (ICCT and Diesel Net 2013). Korea is also strengthening its own fuel efficiency standards. Korean measures required new passenger cars to achieve 39 mpg by 2015. This threshold is being raised to 56 mpg by 2020. A separate 2020 target of 33 mpg is in place for light-duty commercial vehicles (Kim and Miller 2015).

Japan deserves particular mention for its success in leveraging its urban character and exceptional population density (around 348 people per square km of land area, versus only 35 in the United States) (World Bank n.d.a) to build and maintain arguably the best passenger rail infrastructure in the world. This helps keep consumer fuel demand down and provides alternative transportation in the case of a fuel shortage. Of the 29.9 billion total domestic transport passengers carried on public transit in Japan for FY 2013, a remarkable 23.6 billion trips relied on passenger rail (Statistics Bureau of Japan 2015). The country's rail transportation network is also privatized to a degree not seen elsewhere in the world. The government privatized Japanese National Railways in 1987 and later privatized Tokyo Metro. Although some lines are still owned by the government or receive subsidies, most operators of Japan's passenger railway infrastructure turn a profit on their own while providing reliable, world-class service (Smith 2011).

Beyond the transportation sector, Korea and Japan deploy a variety of incentives to encourage renewable energy development throughout their entire economies. Renewables' contributions to Korea's total energy supply have long been quite low. The country has a 10 percent target for renewables' share in electricity generation by 2024 (IEA 2016c). The government replaced a previous feed-in tariff mechanism with a renewable portfolio standard (RPS) in 2012, and in 2015 it began implementing a cap-and-trade system (Connick 2014). Japan has taken the opposite approach. It replaced its RPS with a feed-in tariff in 2012, obligating electric power companies to purchase electricity generated from renewable energy sources on a fixed-period contract at a fixed price. The added costs are carried by consumers through a national surcharge. Purchase prices are revised annually (IEA 2016b). This policy, intended in part to increase the share of renewables in the energy mix following the Fukushima disaster, has worked: installed solar capacity in Japan increased from 4.9 GW in 2011 to 35.4 GW in 2015 (BP 2016).

Extensive data regarding the Japanese and Korean energy sectors are widely available. Although both countries lack a strong upstream sector, data outlining their expected future demand and volume of imports inform both government-led energy security planning and efforts by global oil and gas exporters to seal long-term export arrangements. Japan's METI, among the most well-resourced government agencies in the country, publishes regular reports on the sources and volumes of Japan's energy imports and the average price of LNG imported into the country at spot prices, among other topics. Japan's well-respected Institute of Energy Economics offers both an extensive statistical database available only to members and numerous public reports on matters such as Japanese gas supply security (IEEJ n.d.a, n.d.b). The Korean government's Korean Statistical Information Service (KOSIS n.d.) publishes comparable data at a similar scale. Furthermore, the Korea Economic Institute of America (n.d.) conducts analyses of the country's energy sector. Much of this reporting is available in English and can be shared with the United States and other IEA partners.

Japan's INDC calls for a GHG emissions reduction of 26 percent below 2013 levels by 2030. The INDC offers a specific target for methane emissions, stipulating a 12.3 percent reduction within the timeline of Japan's broader commitment (Government of Japan n.d.). Korea's INDC indicates a plan to reduce GHG emissions by 37 percent from business-as-usual levels by 2030. This target factors in all of the country's economic sectors (Government of Korea n.d.).

D. Additional U.S. National Security Objectives in the Context of Allies and Partners

The "shale revolution" has strengthened the collective energy security of the United States and its allies and partners, in a manner consistent with the G-7 Energy Security Core Principles. For example, diversion of LNG cargoes bound for the U.S. to international markets combined with U.S. companies' initiation of LNG exports and, separately, the rescinding of the crude oil export ban support the development of flexible, transparent, and competitive energy markets and the diversification of energy fuels, sources, and routes. These efforts are also consistent with U.S. national security interests of keeping European and Asian allies and partners free from political coercion stemming from reliance on certain fuel suppliers.

In addition, the energy security of U.S. allies and partners is enhanced by new approaches in diplomatic and military spheres that reflect the multifaceted objectives explicated by the G-7 principles. Specific policies led by the United States are described below.

i. Maintaining Strategic Reserves

Among the most important components of U.S. support for IEA is the continued holding of strategic reserves pursuant to the Co-ordinated Emergency Response Measures (CERM), which provide a means of response to both actual and imminent supply disruptions. U.S. government-held crude stocks, held in the Strategic Petroleum Reserve facilities near the Gulf of Mexico, currently total 695 million barrels and equate to 148 days of domestic import cover.[18] The importance of global strategic reserves has increased because holders of global spare capacity have largely boosted oil production and reduced their spare capacity available in the event of a supply disruption. However, as non-OECD oil demand increases, IEA reserves will provide for progressively less global demand cover. IEA, bolstered by U.S. leadership, is therefore exploring greater collaboration with non-IEA holders of strategic reserves, namely China and India. In 2014, DOE signed a memo of understanding with China to support their development of a Chinese SPR (DOE 2014b), and have since been actively cooperating on SPR-related issues (DOE 2015a). Although

[18] Continually updated data on the SPR, including revisions to the figures cited here, are available from DOE at http://www.spr.DOE.gov/dir/dir.html and http://energy.gov/fe/services/petroleum-reserves/strategic-petroleum-reserve/spr-quick-facts-and-faqs.

reliable data on non-OECD oil stocks are not available, some analysts have estimated that China has doubled the size of its strategic petroleum reserve between November 2014 and mid-2015 to 190 million barrels (about 1 month of Chinese oil imports) and that China will add another 70 million to 90 million more barrels by the end of 2016 (Rose and Aizhu 2015). Some private analysts suggest that China's strategic reserves might be significantly higher. India is also building a strategic reserve that will provide it with 40 days of import cover (Business Standard 2016). IEA engagement includes work to enhance data collection for the strategic reserves of both countries and potential future integration of their reserves into the CERM. Its work to increase the transparency of non-OECD petroleum stocks is a high priority and will improve global energy security.

ii. Fostering Cooperation through Multilateral Organizations

The United States supports energy security cooperation efforts through preeminent multilateral engagements, including G-7 conferences and gatherings of the Asia-Pacific Economic Cooperation (APEC) forum. Consistent with the aforementioned G-7 Core Energy Principles, developed in 2014, the G-7 format includes meetings of member state energy ministers. Recent communiqués indicate ongoing work on several priorities, including developing energy vulnerability assessments that focus on security of supply in the electric power sector, marshaling IEA resources to help develop options to strengthen the resilience and flexibility of gas markets, combating cyber threats, and lending support to vulnerable countries such as Ukraine (G-7 2016b). APEC's engagement infrastructure, like the G-7's, includes an energy component. Its Energy Working Group focuses on strengthening member states' energy security, lowering regional carbon intensity, and supporting both increased information and data exchanges and joint R&D programs. APEC's benchmark goals include doubling the share of renewables in member states' aggregate energy mix by 2030, and reducing the group's energy intensity by 45 percent from 2005 levels by 2035 (APEC n.d.). In addition to these forums and separate bilateral energy cooperation efforts carried out worldwide, the United States engages on global energy collaboration through several other mechanisms. These include the G-20, the U.S.-China Strategic and Economic Dialogue, the North America Leaders' Summit and meetings of the North American energy ministers, the Summit of the Americas, the Energy and Climate Partnership of the Americas, the U.S.-EU Energy Council, and the U.S.-Africa Energy Ministerial.

iii. Helping Emerging Producers Link to Global Markets

U.S. efforts to help oil and gas producers build links to the global market are best illustrated by Washington's long-standing engagement in the Caspian. The United States has consistently focused on promoting regional pipelines and infrastructure while supporting the efforts of suppliers such as Azerbaijan, Kazakhstan, and Turkmenistan to use this infrastructure to export energy to Europe (Goldwyn 2014). The completion of the BTC oil pipeline in 2006 marks the most successful outcome of this policy thus far and has allowed both Azerbaijan and Kazakhstan to diversify Europe's sources of oil supply. With respect to natural gas, the Southern Corridor is a long-standing U.S.-supported effort to bring large volumes of Azerbaijan's Caspian Sea gas to European markets. In June 2015, work began to expand the South Caucasus pipeline, the first leg of the corridor, which transports gas from Azerbaijan to the Georgia-Turkey border. The second leg, the Trans-Anatolian pipeline, will provide Azeri gas for Turkish domestic use while transporting the remaining volumes to the Turkey-Greece border; construction began in March 2015. The final leg, the Trans-Adriatic pipeline, will move gas to Italy for purchase by other European off-takers; construction is scheduled to begin in 2016 (EIA 2015h). The United States is committed to supporting completion of the Southern Corridor and helping ensure that the Trans-Adriatic pipeline will begin transiting Azeri gas to the heart of Europe by 2020 as scheduled. This will further contribute to security of supply on the European continent.

Chapter 2: Energy Security Policy in the Electric Power Sector

I. Introduction: Electricity as National Security Asset

The U.S. power sector is a vast, complex, and interconnected machine that provides just-in-time delivery of power through the use of more than 7,700 operating power plants that generate electricity from a variety of primary energy sources. The system includes 707,000 miles of high-voltage transmission lines, 55,800 substations, 6.5 million miles of local distribution lines, and 3,300 providers who deliver electricity to 147 million customers. The value of the electricity supply chain from fuel to generation to transmission to distribution is estimated at about $1 trillion. The U.S. electricity grid is an impressive engineering feat, hailed as the supreme engineering achievement of the 20th century by the National Academy of Engineering.

Electricity is essential for supporting and sustaining nearly every sector of the modern economy, ranging from industrial output to emergency services to national security. And because electricity cannot be stored at scale, unlike oil or natural gas, the economy is dependent on both the generation of electricity and the transmission and distribution of electricity to end users. A secure, reliable electric power sector is necessary for economic growth, public safety, societal well-being, and proper functioning of critical infrastructure, including national security, defense, lifeline networks, transportation, communications, water, and sewage. 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 Department of Homeland Security lists five basic missions in its 2014 Quadrennial Homeland Security Review, three of which directly relate to the electricity system and other critical infrastructures sectors that depend on electricity. 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. (CNA 2015)

The critical components of the U.S. economy are increasingly converging, sharing resources and engaging in synergistic interactions through common architectures (see Figure 2.1). For example:

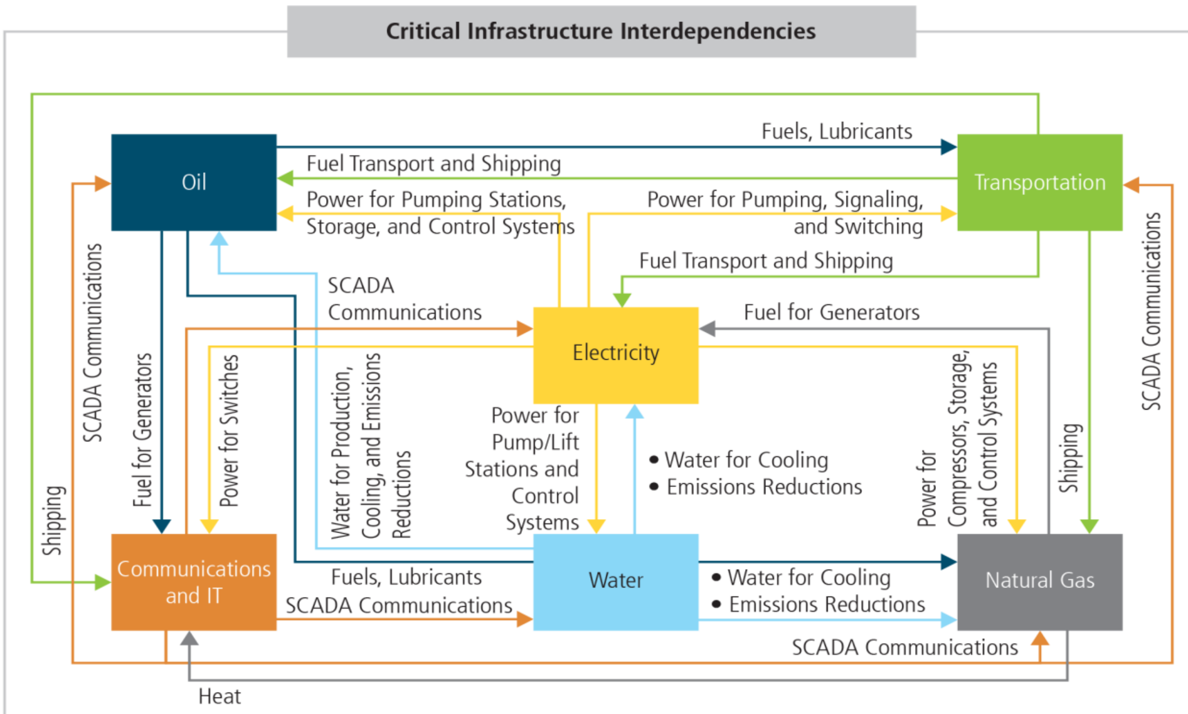
- The oil and gas sectors rely heavily on electricity for production, refining, and distribution to end users. In addition, in the first half of 2016, natural gas was the largest source of primary fuel for electricity generation in the United States.
- The transportation sector depends on electricity for signaling, switching, and increasingly transportation through electric vehicles.
- Water and wastewater treatment and distribution currently consume roughly 4 percent of U.S. annual electricity generation (DOE 2006).
- Information and communications technology (ICT) have been identified by the Department of Homeland Security as critical infrastructure because it provides an enabling function across all other critical infrastructure sectors. In addition, ICT is critical for electricity grid management and communications between customers and various electricity generating assets.
- The financial sector drives the economy and depends heavily on the electricity sector and ICT for security, financial transactions, and communications between parties.

The interdependence of key sectors of the economy and the essential role of electricity are illustrated by two recent weather emergencies. First, 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 (FERC and NERC 2011). As a second example, after Superstorm Sandy in 2012, utilities and the public experienced massive power outages in the Northeast. At the same time, recovery crews were hampered by failures of communications systems that were almost entirely dependent on electricity; back-up systems generally stopped providing power 72 hours to 96 hours after being triggered.

Thus prolonged electricity outages represent a threat to national security and the economy. Moreover, electricity infrastructure and supply chains extend across state and international boundaries, connecting the electricity security of the United States with that of U.S. allies and partners. Even where there are no direct electric power connections, such as with allies and partners in Europe and Asia, cyberattacks and threats to electricity supply chains affect the security of the United States. The increasing recognition of the critical nature of electricity to the U.S. economy has made it the subject of the second installment of the QER.

For the United States, as well as our allies and partners, the electric power sector is rapidly evolving in ways that affect its security. Some changes have resulted in improvements to the energy security of the system: electricity markets have become more liquid, transparent, and competitive and electricity generation has increasingly shifted to clean energy sources such as wind and solar. Other trends have created new vulnerabilities and prompted changes in how the electric power sector operates to maintain energy security, such as new technologies for electricity generation and distribution, migration away from traditional models of baseload generation, and distributed energy resources. In addition, growing threats from severe weather, emerging cyber and physical attacks, and aging infrastructure have increased the vulnerability of the electric power sector. To add to the complexity of managing these changes, the electric power sector is managed by multiple government levels and agencies, spanning federal, state, local, and tribal levels, all of which exercise some amount of jurisdictional authority and oversight.

Figure 2.1. Critical Infrastructure Interdependencies



Source: **Finster et al. 2016; DOE 2017**

Note: The financial services sector (not pictured) is also a critical infrastructure with interdependencies across other major sectors supporting the U.S. economy.

The following sections assess the energy security of the United States, its partners, and allies in six categories and describe some of the policies that address these vulnerabilities. Those categories are taken from the text of the legislation requesting this report—the Fixing America's Surface Transportation (FAST) Act (Public Law 114-94)—and represent the full breadth of energy security principles adopted in 2014 by the energy ministers of the Group of Seven.

Energy security can be considered in relation to those categories as follows:

Energy supply diversity and resiliency. Energy security is improved by having sufficient diversity in the fuels used to generate electricity, routes used to deliver fuels to generators, and location of generators that produce electricity. Each provides a buffer against disruptions that might affect a particular type of fuel or geographic area, such as weather events or terrorist activities.

National security objectives. Energy security is improved in the electric power sector when the probability of experiencing an outage is reduced and when any outages that do occur are short, with minimal damage to society and the sector.

Well-functioning and competitive energy markets. Energy security is improved when agents in the market have limited market power and electricity markets are liquid and transparent.

Consumers and the economy. Energy security is improved when high or volatile electricity prices have a limited effect on consumer spending and thus GDP; this occurs when electricity consumers have the ability to reduce electricity consumption in the face of high prices or maintain spending in the face of electricity outages.

Environmental considerations. Energy security is improved when electricity can be generated without posing a threat to the environment, from either higher emissions of greenhouse gases (GHGs) or other risks, such as other air or water pollution or seismic activity.

United States trade balance. The United States trade balance does not directly impact the security of the U.S. power sector. However, the United States trades electricity with both Canada and Mexico in order to provide economic and reliability benefits to all countries. The effect of these energy flows can affect energy security, but do so through an effect on U.S. GDP, resiliency and reliability, and national security, which are discussed in their respective categories.

II. Defining and Assessing Electricity Security in the United States

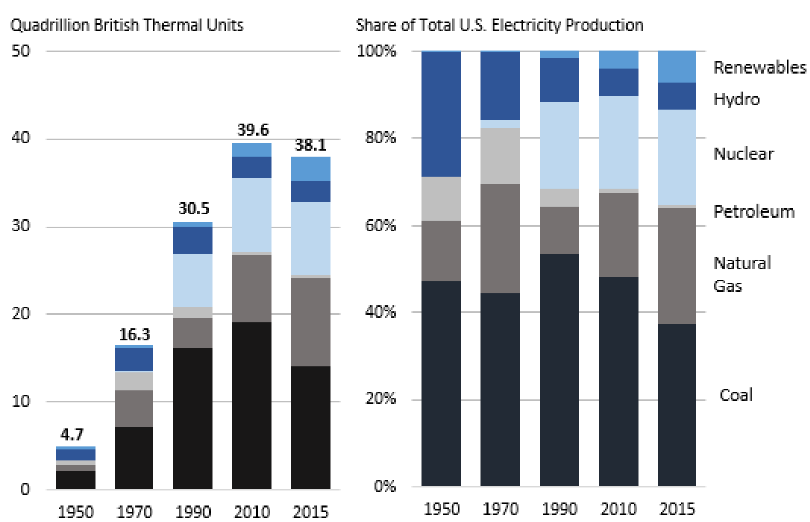
The electric power sector in the United States is rapidly evolving in ways that affect the energy security of the system. This section considers those changes and future trends within the context of the G-7 energy security principles. Some such changes have resulted in improvements in the energy security of the system: the electric power sector has become more competitive over the past several decades, electricity markets have become more liquid and transparent, and electricity generation has increasingly shifted to renewable sources such as hydro, wind, and solar, all of which reduce greenhouse gas emissions. Other trends, such as the migration away from traditional models of baseload generation, have prompted changes in how the electric power sector operates to maintain energy security. These changes and related policies are discussed below and provide a snapshot of the current state of energy security for the electric power sector.

A. Energy Supply Diversity and Resiliency

Fuel and supply diversity is important to the energy security of the electric power sector. Diversity in the fuels used to generate electricity provides a buffer against disruptions that might affect any particular type of fuel; disruptions could occur with respect to fuel production or transport to the generators. Diversity in the location of generators that supply electricity provides a buffer against disruptions that might affect a particular geographic area, such as from weather or terrorist attacks.

On a national scale, the electric power sector in the United States has historically been highly diversified in terms of types of fuel and generation location. Particular regions of the country can be less diversified than the nation as a whole, but all regions generate electricity using multiple fuel sources. Since at least 1950, coal has generated the largest share of electricity, followed by natural gas, oil, nuclear, and renewables, but not always in that order (see Figure 2.2). The use of oil to generate electricity has mostly been eliminated because of the high cost of oil compared with other fuel sources. Coal generation has decreased because of market pressures stemming from low natural gas prices and concerns about pollution from coal combustion. Conversely, electricity generation from natural gas and wind has increased substantially because of lower natural gas costs, tax incentives, and greater environmental benefits. In April 2015, natural gas surpassed coal as the largest generator of electricity in the United States for the first time. In the foreseeable future, most new electric generating facilities are expected to be solar, natural gas, and wind (EIA 2016i).

Figure 2.2. Historical energy consumption in the United States, 1950–2015

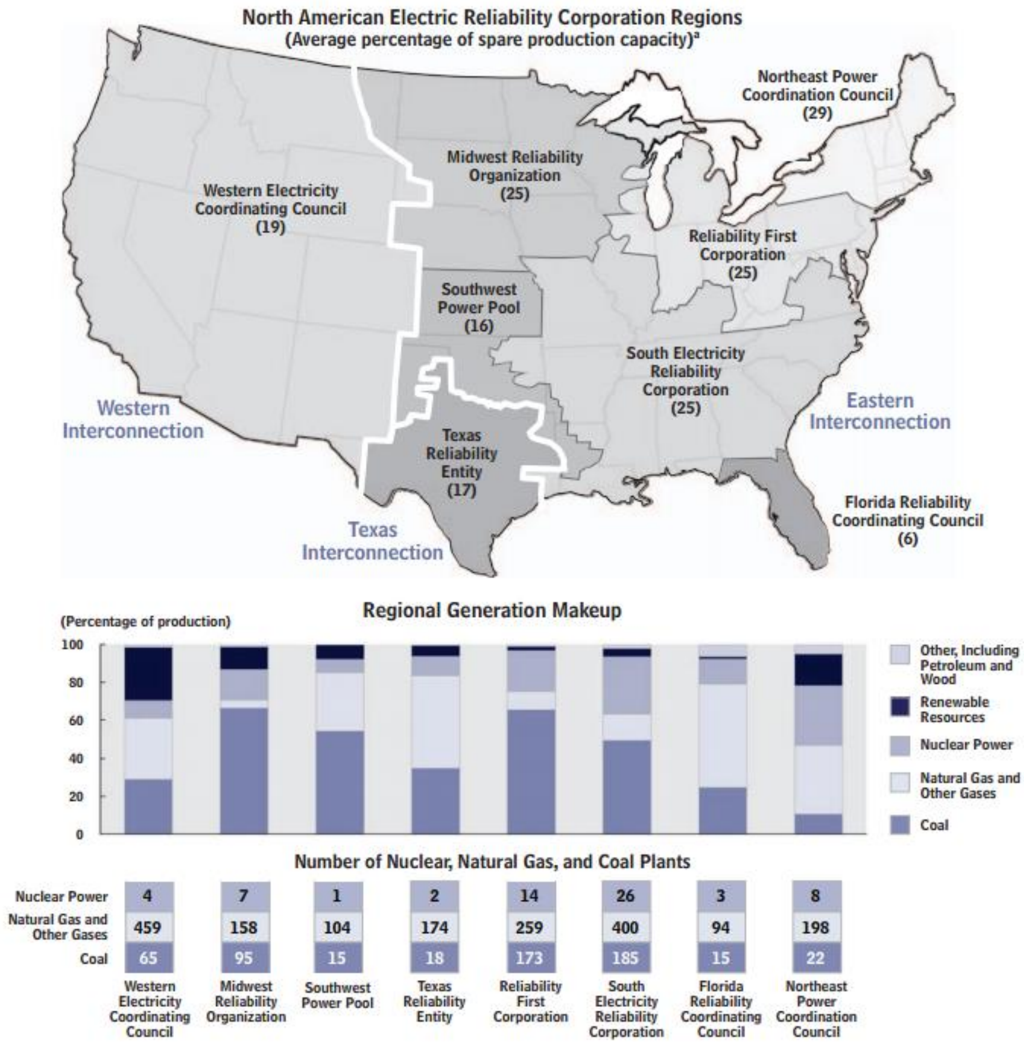


***Source*: EIA (2016a)**

Note: "Renewables" includes wind, solar, biomass, and geothermal sources, with hydro as a separate category. Electricity imports are not included.

With respect to geographic diversity, all regions of the United States have access to electricity generation from each of the dominant types of generating units (see Figure 2.3). Some parts of the country have a natural advantage for particular types of generation; for example, electricity generation from solar represents a greater share of total generation in the western United States, and generation from wind is greatest in the plains states and Texas.

Figure 2.3. The electric power sector in the United States, 2009



***Source*: CBO (2012)**

Note: The number of plants in each NERC region is approximate, because the number of plants is provided on a statewide basis, and NERC boundaries do not coincide with statewide boundaries.

[a] Spare production capacity is as reported to EIA.

This diversity in fuels and supply of generation reduces but does not eliminate the likelihood that a disruption could create an electricity outage. The concentration of a particular type of generating units in a region of the country can create a greater risk of electricity outages during disruptions that affect that region or the fuels it relies on more heavily. Further diversification of electricity fuels or supplies can reduce the risk of outage and thus improve energy security, but only to the extent that potential disruptions associated with the new fuels or generating locations are uncorrelated with existing fuels and generating locations. It is also possible that new fuels or generating locations could reduce energy security if they lowered U.S. performance in another area affecting energy security, such as increasing GHG emissions.

i. Energy Security Challenges for Different Fuel Types

Different energy security challenges are associated with each of the major fuel types.

a. Coal Fuel Production

In 2015, about a third of electricity generated in the United States came from coal. The production of coal, from both underground and surface mines, in the United States steadily increased from the 1960s to a high of 1.17 billion short tons in 2008. Since then, coal production has declined because of the economic recession in the late 2000s, lingering economic slowdown, and decreases in coal-based electricity generation. Total U.S. coal production estimates for 2016 are around 726 million short tons (EIA 2016g).

Coal is transported from mines and processing plants to consumers by rail, which represents nearly 70 percent of coal deliveries in the United States (EIA 2016f), as well as by barge, ship, and truck. Although the potential exists for rail strikes or other rail outages to disrupt coal transport across the United States, redundancy in the rail system largely ameliorates those concerns. In addition, the high cost of coal transport relative to production creates an incentive to locate coal-fired power plants near mines. To comply with the Acid Rain Program of the Clean Air Act, however, a large quantity of low-sulfur coal from the western United States is transported by rail to coal-fired generators in the East. Coal can be stored on-site in open areas; in 2015, the average coal stockpiles held by electric power plants ranged between 75 and 100 days of consumption (EIA 2016c).

The energy security challenges associated with coal are primarily associated with mining, GHG and other emissions during its combustion, and the management of coal ash. Various policies, laws, and regulations across the Federal, state, and tribal landscape govern standards for worker safety, operations, and environmental protection in the coal sector. The main Federal regulation related to coal production is the Surface Mining Control and Reclamation Act (SMCRA), which was enacted in 1977 and is administered by the Office of Surface Mining Reclamation and Enforcement at the Department of the Interior (DOI) (Pub. L. 95-87, Aug. 3, 1977). Regulation of worker safety issues is done by the Mine Safety and Health Administration at the Department of Labor. Emissions from coal-fired generators are regulated by the Environmental Protection Agency, as discussed in more detail below.

b. Natural Gas Fuel Production

Between 2010 and 2015, the share of electricity generated by natural gas grew from 20 to 33 percent, surpassing coal's share for the first time. The United States has the world's fifth-largest proven reserves of natural gas (BP 2016). New technologies for producing natural gas including hydraulic fracturing, or fracking, and horizontal drilling contributed to increased domestic production—from 18 to 27 trillion cubic feet (tcf) between 2005 and

2015 (EIA 2016g, 2016i)—and the expansion of one of the most liquid natural gas markets in the world at Henry Hub. As increases in domestic production outpaced growth in demand, the United States began to import less natural gas and export more. In 2015, the United States imported 2.7 tcf of gas, mostly from Canada, and exported 1.8 tcf of natural gas, mostly to Mexico (EIA 2016j, 2016k). Since 2010, U.S. gas exports have more than doubled.

The U.S. natural gas system is a highly-integrated transmission and distribution grid consisting of more than 300,000 miles of pipelines that can transport gas to and from nearly any location in the Lower 48 states. That network, however, does not eliminate the concern that natural gas availability could be limited to gas-fired power plants during extreme weather events or other types of disruptions, as described in Chapter 1.

The majority of gas is piped to processing plants and then to underground storage facilities throughout the United States. In 2015, the United States had 385 reported natural gas storage facilities with roughly 4.66 Tcf of designed capacity. Most existing storage facilities are depleted natural gas or oil fields that are close to consumption centers (EIA 2015c). But unlike coal and nuclear generators, these storage facilities are rarely located on the site of a natural gas–fired generator. Thus, gas tends to be delivered as a just-in-time fuel source. Most new natural gas–fired generation facilities are being built near the major natural gas production areas, which lowers the cost of building means of transport but does not eliminate concerns about just-in-time delivery.

As was evidenced by the large release of natural gas at Aliso Canyon in 2016, these underground storage facilities can pose a concern to the energy security of the United States. The leak was caused by damage to a well casing about 500 feet underground; it released about 5.4 billion cubic feet of natural gas and involved the venting of about 94,000 metric tons of methane, a GHG (CA DOC 2015; Lattanzio and Parfomak 2016). It also represented the loss of significant storage capacity for use in the winter, when natural gas is a dominant fuel used for heating.

c. Nuclear Fuel Production

The United States is the world's largest producer of nuclear power, accounting for more than 30 percent of global generating capacity (NEI 2016b; WNA 2016). Since 1990, U.S. nuclear capacity has remained roughly constant, at 100,000 megawatts (MW), with incremental retirements and additions mostly canceling each other out. Scheduled closures between 2016 and 2025 will result in the loss of more than 8,000 MW of capacity; scheduled additions in that same time frame are over 5,000 MW of capacity.

The use of nuclear power to generate electricity can have both positive and negative implications for energy security. Nuclear power does not produce GHG emissions, which suggests that along that dimension, the use of nuclear power improves the energy security of the United States compared with the use of coal or even natural gas to generate electricity. Conversely, the United States must import most of the uranium and rare earths used to fuel and operate nuclear reactors, with a significant amount coming from Russia and China.

In addition, nuclear power in the United States has implications for national security, which extend beyond the scope of energy security. The presence of nuclear energy in the United States enables the U.S. government to play a global leadership role in the management of nuclear material for use in energy production and nonproliferation of nuclear fuels for use in weapons. Conversely, the long-term storage of spent nuclear fuel rods represents an environmental and national security concern.

In 2015, operators of U.S. nuclear power reactors purchased 57 million pounds of uranium, of which 96 percent was imported into the United States. About half, 47 percent, came from Australia and Canada. More than a third, 37 percent, originated in Russia, Kazakhstan, and Uzbekistan, and 10 percent came from countries in Eastern Europe and Africa. With respect to rare earth materials, the lithium isotope Li-7 is used to stabilize the pH in pressurized water reactors. There are currently only two suppliers of Li-7, one in Russia and the other in China. In 2015, the plant in China was down for maintenance, which created a potential shortage of Li-7 and potentially limited the operational ability of some reactors. The Department of Energy (DOE) is currently investigating alternatives to Li-7 for reactor operation.

For domestic mining of uranium ore, policies and regulations depend on the extraction methods and facilities employed. For conventional mining, DOI's Office of Surface Mining Reclamation and Enforcement and related individual state agencies are responsible for regulatory activities. Once the uranium ore undergoes chemical treatment and further processing, regulatory authority moves to the Nuclear Regulatory Commission (NRC), which also has import licensing authority for all nuclear materials and fuels.

Spent nuclear waste represents another energy security issue. The Nuclear Waste Policy Act of 1982 requires DOE to develop a permanent geologic repository for spent nuclear waste to protect public health, safety, and the environment (GAO 2009). According to the NRC, two methods are acceptable for storing spent fuel after it is removed from the reactor core: (1) spent fuel pools at the reactor sites, designed specifically for the fuel and facility; and (2) dry cask storage, also onsite. Pools currently account for 78 percent of spent fuel storage; dry cask storage is generally used when pool capacity is reached. These are considered only temporary storage options for spent fuel, but the Federal Government has yet to develop a long-term solution (GAO 2013). As the amount of spent fuel rises, the pools are becoming increasingly full, leading to concerns that they may release large amounts of radiation in the event of an accident, despite the small probability of such accidents. Further, many of the sites where nuclear waste is stored are near large populations or major water sources, or both, and take up land that could be used for other purposes.

d. Renewables and Hydropower

In 2015, 6 percent of the electricity generated in the United States was from hydropower and 7 percent from other renewables, including wind, biomass, geothermal, and solar. Wind and solar energy represents the fastest-growing sources of renewable generation, with significant capacity additions each year since 2009 (EIA 2016e). Forty states currently maintain utility-scale (>100 kilowatts) wind energy projects totaling 8.6 gigawatts (GW). States with the greatest wind potential include Texas, Iowa, California, Oklahoma, and Kansas.

One concern for energy security is that wind generation and electricity consumption often are not co-located, which necessitates high-voltage transmission lines to move the generated electricity from wind turbines to population centers. The development of new transmission lines to carry power from wind farms to the grid represents a significant challenge. Other energy security considerations associated with expanded reliance on renewables include the intermittency of wind and solar resources (discussed more below) and the importance of rare earth materials for the operation of renewable generating units.

ii. Policies That Affect Fuel Diversity

Fuel diversity in the power sector for different regions of the country is mostly a function of the dynamics of regional energy markets and the availability of fuels and other resources, but some Federal and state policies influence the portfolio of fuels consumed and resulting power generation technologies. A variety of policies that create financial incentives for a particular types of generation, such as the renewable portfolio standard, renewable investment and production tax credits, and nuclear loan guarantee programs, are discussed in more detail in Section II.E.

A standard for fuel diversity for electric utilities was put in place under the Energy Policy Act of 2005 (EPAct 2005), which amended the Public Utility Regulatory Policies Act (PURPA) of 1978 by including a “Fuel Sources” standard under Section 111(d)(12). The standard states:

> Each electric utility shall develop a plan to minimize dependence on 1 fuel source and to ensure that the electric energy it sells to consumers is generated using a diverse range of fuels and technologies, including renewable technologies.
> (Pub. L. No. 109–58, Aug. 8, 2005)

Concerns have recently been expressed by the U.S. utilities, utility commissions, and regulators about the growing reliance on natural gas and the corresponding effect on fuel diversity in the U.S. grid (NERC 2014b, 2016b). Although the country as a whole still maintains significant diversity, some regions of the United States are becoming increasingly dependent on natural gas. For example, grid operators and utilities in the Northeast have experienced new builds of natural gas generators and recent retirements of large coal and nuclear generators. As discussed by NERC (2016b), the traditional balancing of natural gas demands for power generation and other sectors that occurs in the winter months is likely to happen more frequently over the course of the year as the power sector share of natural gas fuel increases.

B. National Security Objectives

A reliable and stable electric power sector is essential for a thriving economy, public safety, and the proper functioning of many vital sectors, including transportation, communications, water, and sewage. 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 Department of Defense (DOD), for example, is the largest customer of the electric grid in the United

States and uses electricity to execute its mission essential functions. DOD's reliance on commercial power presents many of the same challenges faced by all electricity customers: the transmission system is highly vulnerable to weather-related damage, natural disasters such as earthquakes, and physical attacks; electricity substations are vulnerable to cyber and physical attacks, as well as to geomagnetic storms; the distribution system is highly vulnerable to weather, and natural disasters, and control centers are vulnerable to cyber and physical attacks. While the electric grid in the United States is one of the most reliable in the world, it still experiences significant, unexpected power outages. An estimated 679 widespread outages occurred from 2003-2012, with costs averaging $25-$70 billion per year (Executive Office of the President 2013). In 2015 alone, DOD facilities experienced approximately 127 outages that lasted 8 hours or longer, caused by an equal combination of weather and equipment failure (DOD 2015).

As a result, the reliability and resilience of the electric power sector represent a national and energy security priority. For the purposes of this discussion, these terms are defined as follows:

- ***Reliability*.** The ability of the electric power sector to provide a stable source of electricity to consumers, both households and businesses, under normal operating conditions.
- ***Resilience.*** The ability of the electric power sector to withstand and recover from any disruptions created by extreme weather, cyberattack, terrorism, or other unanticipated event.

i. Reliability: Future Trends and Policies

The electricity grid is a complex network of transmission and distribution systems connecting numerous geographically dispersed electricity generating resources to many end users over a large geographic footprint. The National Academy of Engineering describes the electricity grid as one of the great engineering achievements of the 20th century.

Reliable electricity supply requires coordination over a range of time frames and layers of the electricity system. Since large amounts of electricity cannot be efficiently stored, the maintenance of reliability requires the continuous matching of supply (generation output) and demand (consumption) while honoring network limitations. Reliability can be threatened when any portion of the production and delivery chain is disrupted. The high-voltage grid must also be operated such that the quality (voltage, frequency, and waveform distortions within acceptable ranges) of electricity is maintained for normal conditions and credible contingencies without loss of load. Finally, the supply of individual customers depends on the integrity of lower-voltage distribution networks. Despite periodic high-profile reliability events, such as the Northeast blackout of 2003 and the California electricity crisis of 2001, the most supply interruptions to individual consumers are small-scale disruptions of distribution service due to storm damage, vegetation, animal encounters, or other relatively mundane events. As a result, U.S. customers experience an average of 1.5 to 2 power interruptions each year and go without electricity for 2 to 8 hours. Rural customers tend to be exposed to more frequent and prolonged outages than urban customers (Rouse and Kelly 2011).

The most critical need for coordination is in the short term. When electricity systems experience an imbalance of supply and consumption, the frequency of the system will deviate from a nominal level. Large frequency excursions can automatically shed load, damage equipment, degrade load performance, and interfere with system protection schemes, which may ultimately lead to system collapse. In this way, localized imbalances, if not dealt with promptly and properly, can lead to cascading, regional outages. Restoration from such outages would typically be on the order of hours to days in extreme circumstances. This interconnected reliance of individual electrical control areas on the operational practices of their neighbors necessitates regional standardization, coordination, and oversight of the operation of electricity systems in real time. Complex control and protection systems are employed to ensure that the near exact amount of generation required to meet demand at all times is available to keep the frequency within an acceptable range. Further, the delivery capacity of the grid must be adequate to stably deliver the generated electric power and energy to all the loads at all times, including during the outage of any given element.

Maintaining short-term supply-demand balance requires long-term planning to ensure adequate generation and network capacity. Supply and delivery infrastructure enhancements can require relatively long lead times of five years or more, and thus grid infrastructure must be planned years in advance to meet forecast needs. Because resource capacity shortfalls are relatively predictable (e.g., during a heat wave), they can usually be managed without risk of cascading outages. However, shortfalls can require the curtailment of consumer load, through either agreed-upon demand-response arrangements or the occasional involuntary load curtailment, to ensure that demand does not exceed available supply.

Electricity supply, production as well as delivery, is well secured for all expected single contingencies (N-1) and very high-probability double contingencies (N-2). The infrastructure is also designed to be operated such that the impact of extreme contingencies is localized and will not cause wide area cascading outages. This means that each electricity control area is required to operate its system so that it can recover from the loss of its single largest source of supply or transmission within minutes in a manner that does not threaten the operational integrity of its neighboring systems.

a. Emerging Reliability Trends

Over the past decade, several trends have emerged that have required changes in how the electricity system maintains reliability. One such trend is an increased reliance on critical materials for the production, transmission, or storage of electricity (see Appendix B for a discussion of critical materials). These trends are currently being addressed in ways that maintain an adequate level of reliability and stakeholders are engaged in a process of considering how to employ appropriate operational protocol to maintain future reliability as these trends continue.

Renewable generation. The high penetration of renewable generation as a source of power presents new challenges. First, the variability of wind and solar generation can result in volatility of supply from these sources; conventional sources must make up any difference between supply from renewable sources and demand. To the extent that large amounts of renewable generation are co-located and subject to the same weather conditions, these swings in the need for conventional generation can be large. Second, AC power networks are dependent on both real power and reactive power, which is necessary to energize high-voltage transmission facilities while maintaining voltage stability in the system that connects generation to load. Traditionally, both real and reactive power have been supplied by conventional generation sources with a mechanical rotor that rotates in synchronism with the system frequency. Many renewable resources are not programmed to provide reactive power or frequency support. However, the inverters used to condition their output can have this capability included as an integrated feature, and this capability is beginning to be required by regulators, for example, FERC Order 661a (FERC 2005; CAISO 2015).

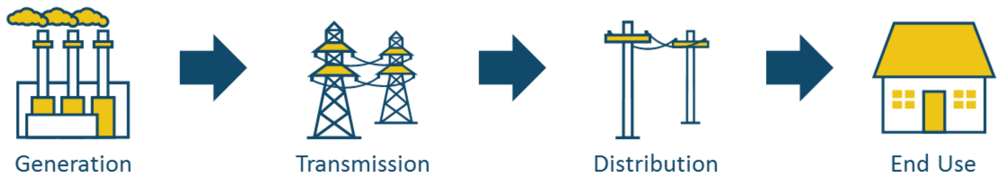
Distributed resources. The deployment of increasing amounts of small-scale renewable generation and other distributed resources in distribution systems is another trend that requires operational changes to maintain reliable operation of low-voltage localized distribution networks. These changes are made complicated by the lack of visibility and control presently achievable with existing infrastructure. For example, under high penetration of distributed solar generation where local generation serves the majority of the load, the transmission network can be extremely lightly loaded, potentially resulting in high-voltage problems. Although voltage levels can be actively managed on high-voltage transmission systems, system operators currently have fewer tools for managing the distribution level. As distributed resources multiply, however, new tools are likely to emerge to manage distribution level reliability.

Two-Way Electricity Flows. The electricity system has historically operated using a one-way flow of electricity and information from power generation to customers. New technologies, including distributed resources, smart grid technology, electricity storage, and consumer applications enable two-way flows in electricity (see Figure 2.4). Although these new technologies allow for increased flexibility, higher system efficiency, reduced energy consumption, and increased consumer options, they also present new challenges and complexity for maintaining reliability of the electric power sector. These developments will necessitate the evolution and development of new reliability metrics and criteria.

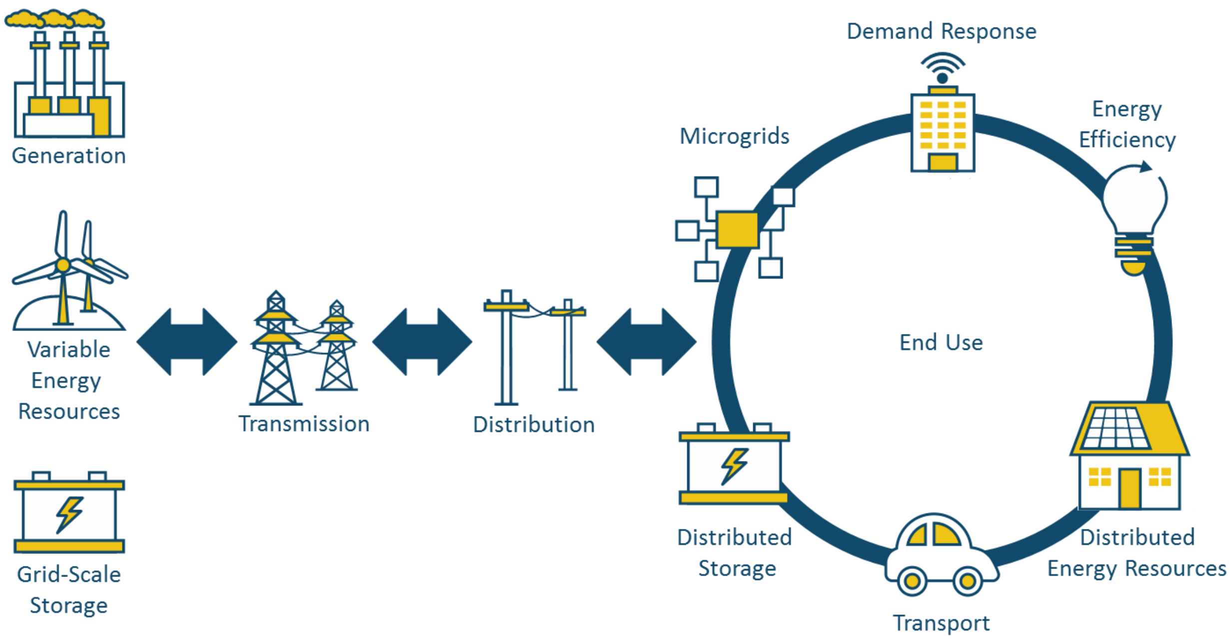
Demand variability. Other factors may also affect variability in demand. Rate incentives, smarter loads, and efficiency improvements all can make forecasting and predicting demand challenging in both long-term planning and operational time frames.

Figure 2.4. Traditional One-Way Flow of Electricity and Emerging 21st Century Two-Way Flow of Electricity

Electricity Supply Chain with Traditional One-Way Flow



Electricity Supply Chain with Emerging 21st Century Two-Way Flow



Source: DOE 2017
Note: Arrows represent power flows

ii. Policies That Affect Reliability

The regulatory framework is fragmented among Federal, state, and sometimes local jurisdictions, such that a single, highly interconnected grid spanning many states is subject to differing jurisdictions. The primary national bodies involved in electricity reliability are the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation.

a. Oversight and Reliability Standards

The Federal Energy Regulatory Commission (FERC) is an independent agency within DOE that regulates the interstate transmission of electricity, as well as natural gas and oil.

Among others, FERC acts under the legal authority of the following Federal laws passed by Congress:

- ***Federal Power Act (FPA).*** Authorizes the regulation of the sale and transportation of electricity (16 U.S.C. § 791a et seq.).
- ***Public Utility Regulatory Policies Act (PURPA).*** Authorizes the establishment of rates and regulatory treatment for cogeneration and small power production facilities (Pub. L. No. 95-617, Nov. 9, 1978).
- ***Energy Policy Act of 1992 (EPAct).*** Creates a category of power producers, called exempt wholesale generators (EWGs), in order to allow utilities to transmit electric power on behalf of others over their own transmission lines and to reduce barriers so additional nonutilities can enter the market (Pub. L. No. 102-486, Oct. 24, 1992).
- ***Energy Policy Act of 2005 (EPAct 2005).*** Authorizes the certification of a national electric reliability organization (ERO) and procedures for establishing mandatory reliability standards. It also authorizes oversight of the reliability of the electricity transmission grid as well as pricing and conduct in electricity markets. (FERC has subsequently certified the North American Electric Reliability Corporation (NERC) as the independent ERO (Pub. L. No. 109–58, Aug. 8, 2005).

NERC is the national entity most responsible for the oversight of standards relating to short-term (operational) reliability in U.S. electricity systems. The interconnected nature of electric power sector makes it necessary to have standards and procedures for operation that ensure individual systems do not negatively affect the reliability of their neighbors. Absent such standards, individual utility control areas could benefit from free riding on the resources of surrounding systems, while also threatening the integrity of those systems. (Prior to 2005, NERC was a voluntary organization designed around self-regulation, but it was reorganized after the 2003 blackout because it was deemed insufficiently authoritative.) NERC and its regional organizations also provide forums in which long-term regional resource planning by individual utilities and system operators can be discussed and coordinated.

NERC develops and enforces mandatory standards for the reliable operation and planning of the bulk power system throughout North America subject to the approval of FERC. It develops reliability standards through an open stakeholder process. After standards are approved by NERC's stakeholders and then its board, NERC files the standards with FERC and the Canadian provinces. FERC can approve or remand the standards, and it can direct NERC to address a particular subject. Significantly, FERC cannot write the standards.

Most enforcement is done by NERC, with FERC oversight. FERC also has authority to enforce without NERC, but such cases have been infrequent. Penalties for violations are authorized up to $1 million per day. The key reliability standards include those for balancing resources and demand in real time; transmission planning; interconnection operations, involving real-time oversight by about 15 utilities monitoring the operations of multiple utilities in a region; and transmission operations. A key principle of these standards is to plan and operate the grid so that it will remain stable even after a contingency, such as the sudden loss of a generating facility. The enforceable standards in place address various aspects of grid planning, facilities design and maintenance, and operation as grouped in various areas. Following is a brief overview of some of the NERC reliability standards:

- ***Transmission planning (TPL).*** Specifies transmission planning requirements for ensuring the bulk system will operate reliably for future forecast scenarios across normal and credible contingency conditions.
- ***Protection and control (PRC).*** Specifies protection and control performance requirements to ensure operational reliability of the bulk system.
- ***Critical infrastructure protection (CIP).*** Specifies requirements for identifying and protecting critical electric power sector infrastructure across a broad range of potential threats.
- ***Generation and load balancing (BAL).*** Specifies performance requirements for ensuring system frequency remains with acceptable ranges as supply resources balance supply in real time.
- ***Transmission operation (TOP).*** Specifies requirements to ensure that the transmission system is scheduled, operated, and monitored to ensure operational reliability.
- ***Interconnection reliability operations and coordination (IRO).*** Specifies coordination requirements to ensure operational reliability across regions of the interconnected power system.
- ***Emergency preparedness and operations (EPO).*** Specifies requirements to ensure a return to reliable operation as efficiently as possible after wide-area system disturbances.

Many areas are outside of FERC's jurisdictional responsibility and are dealt with by state public utility commissions. Areas considered outside of FERC's responsibility include the following:

- regulation of retail electricity sales to consumers;
- approval for the physical construction of electric generation facilities;
- regulation of activities of the municipal power systems, Federal power marketing administrations such as Bonneville Power Administration, and most rural electric cooperatives;[19]
- regulation of nuclear power plants (which are regulated by the NRC); and
- resolution of reliability problems related to failures of local distribution facilities.

b. Increased Reliability through Market Design

Due in part to emerging trends within the power system and their effect on electricity market operation, many independent system operators (ISOs) and regional transmission organizations (RTOs) have implemented or proposed changes to the design of their electricity markets to address concerns with reliability and efficiency. These design changes, some of which have been required by FERC, have been proposed with the

[19] Many such entities still follow reliability standards even though they are not mandatory standards as they are for FERC jurisdictional entities.

intention of improving short-term economic efficiency in the production and delivery of reliable electric power, supporting long-term economic efficiency and entry and exit of resources, ensuring fair and equal treatment of all market participants, and ensuring adaptability to new resources or new electric reliability needs based on changing conditions. Table 2.1 shows a few of these design changes in various regions.

Table 2.1. Changes to electricity market operation and design

Market Design Change	Description	Regions
Introduction of new flexible ramp products	With increased variability and uncertainty, resources are being asked to ramp up and down more frequently. This new market product is to ensure enough resources are available to provide needed ramp, put a price on providing that ramp, and incentivize resources to do so.	MISO, CAISO
Prices during shortage conditions	Because of the greater potential of lowering energy prices due to variable energy resources (VER) and low natural gas prices, ERCOT, an energy-only market, has introduced an operating reserve demand curve that provides a price adder to the energy price that depends on the systems risk level. Other areas have something similar, but with lower caps and only when the system is short on minimum reserve requirement.	ERCOT
Pay for performance regulation	Because of the large increase in energy storage, most of the ISOs, through FERC Order 755, have implemented new rules that can allow for limited energy storage resources to provide regulation, an ancillary service, to the system.	All
Pricing during demand-response deployments	With increased demand response, the ISOs have been evaluating the most efficient way to set the energy price when demand-response resources are called on to provide energy.	ISO-NE, ERCOT, MISO, NYISO
Market expansion	Some regions have added new utility areas to their system to increase benefits of diversity of VER, provide for greater competition, and reduce costs overall.	CAISO, MISO, SPP
Alignment of day-ahead electricity markets with natural gas markets	With FERC Order 809, a number of markets have proposed adjusting the closing time of their day-ahead electricity market so that it aligns with natural gas markets. This will ensure that the two markets are more aligned and natural gas resources can more efficiently bid quantities and costs within each market.	PJM, MISO, SPP
Offer flexibility	Resources can now have the ability to change their offer costs, particularly when the cost of fuel increases throughout the day. This better aligns the	PJM, ISO-NE

	market with actual costs, mostly to assist with changing natural gas costs for natural gas units.	
Capacity performance products	Because of some of the higher risk and outage levels of resources during polar vortex conditions, some regions have put strict performance rules in their capacity market to ensure that those resources can guarantee delivery of energy during both summer and winter high-risk periods.	PJM, ISO-NE

Note: MISO = Midcontinent ISO; CAISO = California ISO; ERCOT = Electric Reliability Council of Texas; ISO-NE = ISO New England; NYISO = New York ISO; SPP = Southwest Power Pool; PJM = Pennsylvania–New Jersey–Maryland Interconnection

c. Federal Funding Priorities

In addition to the adaptation and enforcement of known operational standards and best practices, there is a Federal role in the development of the next generation of technologies and practices needed to help maintain reliability, given the trends faced today by electricity systems. DOE supports the Grid Modernization Initiative (GMI) program, which represents a comprehensive effort to help shape the future of the electric grid. One objective is to solve the challenges of integrating conventional and renewable sources with energy storage and smart buildings, while ensuring that the grid is resilient and secure enough to withstand growing cybersecurity and climate challenges. Through this program, DOE will frame new grid architecture design elements, develop new planning and real-time operation platforms, provide metrics and analytics to improve grid performance, and enhance government and industry capabilities for designing the infrastructure and regulatory models needed for successful grid modernization.

As part of the GMI, in January 2016, DOE announced funding of up to $220 million over three years for DOE's National Labs and partners to set up the Grid Modernization Laboratory Consortium (GMLC), which will support critical research and development in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas. Research areas of specific interest funded under the GMLC include cybersecurity, transformer spare assessment methods, integration of renewables and emerging distributed resources, and advanced real-time operational reliability assessment tools.

To enhance the reliability for DOD, nearly all DOD facilities maintain on-site backup generation capabilities. As of 2011, these facilities relied heavily on diesel generators to support the continuity of operations during short-term outages, with enough fuel on-site to sustain basic installation functions and critical missions for 3-7 days. The number and type of generators are based on the number of people, the size of the installation, and the type of services each installation provides, among other factors. Furthermore, as part of the National Response Framework, and the Defense Production Act, DOD facilities may be considered critical assets and thus there may exist processes to ensure the prioritization, protection, and restoration of these installations during emergencies. To further enhance its energy resiliency, DOD is pursuing increased use of renewable energy. Roughly 2 percent of DOD total energy consumption came from renewable sources in FY2015.

iii. Resilience: Future Trends and Policies

While the goal of *reliable* electricity supply seeks to minimize the number and scope of electricity service interruptions, the goal of a *resilient* system is to ensure quick recovery from and minimize damages caused by events that do occur. Over the past several decades, as a consequence of various natural and human-caused events, widespread outages have resulted in high societal costs, ranging from structural damage and prolonged outages to operational impacts and resource constraints, in some cases amounting to hundreds of millions of dollars (EPRI 2016b). Although utilities have been addressing safety and reliability for decades, the need to build additional resilience and redundancy into their infrastructure investments reflects a more recent trend. Keogh and Cody (2013) note a lack of standardized metrics and approaches to evaluate resilience, pointing out that existing frameworks for reliability investments are not well suited for large-scale and historically unprecedented hazards. Traditional deterministic planning processes do not provide an investment decision framework that allows for consideration of traditional reliability investments alongside resilience investments. Such a framework is needed to illuminate the potential relative costs and benefits of investments that may serve to meet multiple needs.

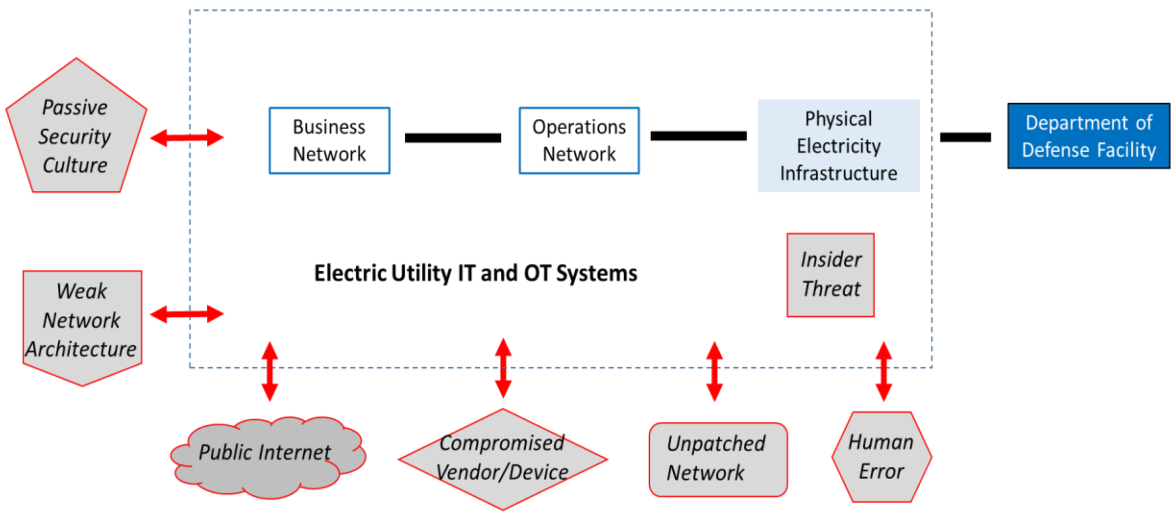
a. Emerging Trends That Affect Resilience

The growing interconnectedness of the electric power sector has increased the exposure of large sections of the grid to events that might induce an outage. At the same time, that vulnerability has increased as a result of the growth in severity, likelihood, and interconnectedness of potential threats. Climate change is contributing to rising sea levels and an increase in the frequency and severity of extreme weather events (Melillo et al. 2014). Planners are also tasked with addressing rising potential threats of individual or state-sponsored physical and cyberattacks. These growing threats have placed resilience in the spotlight for the electric power industry.

In recent years, concerns have risen over the potential for wide-area electrical outages resulting from geomagnetic disturbances, coordinated physical or cyberattacks, or exposure to an electromagnetic pulse resulting from detonation of a high-altitude nuclear device. (Cyberattacks also represent a threat and are discussed further below.) Resilience is also threatened by extreme weather events, such as heatwaves, drought, hurricanes, and floods. If a widespread outage occurs from one of these causes, the restoration of service could be slow relative to conventional electrical outages, taking many hours to several days or even weeks. Although such events fall outside of traditional reliability planning for electricity systems, their potential high damage has resulted in emerging evaluation and mitigation efforts, and in some cases standards. These potential threats represent an escalation in the frequency or intensity of potential problems that have been of concern to, but not a primary focus of, electricity system planners. They include the following:

- **Sophisticated cyberattacks.** Cyberattacks in the electricity sector are executed in many forms, ranging from surveillance to theft to service disruptions. Publicly available information on domestic and global cyberattacks in 2016 demonstrate the growing frequency of attacks and increased sophistication of the attackers. As one example, in December 2015, three of Ukraine’s regional electricity distribution companies experienced simultaneous cyberattacks 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. As a second example, in late October, the Mirai botnet leveraged a network of 100,000 Internet devices to overwhelm the critical IT systems of a single internet firm in the United States (Dyn 2016). (A botnet is an interconnected network of computers infected with malware and controlled by cybercriminals). This was the largest recorded distributed denial of service attack in history. The result was a disruption of service to broad swaths of the internet across Europe and North America. As the electric industry increasingly incorporates information technology system into its operations, the power grid becomes increasingly exposed to a variety of cyberattack vectors (see Figure 2.5). As a result, NERC instituted a series of CIP cyber security reliability standards. These standards address identifying vulnerable components and developing strategies for enhancing their security, training of personnel, planning for cybersecurity response and recovery efforts, among many others.

Figure 2.5. Example Cyberattack Vectors for an Electric Utility



Source: **ICS_CERT 2016**

Notes: 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.

- ***Coordinated physical attack.*** A coordinated physical attack has the potential for sustained damage to critical system components and may simultaneously incapacitate several grid components, rendering the system vulnerable to widespread cascading outages. As a result, NERC instituted a standard (CIP 014) to require identification and protection of critical transmission facilities that, if attacked, could result in uncontrolled cascading outages. Accordingly, efforts are under way to identify critical grid components in order to design mitigation measures. The goal of the efforts is reduce the likelihood that long-term unavailability of a limited number of critical system components would equate to long-term electrical outage across a widespread area from a cascading event.

- ***Geomagnetic disturbance (GMD).*** Coronal mass ejections (CMEs) can cause changes in the earth's magnetic field, resulting in electric fields that induce low-frequency currents in the power system. The flow of these geomagnetically induced currents (GIC) in power transformers during an extreme (100-year storm) is likely to cause widespread voltage collapse (blackouts) due to a spike in reactive power demand that will be difficult to meet. How this can affect the bulk power system was demonstrated on March 13, 1989, when a severe GMD event caused the collapse of the Hydro Quebec system. During this event, a single transformer in the northeastern United States failed because of thermal damage caused by GIC, but a large number of such transformer failures are unlikely in an extreme storm because voltage collapse would likely occur before overheating would damage the transformers. The actual thermal susceptibility of power transformers to varying GIC levels is still being studied; research to date does not indicate widespread transformer failure during GMD events. Although electrical outages would still be widespread in the 100-year extreme storm, restoration from such an outage would probably be of the same duration as cascading electrical events.

- ***High-altitude electromagnetic pulse (HEMP).*** A high-altitude detonation of a nuclear weapon generates an electromagnetic pulse (EMP) that can affect the bulk power system over a wide area. HEMP has three components, known as E1, E2, and E3. E1 is an extremely fast rising and high energy pulse that can result in damage to electronic components. E2 has characteristics similar to those of lightning, but since it is preceded by the E1 pulse and it covers a wide area, more study is required of this phenomenon. Because of its lower field strength and existing lightning protection measures, E2 is not expected to cause damage to transmission assets. E3 is similar to an extreme GMD event except that the pulse is more intense but lasts only a few minutes instead of hours. But a strong enough pulse will cause voltage collapse in only a few minutes.

- ***Intentional electromagnetic interference (IEMI).*** Intentional electromagnetic interference (IEMI) differs from HEMP in two main ways: IEMI weapons generate only an E1 pulse, and the effects would be geographically limited to a single substation or control center. The EMP created by an IEMI weapon can be very intense, and some weapon designs can generate pulses that exceed HEMP levels in both amplitude and rise time. However, because the weapon footprint is very limited, a large coordinated attack would be required to significantly affect the bulk power system.

- ***Extreme weather events.*** Extreme weather events, especially hurricanes, are the primary cause of damage to electric transmission and distribution infrastructure and the leading cause of power outages. Hurricanes and nor'easters are particularly destructive due to high winds, intense precipitation and coastal flooding associated with storm surges. At times, grid operations and system reliability are also challenged by unusual weather patterns such as extreme temperatures during spring and fall. The increased severity and frequency of extreme weather events over the recent past has been the principal contributor to an observed increase in the duration of U.S. power outages between 2000 and 2012 (Larsen et al. 2015). Climate change is projected to continue causing an increase in the frequency and intensity of various types of extreme weather events (DOE 2015).

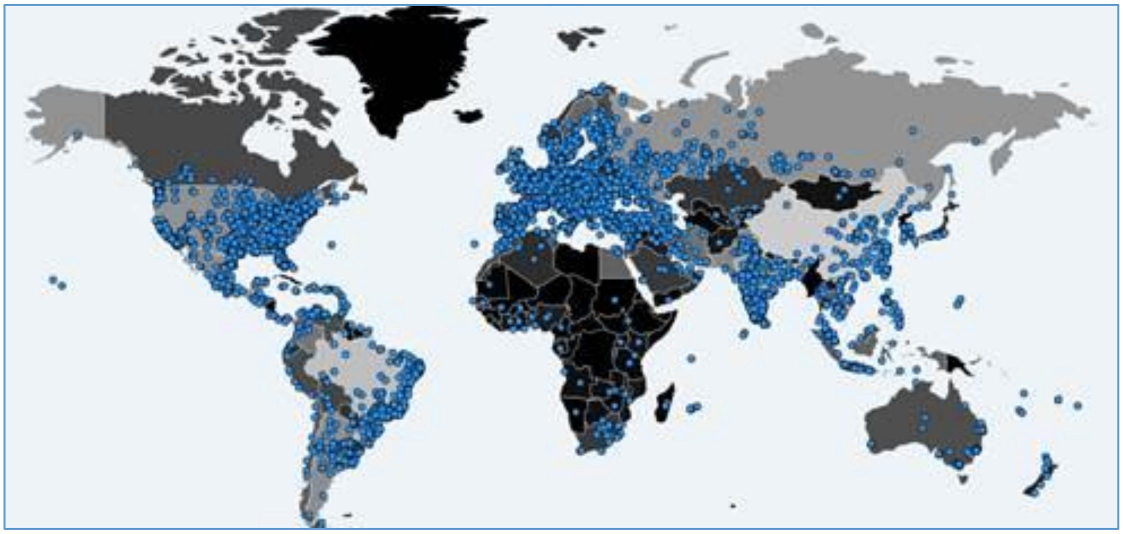
Many of these threats to electricity system resilience can be countered or mitigated by investments from electric power companies and distribution utilities. But these organizations and their regulators have struggled with the question of whether the benefits of such investments justify the increases to utility rate bases necessary to fund them. With respect to resilience upgrades associated with storm hardening and extreme weather, EEI (2014) has documented the challenge faced by utilities. Although recovery of capital investments and operational expenses has traditionally been considered in the context of general rate cases, rate base additions have not proved to be a reliable approach to cost recovery for storm response expenses. The EEI report details a number of recent cases and suggests that possible explanations include overall increasing costs and unpredictability of storm events.

For example, Superstorm Sandy in October 2012 was one of the most destructive storms to hit the Northeast region and cost dozens of lives, in addition to power outages for over a million electric customers. In response, Public Service Enterprise Group (PSE&G) requested approval to invest $2.6 billon to harden its system against severe weather, of which $1.2 billion was approved by the New Jersey Board of Public Utilities. To support this request, analysis by the Brattle Group assumed "another Sandy" (i.e., the same event exposure in terms of flood extent, outage length, and number of customers) and evaluated a portfolio of investments based on number of hours of lost load avoided and a value of lost load estimate (Zarakas et al. 2014). In the neighboring state of New York, Fazio and Strell (2014) describe the experience of the Consolidated Edison Company (ConEd). ConEd's rate case proceeding for post-Sandy settlement, which originally failed in 2013, was later approved with the inclusion of an order to conduct a climate change vulnerability study, "Storm Hardening and Resiliency Collaborative Report" (ConEd 2013).

b. Emerging Cybersecurity Trends

The nation's power system consists of both legacy and next-generation technologies. New grid technologies are introducing millions of novel, intelligent components to the electric grid that communicate in much more advanced ways (e.g., two-way, wired, and wireless communications) than in the past. Cybersecurity is important because the bidirectional flow of two-way communication and the control capabilities in the modernized grid enable an array of new functionalities and applications. With this new functionality comes new threats, including cybersecurity threats. The October 2016 Mirai botnet attack provides just one example of the reach of these internet connected devices (see Figure 2.6)

Figure 2.6. October 21, 2016: The Mirai botnet Hack Had Global Reach



Source: Malware Tech 2016

To enable society to take advantage of the new technology and maintain grid reliability and resilience, these threats must be addressed. These new components will operate in conjunction with legacy equipment that may be several decades old and provides no cybersecurity controls. Traditional information technology (IT) devices typically have a lifespan of 3 to 5 years. In contrast, operational technology (OT) devices can have a lifespan of 40 years or longer. Addressing potential cybersecurity events is a challenge with this constantly changing IT and threat environment.

With the increase in the use of digital devices and more advanced communications and IT, the overall attack surface has increased. For example, substations are modernized with new equipment that is digital, rather than analog. These new devices include commercially available operating systems, protocols, and applications as alternatives to proprietary solutions that are specific to the electric power sector. Many of the commercially available solutions have known vulnerabilities that could be exploited when they are installed in control system components. Potential impacts from a cyber event include billing errors, brownouts or blackouts, personal injury or loss of life, operational strain during a disaster recovery situation, and physical damage to power equipment.

Another change is the convergence of IT and OT. Historically, IT has included computer systems, applications, communications technology, and software to store, retrieve, transmit, and process data, typically for a business or enterprise. OT has focused on physical equipment-oriented technology that is commonly used to operate the energy sector. Currently, multiple groups and operators often independently gather and analyze information from isolated and stovepiped systems that have been developed to provide security monitoring for physical, enterprise, and control system environments. As the threat landscape has evolved, there is a greater need to have a coordinated view of all aspects of an organization's security posture (i.e., situational awareness) and events (both unintentional, such as a component failure, and malicious) that may affect an organization's security posture and responses to those events.

iv. Policies That Affect Resilience and Cybersecurity

Many policies have been issued that are designed to increase resilience or reduce cybersecurity threats. Some of the more important are described in this section.

a. Electricity Infrastructure Security

The Fixing America's Surface Transportation (FAST) Act includes several components to improve the security of U.S. energy infrastructure (Pub. L. No. 114-94, Dec. 4, 2015). As part of the FAST Act, FERC and DOE are required to develop and implement processes and tools to protect critical electric infrastructure information (CEII) and to facilitate needed sharing of CEII among stakeholders to ensure security and resilience of energy infrastructure during emergencies. In addition, the FAST Act provides authority for DOE to mandate specific actions to protect energy infrastructure in response to a grid security emergency, as identified by the President.

b. Federal Support for Utilities

DOE's Cybersecurity for Energy Delivery Systems (CEDS) program funds the development of cybersecurity solutions for energy sector asset owners (electric, oil, and gas). The CEDS program focuses on reducing "the risk of energy disruptions due to cyber incidents as well as survive an intentional cyber assault with no loss of critical function." The projects are aligned with five project areas:

- building a culture of security;
- assessing and monitoring risk;
- developing and implementing new protective measures to reduce risk;
- managing incidents; and
- sustaining security improvements.

Other actions taken by the federal government include Executive Order 13744, "Coordinating Efforts to Prepare the Nation for Space Weather Events." The order directs the federal government to take steps to better understand and improve prediction capabilities for space weather (e.g., GMD) that could affect electric utilities in the United States. It also directs a variety of federal agencies to develop plans and actions that would reduce the exposure of critical infrastructure during a credible threat and quickly respond and recovery from such threats. Also addressing GMDs, FERC issued Order 830, which directs utilities to collect data associated GMD events and make that data public.

c. Federal Policies for Improving Climate Resilience

Recognizing the vulnerabilities to the electric power sector posed by climate, the Federal Government has taken a variety of actions to improve the resilience of the power sector. In June 2013, President Obama announced the Climate Action Plan, which identifies activities the United States is taking to prepare for a changing climate, effects of which are already evident across the country. Those include the following:

- ***Executive Order (EO) 13653,*** Preparing the United States for the Impacts of Climate Change (November 2013), directs Federal agencies to take steps to help American communities strengthen their resilience to extreme weather and prepare for other impacts of climate change. EO 13653 also instructs agencies to provide the information, data, and tools that local, state, and private sector leaders need to take timely and informed actions to improve preparedness and resilience in critical systems, including energy systems. EO 13653 also established a short-term task force of state, local, and tribal officials to advise on key actions the Federal Government can take to better support local preparedness and resilience-building efforts. In the fall of 2014, this task force recommended removing barriers to resilient investments, modernizing grant and loan programs, and developing information and tools to better serve communities.
- ***The Council on Climate Preparedness and Resilience*****,** also created by EO 13653, leads the development of national principles for adaptation. The Council is also facilitating development of information, data, and tools for climate change preparedness and resilience to support Federal, regional, state, local, tribal, private sector, and nonprofit sector efforts to prepare for the impacts of climate change.
- ***Presidential Memorandum: Climate Change and National Security*** (September 2016) directs Federal departments and agencies to take action to ensure that climate change-related impacts are fully considered in the development of national security doctrine, policies, and plans.
- ***The U.S. Climate Resilience Toolkit*****,** launched in July 2016, is a website designed to help consumers find and use tools, information, and subject matter expertise to build climate resilience. It is managed by the National Oceanic and Atmospheric Administration and offers information from across the U.S. Federal Government.
- ***Partnership for Energy Sector Resilience*** is an initiative led by DOE to enhance U.S. energy security by improving the resilience of energy infrastructure to extreme weather and climate change impacts. The Partnership is designed to accelerate investment in technologies, practices, and policies that owners and operators of energy assets can use to reduce climate and weather-related vulnerabilities.

d. Cybersecurity Planning

To adequately address potential threat agents and vulnerabilities, cybersecurity must be included in all phases of the system development life cycle, from the design phase through implementation, operations and maintenance, and sunset. Cybersecurity must address deliberate attacks launched by disgruntled employees and nation-states, as well as non-malicious cybersecurity events, such as user errors or incorrect documentation.

To address current and emerging cybersecurity threats and vulnerabilities, utilities, government agencies, academia, research organizations, and vendors are implementing an overall mitigation strategy at the enterprise level. This overall strategy is then tailored to the specific environment—IT, operations technology, and physical security. An Integrated Security Operations Center (ISOC), includes corporate systems, control systems, and physical security. Currently, multiple groups and operators independently gather and analyze information from data centers, substations, networks, and physical security and field equipment. Data are also collected and analyzed from external sources. Correlating this data to find suspicious activity can be extremely challenging and often occurs only long after an incident happened. An ISOC is designed to collect, integrate, and analyze alarms and logs from these traditionally siloed organizations, providing greater situational awareness to the utility's security team. Additionally, an ISOC allows utilities to transition to an intelligence-driven approach to incident management, which is more effective for handling advanced threats.

e. Other Federal Standards and Policies for Addressing Cybersecurity and Resilience

In late 2006, Federal electric reliability standards became mandatory and enforceable in the United States. The NERC Critical Infrastructure Protection (CIP) standards provide a set of compliance-based requirements for the bulk electric system (BES) in North America. These standards are mandatory for generation and transmission systems only. They were developed to provide a minimum set of cybersecurity requirements for electric power utilities in North America. As stated in each standard, "The standards include requirements in support of protecting BES cyber systems from compromise that could lead to misoperation or instability in the BES" (NERC 2016a).

A key additional resource is the Electricity Information Sharing and Analysis Center (E-ISAC). Operated by NERC, E-ISAC gathers information, coordinates incident management, and communicates mitigation strategies related to cybersecurity with public and private stakeholders in the electric power sector. E-ISAC collaborates closely with DOE and the Electricity Subsector Coordinating Council (ESCC), which represents the electric power sector.

Executive Order 13636. On February 12, 2013, the President of the United States issued Executive Order 13636, Improving Critical Infrastructure Cybersecurity.[20] This order identifies specific policy goals for critical infrastructure in the United States as follows:

> It is the policy of the United States to enhance the security and resilience of the Nation's critical infrastructure and to maintain a cyber environment that encourages efficiency, innovation, and economic prosperity while promoting safety, security, business confidentiality, privacy, and civil liberties.

In support of this policy, the order focuses on enhancing cybersecurity in critical infrastructure by improving cybersecurity information sharing and fostering the development and implementation of risk-based standards. As part of this effort, Section 7 of the order requires the Secretary of Commerce to have the director of the National Institute of Standards and Technology (NIST) lead an effort for developing a framework to "reduce cyber risks to critical infrastructure." Version 1.0 of the *Framework for Improving Critical Infrastructure Cybersecurity* was published by NIST in 2014.

Presidential Policy Directive 21. DOE's role in addressing the electricity system as a critical component of national security is growing as the threat landscape has evolved.

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[20] https://www.federalregister.gov/articles/2013/02/19/2013-03915/improving-critical-infrastructure-cybersecurity.

Presidential Policy Directive 21 (PPD21), Critical Infrastructure Security and Resilience,[21] was issued by President Obama on February 12, 2013. The directive seeks to advance "a national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure." This directive is intended to drive the Federal approach to strengthen the security and resilience of the critical infrastructure in accord with three strategic imperatives:

- Refine and clarify functional relationships across the Federal Government to advance the national unity of effort to strengthen critical infrastructure security and resilience.
- Enable effective information exchange by identifying baseline data and systems requirements for the Federal Government.
- Implement an integration and analysis function to inform planning and operations decisions regarding critical infrastructure.

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. The directive also states:

> All Federal department and agency heads are responsible for the identification, prioritization, assessment, remediation, and security of their respective internal critical infrastructure that supports primary mission essential functions. Such infrastructure shall be addressed in the plans and execution of the requirements in the National Continuity Policy.

Based on the above and other verbiage in the directive, a clarification of Federal roles and responsibilities is a major theme, along with improvements in information sharing.

Presidential Policy Directive PPD-41. Presidential Policy Directive PPD-41, United States Cyber Incident Coordination,[22] was issued by President Obama on July 26, 2016. The directive "sets forth principles governing the Federal Government's response to any cyber incident, whether involving government or private sector entities."

In responding to any cyber incident, Federal agencies are required to undertake three concurrent lines of effort: threat response; asset response; and intelligence support and related activities. In addition, when a Federal agency is an affected entity, it shall undertake a fourth concurrent line of effort to manage the effects of the cyber incident on its operations, customers, and workforce.

[21] http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.
[22] https://www.whitehouse.gov/the-press-office/2016/07/26/presidential-policy-directive-united-states-cyber-incident.

In carrying out incident response activities for any cyber incident, the Federal Government will be guided by the following principles:

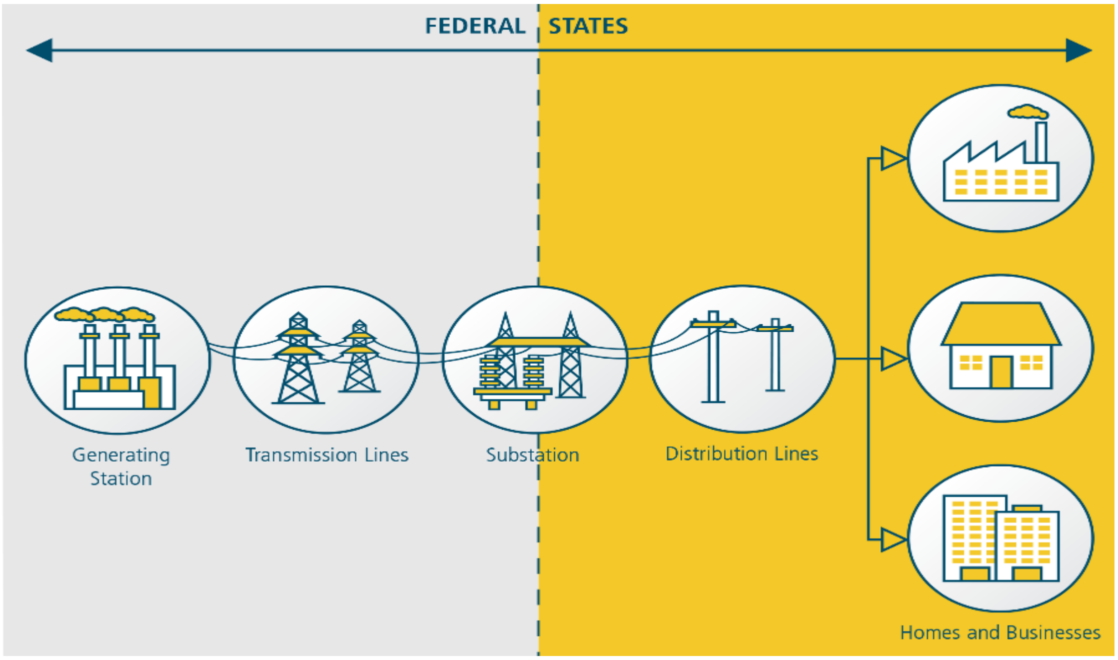
- shared responsibility
- risk-based response
- respecting affecting entities
- unity of government effort
- enabling restoration and recovery

The annex to PPD-41, United States Cyber Incident Coordination Policy, provides further details concerning the Federal Government coordination architecture for significant cyber incidents and prescribes certain implementation tasks. As the designated sector-specific agency for the energy sector, DOE plays a role in all aspects of incident response and ensures response efforts take into account unique characteristics of the energy sector being affected.

FAST Act. In addition to requesting this report, 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." 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. Figure 2.7 clearly illustrates the interconnectedness of the electricity system across existing federal and state jurisdictions; the national security responsibilities included in the FAST Act must be addressed without regard to jurisdictional boundaries.

Figure 2.7. Current Jurisdictional Boundaries and the Security of the Electricity System



Source: Behr and Sobczak 2016

The FAST Act also 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.

C. Well-Functioning and Competitive Electricity Markets

Energy security for electricity markets is improved when agents in the markets have limited market power and electricity prices are transparent. Well-functioning and competitive energy markets allocate available resources efficiently, such that a balance of supply and demand is reached through voluntary transactions rather than involuntary interruptions of service. Over the longer term, more efficient operations should yield prices more reflective of the cost of service, leading to a better alignment of the benefits of electricity consumption with the true costs of providing it.

Since the late 1990s, the U.S. electricity industry has gone through significant restructuring of how wholesale electric energy is bought and sold. Policymakers have pursued the goal of a more open and competitive electric power sector, with the belief that fostering competition can lead to innovation and efficiency improvements and ultimately lower costs (Stoft 2002). However, the reliable operation of an electricity system becomes increasingly complicated as more firms and entities engage in electricity trade. Over two-thirds of U.S. consumers reside within regions where an ISO or RTO directs and oversees system operations to ensure there is efficient and reliable supply of electricity and non-discriminatory incentives for market participants to compete and provide energy and other electric services. ISOs and RTOs are the entities largely responsible for reliability and security of the bulk power system. The pursuit of their mission to ensure broad and open access to the power system while maintaining reliable operations has led to the development of extensive, often complex, design features in wholesale markets for electricity and the many ancillary services required to support reliability and efficiency of the bulk power system. ISOs and related state and regional agencies achieve the dual goals of access and reliability through combinations of market design, resource adequacy policy, and market oversight.

i. Electricity Market Changes

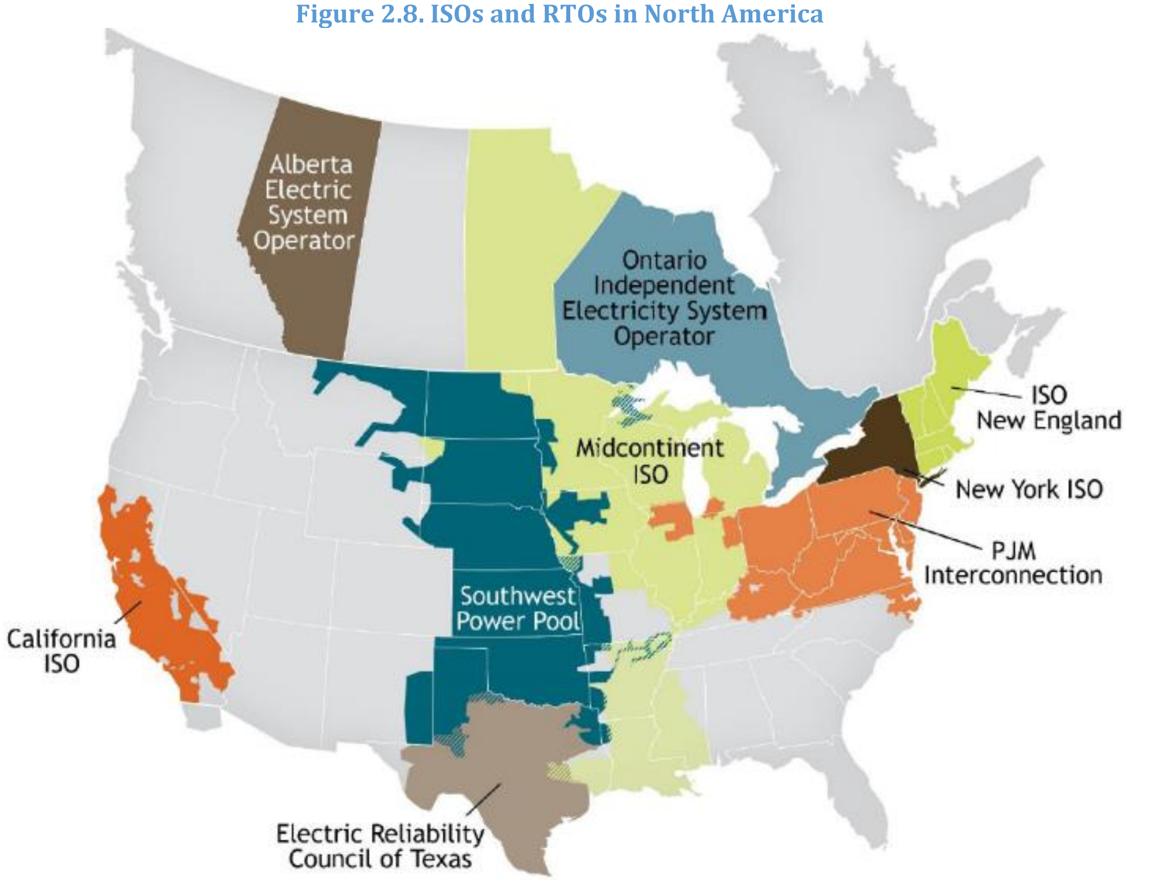
a. Market Design

Numerous standards are enforced on U.S. electricity operators and planners to ensure the reliability of the grid. These include mandatory reliability standards from NERC, as well as regional requirements enforced through regional reliability organizations, state jurisdictions, or the ISOs' reliability requirements themselves. Electricity markets use these reliability and security requirements as a primary design feature in the ways that energy and reliability services are purchased and sold. For example, energy markets ensure that the amount of energy that is purchased and sold will not lead to overloading the transmission system during either normal conditions or N-1 outage conditions. NERC balancing and frequency control standards directly influence the products that are traded in the ancillary service markets.

Seven regional ISOs and RTOs exist in the United States, and two additional ISOs operate in Canada (Figure 2.8). Each of these different markets has unique aspects and even distinct products. However, many features of the markets are fairly well aligned. In all markets, the vast majority of commercial activity occurs outside of ISOs, through bilateral arrangements and other forms of trade, in advance of the daily time frame with which ISOs are primarily concerned. All U.S. ISOs have day-ahead and real-time energy markets, where energy is sold and purchased largely to balance the forward positions reached by market participants over longer time frames. Energy in ISOs is also bought and sold at locational prices, as granular as the generator substation node on the system. These locational prices internalize the congestion costs that any individual transaction imposes on other users of the network. All ISOs also have ancillary service markets, where reserve capacity is held back from selling into the energy market so that it can be used in case of emergencies or for short-term balancing. Finally, all ISOs support mechanisms for hedging locational energy prices, typically through the provision of instruments known as financial transmission rights.

Several key features differ across the ISO regions. Markets differ in the frequency with which they calculate prices and the levels to which those prices can rise during periods of scarcity. As discussed below, these elements can influence incentives for investment. In other cases, different ancillary service definitions or financial products exist (Ela et al. 2011; PJM Interconnection 2015). Numerous other specific details vary from region to region, and different market design initiatives are being sought in each region (EPRI 2016a). These differences are due to the different regulatory environments, dominant supplier technologies or load types, transmission system characteristics, or stakeholder processes.

Figure 2.8. ISOs and RTOs in North America



***Source*: FERC (2016)**

b. Resource Adequacy

Another area in which regions differ is their approach to providing incentives for investment in generation resources. Investments in generation and other supply resources are executed under three different resource adequacy paradigms. Much of the country still executes investments through a process of regulatory planning by utilities overseen by local regulatory authorities. These resources are compensated either under cost-based regulatory principles or through long-term contracts between utilities and nonutility generation.

The energy-only paradigm, prominent internationally, continues to be the foundation for valuing resources in the Electric Reliability Council of Texas (ERCOT) market. Supply resources earn revenues through the sale of energy and ancillary services on day-ahead and real-time markets. During periods of scarcity, prices are permitted to rise thousands of dollars above the operating costs of resources in order to allow for the recovery of capital and other fixed costs.

Outside of ERCOT, supply resources in other U.S. markets operated by regional transmission organizations can earn revenues for the provision of capacity, a product defined by the ability to supply energy during peak conditions. (The enforcement of that provision during peak conditions has only recently come under scrutiny and as a result, some ISOs/RTOs have changed their payment terms for capacity.) Some regions assign resource adequacy requirements to load-serving entities (LSEs), which have the responsibility to either self-supply or procure capacity sufficient to cover their required reserve margins. Other regions operate centralized capacity markets, in which the system operator effectively acquires the capacity and allocates the costs to LSEs. The common thread for all these markets is that there is an explicit or implicit value placed on capacity that creates an additional revenue stream for resources and is distinct from the sales of energy and ancillary services.

Each of these three paradigms has proved capable of supporting investment of generation and other resources. New capacity has been added through each of these channels over the last 15 years.

c. Market Oversight

Although competition can provide incentives for innovation and efficiency improvements, the partial deregulation of sectors of the power industry can also increase the potential for market power and manipulation, which can in turn threaten the efficiency and reliability of electricity systems. Market power can influence reliability directly, when entities attempt to withhold supply from the market, or indirectly, through the creation of financial instability. Reliability events during the California electricity crisis were largely caused by the financial instability of market participants, rather than a shortfall of physical capacity (Joskow 2001). At the same time, the overzealous pursuit of potential market abuse can produce reliability difficulties when it prevents suppliers from fully recovering their actual costs of supply (MMI 2016) or discourages participation in markets out of fear of future liability.

As part of its role as the agency that regulates interstate commerce in electricity, natural gas, and petroleum productions, FERC is the entity with primary responsibility for oversight of the competitiveness of wholesale power markets. The Federal Power Act of 1935 gave FERC the responsibility for ensuring that electricity prices were "just and reasonable" (16 U.S.C. § 791a et seq.). The Energy Policy Act of 2005 further expanded FERC's responsibility into the monitoring of energy trading and reporting. In this capacity, FERC performs several functions, including the following:

- regulation of transmission and wholesale sales of electricity in interstate commerce;
- review of certain mergers and acquisitions and other corporate transactions by electricity companies;

- review of siting applications for electric transmission projects under limited circumstances;
- monitoring and investigating firm behavior and the performance of energy markets; and
- administration of accounting and financial reporting regulations of regulated companies. (Pub. L. No. 109–58, Aug. 8, 2005)

ii. Emerging Trends in Electricity Markets

As the power system goes through substantial changes, new challenges are created for the design and operation of electricity markets. Several trends of emerging technologies, combined with environmental and other policy priorities, are creating new challenges that affect that interface of markets and system reliability.

Large-scale variable energy resources. Most sources of renewable electricity generation are variable energy resources (VER) and their output is characterized as variable, nonsynchronous, and usually uncorrelated with demand. Production-based subsidies for renewable investment combined with the low or zero variable cost of renewable energy can reduce average energy prices, sometimes generating negative prices, such that other resources earn less revenue and over the long-term are unable to support the energy demand and reliability needs of the grid (Ela et al. 2014). The variability of these resources can also increase the volatility of wholesale energy prices (Papalexopoulos et al. 2015). In addition, the widespread integration of VER at both utility scale and distributed across all consumer segments significantly changes the time dimensions in which grid operators must function, complicating operations. It underscores the need "to coordinate time and space within the electric grid at greater resolution or with a higher degree of refinement than in the past" (von Meier 2014). Finally, some types of VER are often located far from demand centers, which increases the need for new mechanisms related to the planning and funding of transmission resources. A recent White House report noted, "The distinctive characteristics of [VERs] will likely require a reimagining of electricity grid management" (2016).

In response to these trends, a greater need for flexibility attributes in other resources has emerged, such as fast response times, quick start-up times, and lower minimum generation levels. These attributes, however, may not be incentivized properly within some electricity market frameworks.

Distributed energy resources. There has been an influx of resources connected directly to the distribution system, referred to as distributed energy resources (DER). These resources may increases challenges associated with distribution reliability forecasting, and control. The wholesale electricity markets may not always allow for small, distributed resources to effectively participate and may not value the locational benefits or costs that DER can create. Some researchers have been looking at the potential to extend the market such that DER have more opportunity to participate (Tabors et al. 2016).

Natural gas. The electricity system has also seen a much greater reliance on natural gas-fired generation. While natural gas has cost, operational, efficiency, and reliability benefits, it also has created some new challenges to electricity market operations. Electricity and natural gas markets are both regulated by FERC. However, these markets were not historically coordinated in a way that could lead to the greatest efficiency. Most notably, during the U.S. "polar vortex" conditions in January 2014, gas delivery constraints, nonfirm contract agreements, and higher-than-normal electricity and gas heating demand led to energy price spikes exceeding $1,000/MWh for several hours (PJM Interconnection 2014). Although these conditions did not lead to any involuntary outages, the system was at a much higher risk of outage than typical (NERC 2014a). These issues led market operators and regulatory agencies to consider improvements required to maintain reliability and efficiency, given the existing high reliance on natural gas resources. Many of these changes have been implemented (see, e.g., PJM Interconnection 2014; CAISO 2016). In several regions, most notably California and New England, limits on the storage of natural gas have created an increasing need for better coordination in the timing and regulation of local gas and electricity operations (CAISO 2016).

New technologies. New battery and other small-scale energy storage technologies are participating in ancillary service markets for various ISOs. Demand response is also becoming more of a player within the electricity markets, particularly by providing capacity. Nontraditional transmission facilities, including controllable high-voltage direct current lines, flexible AC transmission systems, and other power flow control technologies (e.g., distributed series reactors) are becoming more commonplace. These technologies have the potential to provide benefits to energy security, but were not generally considered in the original market design. ISOs/RTOs and their stakeholders are now considering how to incorporate these technologies while maintaining a fair and efficient electricity market that still ensures reliability of the power system.

iii. Policies That Affect Market Operation

The Federal Government has implemented multiple types of policies to improve market competitiveness and operation. One is market oversight, discussed above. Others include enabling third-party access to infrastructure and increasing transparency in data about market fundamentals.

a. Enabling Third-Party Access to Infrastructure

In addition to being responsible for the oversight of pricing practices in electricity markets, FERC has pursued strong regulations and measures to promote access to electricity systems by nonutility generation companies and consumers. FERC Order 888, Promoting Wholesale Competition through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities, was a landmark step in this process. Subsequent orders, such as FERC Order 889, which mandates public posting of available transmission capacity by network operators, have been directed at implementing the spirit of Order 888. These orders represent regulatory efforts to ensure equal access to networks that can remain dominated by a single utility operator by regulating the behavior and responsibilities of vertically integrated operators.

FERC has also pursued efforts, such as Order 2000, to promote institutional changes through the creation of RTOs, under the belief that open access to regional networks is best accomplished by taking operational responsibilities away from dominant integrated firms and agencies.

b. Increasing Transparency in Data about Market Fundamentals

Several Federal agencies, including FERC, the Environmental Protection Agency (EPA), and the Energy Information Administration (EIA), as well as ISOs, promote the goal of open and transparent markets by requiring the reporting and public release of important statistics relating to the status and operation of electricity systems. Relative to other industries, these agencies provide consumers and market participants with a rich wealth of information. These data support and coordinate the planning and investment of individual firms, as well as regional and local governments. In addition, the availability of rich market data has contributed to the extensive study of U.S. energy markets by academics. A broad academic literature in economics and engineering has contributed to the oversight, design, and operation of regional power systems.

As one example of an effort to increase market transparency, in June 2016, FERC issued Order No. 825 that required all RTOs and ISOs to implement sub-hourly settlements, allowing more accurate alignment of the services provided with the prices paid for them. Market rules governing participation of flexible resources, such as hydropower and pumped storage, could be reviewed to determine if additional changes could allow these resources to participate more effectively and ensure just and reasonable compensation.

c. Improving Transparency and Efficiency in Permitting Electricity Infrastructure

The permitting of energy infrastructure in the United States often requires a rigorous analysis of the project by Federal, state, and/or local regulatory agencies; transparency is a major component of that process. The infrastructure system is important for the operation of the entire energy system and the ability of the Nation to access and diversify its energy supply. It also represents a large public investment with significant fiscal, employment, and environmental effects.

Infrastructure that crosses national borders requires a Presidential Permit. The authority to grant Presidential Permits is derived from the constitutional power of the President to conduct foreign relations of the United States. This authority is distinct from the authority granted in certain regulatory statutes to permit facilities used in the import, export, and interstate transportation of energy commodities, including petroleum, petroleum products, natural gas, and electricity, and statutes regulating the importation and exportation of those energy commodities.

Cross-border facilities. Through Executive Order (E.O.) 10485, as amended by E.O. 12038, the President delegated authority to the Secretary of Energy to review applications for cross-border electric transmission facilities. DOE retains and currently exercises the authority to issue Presidential Permits for those facilities.

Commodity imports and exports. Electricity imports are not regulated by Federal statute although informational filings are required by the Energy Information Administration. Authorizations for exports of electricity are issued by the Office of Electricity Delivery and Energy Reliability at DOE pursuant to Section 202(e) of the Federal Power Act. This statute requires DOE to issue an export authorization unless it finds that the proposed transmission of electricity would impair the sufficiency of electric supply within the United States or would impede or tend to impede the coordination in the public interest of facilities, a criterion interpreted primarily as system reliability.

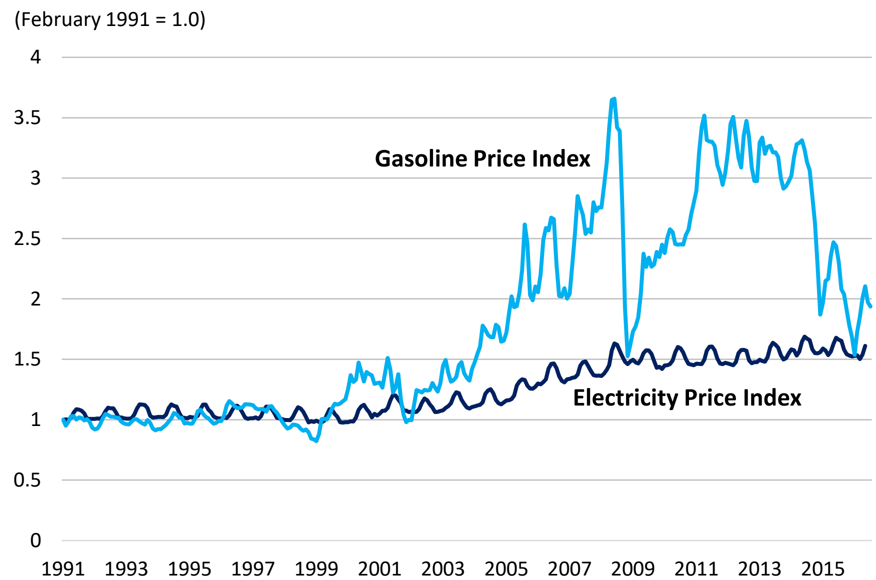
D. Consumers and the Economy

Economic activity is directly affected by the interaction between consumers and the electric power sector. High electricity prices or highly volatile electricity prices cause consumers to shift spending on other goods and services to electricity, which reduces GDP. Energy security is improved when consumers, and thus the economy, are more resilient to disruptions in the power sector. Three approaches have arisen to help consumers reduce their exposure to high electricity prices or electricity outages, all of which are expected to improve energy security: (1) the ability of electricity consumers to quickly respond to prices or other signals from system operators, particularly during the management of physical reliability threats; (2) the ability of energy efficiency to reduce expenditures during periods of high prices or increase the ability of consumers to continue to meet minimal service needs under reduced electricity supply; and (3) the temporary or permanent self-supply of electricity by consumers, which makes them less dependent on the grid.

i. Retail and Wholesale Electricity Prices

Relative to the natural gas and petroleum products industries, retail electricity prices have been remarkably stable over many decades (see Figure 2.9). This stability is a legacy of electric power sector regulation, which emphasizes rate stability as a goal, and it masks the much more volatile cost of supplying electricity apparent in wholesale electricity prices. From the perspective of retail consumers, the price stability facilitates budgeting and planning and reduces the likelihood that consumers will be unable to pay their bills in any given month, which could have economic consequences beyond the higher direct costs of the electricity.

Figure 2.9. Prices for gasoline and electricity in the United States, 1991–2015



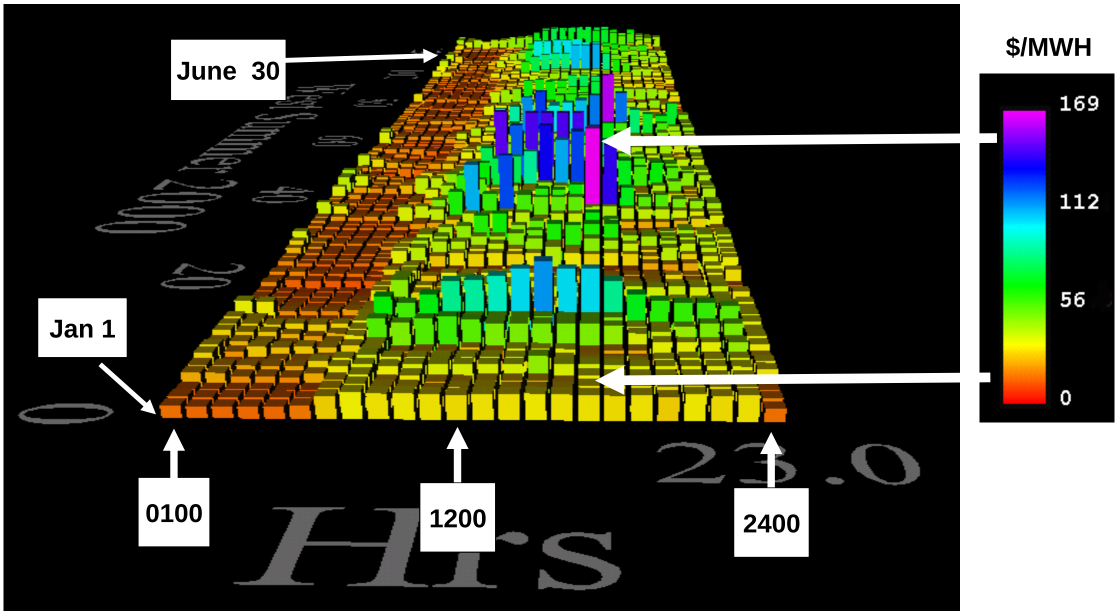
***Source*: EIA (2016l) for gasoline prices; EIA (2016a) for electricity prices**

Note: The price indices for gasoline and electricity were created by dividing historical real prices by their respective average price for February 1991.

Wholesale electricity prices vary much more frequently than retail prices. Although being exposed to the wholesale price volatility may cause some consumers to periodically reduce electricity usage, there are societal benefits when electricity consumers (residences and businesses) are able to adjust their usage in response to changes in wholesale prices. Most important, the electric power sector would operate more efficiently because available system resources would be better utilized (allocative efficiency) and the electricity system would be built to more exacting specifications (productive efficiency). Other benefits, such as lower retail prices would result from these economic efficiency gains.

In recent years, regional ISOs and RTOs have taken steps to increase the transparency of the electricity market and report the underlying volatility of the marginal cost of wholesale power supply. Figure 2.10 shows the day-ahead hourly price for a northeastern wholesale market in the first half of 2000. Hourly energy prices typically varied by a factor of 1.5 to 2 (topping out at about $40/MWh) across the peak and off-peak hours of most spring days, with exceptions. The nominal prices soared on a few days, usually associated with seasonally cold or warm weather, in some cases reaching almost $100/MWh. As summer approached, the volatility of prices increased significantly. Sometimes for 2 or more days in a week, prices were elevated to higher levels (over $160/MWh) for many consecutive midday hours. Prices in subsequent summers exceeded $1,000/MWh in northeastern ISO/RTO markets.

Figure 2.10. Day-ahead hourly wholesale prices in the NYISO Market, January–June 2000



***Source*: Based on NYISO hourly price data**

The above figures illustrate the conflict between the goals of more efficient dynamic pricing and the desire for stable energy prices on the part of consumers. However, the two goals are not fundamentally incompatible. Household budgets and regional macroeconomic conditions are not affected as severely by periodic spikes in energy prices if average costs do not change dramatically. Monthly bills are the fundamental driver of affordability, not the underlying volatility in prices. Despite the increased visibility of volatile hourly power prices in ISO/RTO markets, real *average* prices have remained low or declined over the last several years.[23] Thus there are opportunities to maintain stable energy prices for consumers while also creating an incentive to reduce consumption during periods of high prices.

Rather than volatility, the main energy security threat with regard to consumer electricity prices is large-scale increases in the average costs of supplying customers, which would necessitate large increases in retail prices. A large enough shock to enough electricity consumers could contribute to detrimental regional or national macroeconomic effects. Although large customers have access to financial instruments that allow them to hedge their energy costs, these instruments are not well developed or liquid in the electric power sector compared with the oil and natural gas sectors. Further, such instruments allow firms to hedge their private risk of energy price changes, but these firms do not have sufficient

[23] Borenstein (2007) has demonstrated that customer-level exposure to even hourly varying prices would not substantially increase the volatility in monthly bills and that there are several straightforward mechanisms that retailers can provide to hedge any volatility.

incentive to hedge against the collective macroeconomic risks associated with a regional cost shock.

ii. Dynamic Electricity Pricing and Demand Response

The electric power sector is more stable, and thus energy security is improved, when consumers (or operators) have the ability to quickly change their electricity demand in the face of a supply shock, which could cause prices to rise and possibly lead to a transmission or generation outage. A growing body of research indicates that some customers are price responsive, and a few are very responsive (EPRI 2012b). Several techniques are currently employed on relatively modest scales that give consumers incentives to respond to prices while still avoiding substantial risk to their average bills.

Short-run electric usage can be influenced through adjustments to the retail price in a more frequent and timely fashion, or through payments to consumers to alter their consumption. Two approaches to influencing demand are *dynamic pricing* and *demand response* (DR). The first involves retail price changes to reflect prevailing supply conditions. The effectiveness of dynamic pricing depends on how prices are determined (when they change and by how much), how that is communicated to the consumer, how well system operators can incorporate customer response into unit commitment and dispatch decisions, and what approaches consumers have to reduce consumption. Typically, prices are changed according to a predetermined schedule (often called time-of-use pricing) or in real time (e.g., hourly) as the supply cost changes. Less than 5 percent of residential customers buy electricity under these types of price schedules, and most of those fall under time-of-use pricing. Many of the largest electricity consumers are enrolled or subscribe to dynamic pricing services. Recent research by DOE and others suggested that combining automated technologies with dynamic prices can increase the amount of demand reduction (DOE 2016a; Badtke-Berkow et al. 2015).

The second approach to influencing demand involves a load-serving entity or other third-party contracting with end-use customers by offering a payment or reduction in rate in exchange for the right to demand a reduction in electricity usage for a specified period. DR programs have become prevalent in electricity markets that seek to reduce the system peak or to provide emergency load relief at a time of supply shortfall. The DR contract specifies the conditions under which curtailments can be requested and what is expected of the customer when it is. DR programs often involve direct control by the program provider over specific devices, such as air conditioners, water heaters, and pool pumps, although the specific terms of demand response contracts differ across industrial, commercial, and residential consumers. By entering into the program, customers have expressed their willingness to forgo usage of those devices under limited conditions for a prepaid consideration. The extent of DR-induced changes in electricity usage depends on the incentive payment and noncompliance penalty (EPRI 2012a). Retail load subscribed to demand-response programs exceeds 8 percent of U.S. peak demand, but it is not uniformly spread over the United States (FERC 2012).

A key driver of today's DR programs has been the growth of advanced metering infrastructure (AMI), now deployed for nearly 65 million customers in the United States.

AMIs typically include two-way communications networks that utilities can leverage to improve electric system operations, enable new technological platforms and devices, and facilitate consumer engagement. More than half of deployed AMIs are in five states, with California, Florida, and Texas accounting for over 40 percent of the total. AMI investments have been largely driven by state legislative, regulatory requirements, and ARRA funding (DOE 2014).

iii. Energy Efficiency and Consumers

Energy efficiency investments may produce collateral energy security benefits. More efficient devices and measures can produce the same services at a lower level of power input. Consumers that adopt these measures do so primarily to lower their electricity bills, but in many cases, the energy efficiency adoption also lowers the bills of all other electricity consumers in the long run. If energy efficiency measures also result in lower system demand, reliability can be enhanced in the short run by reducing the need for installed capacity. In the longer run, capacity levels would be expected to adjust to the new, more efficient demand levels, so energy security benefits would come indirectly from the social productivity gain and the efficiency benefits of lower capital requirements.

Currently, energy efficiency programs are largely justified as contributing to either consumer benefits (by improving their own efficiency) or environmental benefits (by reducing the need for generation powered by fossil fuels). Related energy security benefits can arise when increased efficiency allows consumers to meet fundamental needs even under periodic episodes of reduced supply. For example, more efficient refrigeration and cooling could maintain a basic level of comfort even if power supply were insufficient to power all devices. It is worth noting that to date, energy efficiency programs have not been pursued with a focus on security, so such benefits would likely be secondary to the economic and environmental benefits.

iv. Self-Fueling and Fuel Switching

Consumers and businesses can self-provide some of their electric power requirements by installing renewable generation on the premises or place of business or employ on-site devices that convert primary fuels into electricity. If power production exceeds the site's needs, 44 states allow surplus to be sold to the grid (NCSL 2016). If connected directly to an on-premises storage device and properly configured, such systems can supply power to the premises when the grid fails, providing an additional degree of reliability, and hence energy security, for many days or longer when the grid is not functioning.

Substantial improvement in reliability and resilience through these devices requires an additional expenditure (on-site storage or islanding technology, or both) that today is not likely justifiable for most businesses or residences. In the future, economies of scale and scope may reduce the cost to make it more attractive.

An alternative form of resilience available to consumers would be the ability to switch the source of energy for certain critical devices (e.g., providing customers with the ability to heat a home using either electrical or natural gas devices). Large consumers can avail themselves of technologies that allow them to use multiple fuels for heating and process applications and also self-supply electricity through the use of small-scale diesel generation.

v. Emerging Trends for Consumers

The relationship between consumers and wholesale power costs and reliability has always been quite loose, leaving consumption as an area with much untapped potential for improving the efficiency and reliability of electricity supply. Historically, many of the barriers to effective consumer integration into reliability management have been technological. This is largely no longer the case. Many of the remaining challenges involve policy barriers to employing new technologies, as well as the emergence of technologies that can complicate or improve the reliability picture for utilities, particularly at the distribution level.

a. Pricing Policy Challenges

The implementation of fully dynamic pricing has been very slow despite a large number of pilot programs and supporting studies that demonstrate the effectiveness of dynamic pricing methods. There are several sources of resistance to dynamic pricing, including complexity, inertia, a lack of understanding of how dynamic pricing works, and the fear that it can produce price risks that cannot be mitigated. Many of these objections can be addressed through specific elements of program design (Borenstein 2005). In states with electricity retail choice, the proliferation of dynamic pricing options is impeded by the perception among retailing firms that customers do not find such plans attractive. In contrast to dynamic pricing, DR programs have experienced more widespread adoption. Many regions with capacity markets or other resource adequacy policies treat DR programs as capacity resources, providing additional incentive to DR aggregation firms.

b. Emerging Technologies

Some emerging technologies can have an impact on electricity reliability. Electricity use per capita has been declining in many parts of the United States, but one application that could reverse this trend is electric vehicles (EV). Electric vehicle adoption is growing and being aggressively promoted in regions such as California. In addition to placing new loads on the grid, EVs can frequently be clustered, placing new stresses on local distribution systems. In addition, although EV load has the potential to be flexible in terms of the timing of its charging, realizing that benefit requires systems in place that can take advantage of the flexibility.

In many regions, consumers are adopting distributed energy resources (DER), defined by DOE as solar photovoltaic systems, demand response, energy efficiency, and distributed storage. Although not currently widespread, small-scale storage systems including EVs, could become more prevalent in the future. Distributed resources can significantly impact how much, and when, electricity is demanded from the grid and represent a major shift in the response of electricity consumers to the pricing and other incentive signals to which they are exposed. Challenges associated with some types of DER include less predictable demand (net of DER production), the potential for increased distribution level congestion, and declining revenues for infrastructure companies dependent on energy volume for the recovery of their costs.

c. Microgrids

Microgrids offer a means for achieving scale and scope economics in providing reliability and resilience. These allow one or more consumers to isolate, or island, themselves from the electric grid and generate their own electricity. The costs are relatively easy to calculate. The benefits, however, are mostly associated with the cost customers attribute to outages and tend to be difficult for most customers to quantify, particularly for outages lasting more than a day. Deployment of a microgrid requires finding electricity customers located near each other who similarly value uninterrupted power, making them more likely to pay for internally generated power and microgrid technology. That type of microgrid may produce spillover reliability benefits and reduce power supply costs generally, but the resilience benefits largely accrue to the participants. Microgrids constructed to support critical public agencies and services, such as hospitals and first responders, result in benefits that are enjoyed by the population served by those agencies.

d. Behavioral and Program Challenges in Energy Efficiency

Energy efficiency, like dynamic pricing, represents another area in which the identification of technical solutions has proved easier than the inducement of actual adoption of these solutions by customers. Several causes of energy inefficiency have been hypothesized, including a lack of information, liquidity constraints, and skewed incentives between renters and owners of multiunit buildings. Although some of these barriers have been identified and even quantified by researchers, disagreement continues over what policies most effectively overcome the barriers to energy efficiency, and even how significant those barriers actually are (Allcott and Greenstone 2012).

Most electricity efficiency programs implemented in the past 35 years have been sponsored by utilities, municipal utilities, and cooperatives.[24] Incentives to adopt measures, which often require a customer contribution to the cost, were funded largely (in many cases completely) through retail rates. Expenditures were subject to various cost-benefit tests intended to measure expected net benefits from the perspective of different parties.

One challenge with these tests is that measuring the savings that result from a program requires an understanding of baseline use and how devices operate in diverse customer circumstances. Two issues can arise in establishing the baseline against which reductions in consumption are to be measured. First, firms or customers could strategically increase their baselines, as evidenced by a pilot program in Anaheim, California (Wolak 2006). Second, firms can strategically enroll or offer their reductions only during periods when they know their consumption would be lower than the baseline anyway. One prominent example of this phenomenon was California's 20/20 program, which rewarded consumers who reduced their consumption by 20 percent relative to the prior year with a 20 percent rate reduction. Analysts have found that the response seen in this program was not

[24] Some states (California, Wisconsin, and New York) have centralized the design, implementation, and administration of energy efficiency programs, funded by levies against electricity sales or direct transfers from utilities.

significantly different than observed in a typical year due to the natural churn of customer usage (Ito 2015).

vi. Policies Affecting Consumers and the Economy

Much electricity policy in the area of consumer interactions is implemented below the Federal level. This is because, for the most part, regulatory jurisdiction over consumer prices and other consumer-related policies resides at the state and local levels. However, Federal programs and policies still play an important role in several areas.

a. Energy Efficiency Programs and Incentives

DOE's Building Technologies Office (BTO) implements minimum energy conservation standards for more than 60 categories of residential products and commercial equipment. These energy conservation standards establish minimum levels of efficiency that must be met by newly sold products and equipment, applicable going forward. Because the energy conservation standards apply to all products and equipment, the cost of achieving the standard is internalized by the manufacturer, transferring the obligation to achieve efficiency from utility program subsidies to market transactions. The rate of achievement of efficiency gains is determined by the rate of device replacement, which may be driven more by equipment failure than by customers' desire to improve electricity utilization efficiency. As a result, it might take years or decades to turn over the entire stock of devices (EPRI 2014). Between 2009 and October 2016, BTO has issued 44 new or updated standards for appliances and equipment, which DOE projects to save consumers over $550 billion off their utility bills through 2030, and cut carbon dioxide emissions by 2.4 billion metric tons (DOE 2016c). Products covered by standards represent about 90% of home energy use, 60% of commercial building use, and 30% of industrial energy use.

Building standards are another mechanism through which energy efficiency is promulgated through society. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) develops commercial building standards, including the Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1) (IEA 2008). The International Code Council develops residential building standards within the International Energy Conservation Code. A recent DOE analysis shows that homeowners, building owners, and tenants could save over $126 billion on energy bills and reduce carbon emissions by over 840 million metric tons over the next quarter century if energy codes are strengthened and consistently adopted by state or local governments when they are published every 3 years (DOE 2016b).

EPA oversees a voluntary informational program called Energy Star, which uses labels to identify and help promote energy efficiency in products, homes, and buildings nationwide. Energy Star works with companies to evaluate their power usage and potential sources of green energy, and then validates the usage and products with the Energy Star Label. The label can be found on whole buildings as well as individual products such as major appliances, office equipment, lighting, and home electronics to identify them as energy-efficient. Both the DOE and the EPA have sought to expand the Energy Star Program, as well as coordinate other programs that also focus on efficiency, such as the Commercial Building Energy Asset Score program, and the Home performance with Energy Star program.

The Federal tax code provides several tax preferences for energy efficiency investments, including various deductions and credits for improvements to existing residential and commercial properties. Although these credits can help overcome capital constraints and incentive barriers to energy efficiency investments, they can also be taken advantage of by individuals who would have made such investments even without the tax incentives.

b. Demand-Response Programs and Incentives

Federal efforts in the area of demand response have been concentrated in two areas: incentives and subsidies for the adoption of smart grid technologies that can enable demand response and FERC initiatives mandating the implementation of demand response as a form of wholesale market product.

The American Recovery and Reinvestment Act of 2009 (ARRA) provided $4.5 billion in funds for smart grid demonstration and technology deployment projects, including various analyses of consumer behavior in response to the installation of "smart meters." With matching funds from the private sector, DOE and the electricity industry invested in 99 cost-shared projects involving more than 200 participating electric utilities and other organizations to modernize the grid, strengthen cybersecurity, improve interoperability, and collect an unprecedented level of data on smart grid operations and benefits. Project examples include the deployment of 3 million smart meters to over 3 million customers at Florida Power and Light, and the training and education for more than 75,000 people nationwide on building, operating, and maintaining the grid of the future.

Although much of consumer response to pricing incentives is under the jurisdiction of local regulators, FERC has pursued the adoption of demand response as a resource at the wholesale level through its oversight of ISOs and most significantly through its Order 745, which established specific compensation formulas for the payment of demand response. This order has been challenged on both jurisdictional and economic grounds, in part because it established a payment level for DR that some economists have argued is both inflated and discriminatory relative to other forms of equivalent service (Hogan 2016). The order was recently upheld by the Supreme Court, and the implementation of DR at ISO levels has yet to be robustly examined.

Total DR capacity across the United States is shown in Table 2.1. It is important to note that the potential peak reduction from retail DR programs may not all be reduction in "real capacity." There are significant challenges to making DR resources reliable, predictable, and sustainable so that they may function as "proxy generators." Also, the terms related to non-delivery or partial delivery of DR that is called into service by grid operators tend to have penalty clauses that vary from region to region and from utility to utility; and thus, grid operators generally favor more reliable and predictable resources over DR.

Table 2.1. Potential Peak Reduction from Retail DR Programs, by Region and Customer Class

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

Source: **DOE 2017**

c. Support for Low-Income Households

The primary Federal program for helping low-income households with their energy bills is the Low Income Home Energy Assistance Program (LIHEAP). The program is administered by the Department of Health and Human Services with funding from DOE. It provides assistance for low-income households in paying their home energy bills, weatherization, and energy-related minor home repairs, as well as additional support during energy crises. In 2014, about 6.9 million households received assistance for heating, cooling, weatherization, and crisis assistance, 80 percent of whom live below the Federal poverty level (Campaign for Home Energy Assistance 2014). The Department of Energy also operates the Weatherization Assistance Program (WAP), which is designed to lower consumer energy bills. Through WAP, low-income families are eligible for funds to improve the energy efficiency of their homes. According to data from the WAP Technical Assistance Center, over 7 million homes have received WAP assistance, resulting in an average 35% energy consumption savings and energy bill savings in the range of U.S.$400 annually (WAPTAC 2016).

E. Environmental Considerations

Energy security is improved to the extent that electricity can be generated without posing an increased threat to the environment, from either increased emissions of GHGs or other risks (such as mining runoff and water pollution). Environmental pollution in the form of GHGs and other air emissions from generation with coal, oil, and natural gas is significant and poses a threat to the health and safety of U.S. residents. The electric power sector produces roughly 30 percent of U.S. GHG emissions (EPA 2016). Additionally, stringent *economy-wide* GHG reduction targets are anticipated to increase the importance of decarbonizing the power sector even further, because meeting the targets rely on the electrification of other sectors of the economy (EPRI 2016a). For example, the United States has set a goal of a 17 percent reduction by 2020 from 2005 levels and a 26 percent to 28 percent reduction by 2025 from 2005 levels. That commitment puts the United States on a path to reduce emissions 80 percent below 2005 levels by 2050. Achieving the 80 percent reduction would likely require increased electrification of the U.S. economy (DDPP 2015).

The G-7 highlighted the importance of reducing the environmental impact of the energy sector by reducing GHG emissions and promoting sustainable energy technologies as a major contributor to energy security. Analyses of approaches to reduce GHG emissions from the electric power sector consistently find that a diverse mix of zero- and low-carbon power sources will be a key part of the transition, because no single, carbon-free approach has been identified that can meet society's electricity needs (EPRI 2009; EMF 2013; DDPP 2015).

Other environmental concerns include the use of water for cooling of thermal generation, which can result in considerable demand for water. That can place a greater strain on available water sources in arid regions of the United States, particularly during times of drought.

i. Regulatory Policies Affecting the Electric Power Sector

The United States has implemented a range of Federal and state policies to achieve environmental objectives in the electric power sector, including the Clean Air Act (CAA) and Clean Water Act (CWA), both of which are foundational laws designed to protect human health and the environment from the effects of air and water pollution. The CAA sets standards for many pollutants including so-called criteria pollutants (i.e., particulate matter, photochemical oxidants and ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead) and air toxics (e.g., heavy metals). The Mercury and Air Toxics Standards (MATS) introduced rules for acid gases, mercury, arsenic, and metals under the CAA. The CWA sets standards for water quality and regulates discharges of pollutants into U.S. waters. Recent initiatives focused on GHGs include President Obama's Climate Action Plan, regulatory actions such as the Clean Power Plan, bilateral and international agreements, Presidential Policy Directives, and a wide variety of state-level technology and market-based policies.

In 2014, EPA put forth Federal regulation on carbon pollution in a rule known as the Clean Power Plan (CPP). This regulation takes the form of new standards under Section 111(d) of the CAA to reduce CO_2 emissions from the U.S. electric power sector. Although the CPP is currently under legal challenge, full implementation of the CPP in 2030 is projected to cause power sector carbon pollution to fall 32 percent below 2005 levels, with interim targets beginning in 2022. As specified in the CAA, the CPP provides flexibility for states to develop implementation plans to comply with the emissions reduction mandates, which vary from state to state. Although this decentralized approach offers states the ability to accommodate local issues and existing policies, inefficiencies could arise stemming from uncoordinated choices across states (Bushnell et al. 2016).

The CPP falls under the broader U.S. Climate Action Plan, which is built on three environmental core strategies: (1) reducing domestic carbon pollution, (2) preparing for the impacts of climate change, and (3) leading international climate efforts through a suite of regulatory, diplomatic, fiscal, and technology measures (White House 2013). This builds on the "2011 Blueprint for a Secure Energy Future," aimed at developing domestic energy resources, reducing net oil imports, lowering consumers' energy expenditures, and promoting innovation and deployment of clean energy technologies (White House 2011). These broad environmental initiatives are consistent with the G-7 energy security principles.

Another type of electricity policy is portfolio standards, which require that a minimum amount of electricity must come from a certain portfolio of generation technologies. The standard can be expressed in a number of ways, such as the share or total amount of installed capacity, generation, or retail sales. A renewable portfolio standard (RPS) targets renewable energy sources, such as wind, solar, biomass, geothermal, and small hydropower, sometimes with provisions for energy efficiency savings and tradable credits. Roughly 30 states have established RPS policies. California, New York, Oregon, Vermont, and Hawaii have passed some of the most aggressive RPSs. Studies have found that RPSs contribute to the promotion of renewables, a reduction in carbon emissions, and a reduction in total generation (Palmer and Burtraw 2005).

A variant of the RPS is the clean energy standard (CES), which expands the set of qualified energy sources beyond renewables to include other zero- or low-carbon technologies, such as nuclear, coal or gas with carbon capture and storage, and sometimes partial credit for natural gas. President Obama proposed a CES in his 2011 State of the Union Address that would double the share of electricity generated from clean energy sources to 80 percent by 2035. Similar portfolio standards were proposed in the Bingaman-Murkowski energy and water bill, American Clean Energy Leadership Act, and Senator Lindsey Graham's Clean Energy Standard Act (C2ES and RAP 2011).

Many environmental policies encourage energy efficiency as well as demand-response measures to reduce peak power demand; peak power generation tends to be less efficient, more costly, and more polluting. The American Council for an Energy Efficient Economy notes that 25 states have energy efficiency resource standards (EERS) in place that set long-term energy savings targets (ACEEE 2013).

ii. Market-Based Policies Targeting the Electric Power Sector

In contrast to these regulatory approaches to achieve decarbonization goals, many economists favor market mechanisms such as CO_2 pricing policies (Jaffe et al. 1999, 2003), which can take the form of carbon taxes or cap-and-trade programs (Palmer and Burtraw 2005; Stavins 2003). A carbon price or permit requirement raises the operating cost of an electric power plant in proportion to its CO_2 intensity. This approach internalizes the cost of CO_2, allowing emissions reduction targets to be achieved flexibly in a more cost-efficient way than through command-and-control policies, because abatement costs tend to vary across sources and regions. These gains are even more pronounced within the electric power sector, which is especially heterogeneous on both the supply and demand sides.

In 2009, the House of Representatives passed the Waxman-Markey American Clean Energy and Security Act, but the legislation was not successful in the Senate. Although congressional efforts have failed, some U.S. states and regions have successfully enacted carbon pricing mechanisms. In particular, the Regional Greenhouse Gas Initiative (RGGI) established the first mandatory CO_2 trading program in the United States through coordinated cap-and-trade programs for the electric power sector in nine northeastern and Mid-Atlantic states. California's Global Warming Solutions Act of 2006, passing the legislature as AB 32, mandates reductions in future greenhouse gas emissions in the state so that 1990 levels are reached by 2020. In September 2016, California strengthened AB 32 with the passage of SB 32 and AB 197. The former requires the state to cut emissions at least 40 percent below 1990 levels by 2030, and the later establishes a legislative committee on climate change policies to help ensure transparency and accountability (Environment News Service 2016).

To support efforts to measure the climate change damages to society from additional emissions of carbon dioxide, the U.S. government developed official estimates of the social cost of carbon dioxide (SC-CO_2) in 2010 and issued analogous estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) in 2016. Executive Order 12866, Regulatory Planning and Review, requires that Federal agencies perform cost-benefit analyses on all proposed regulations.[25] U.S. agencies are now required to apply the government's estimates to assess the potential benefits of CO_2, CH_4, and N_2O reductions in Federal regulations, including rules affecting appliances, transportation, industry, and power generation. Estimates of the social cost of these GHGs are also being used at state and local levels and in both regulatory and nonregulatory contexts.

iii. Financial Incentives

The broader environmental policy landscape also features a variety of financial mechanisms to encourage the deployment of low-carbon electricity sources, including tax credits and loan guarantees. These have stimulated innovation in relevant sectors. Although environmental considerations were not the primary focus, several provisions of ARRA directed funds to programs targeting renewable energy deployment, energy efficiency, basic research, and loan guarantees (C2ES 2013).

The U.S. government has supported renewable energy and other energy sources through Federal tax incentives, which take the form of a production tax credit or investment tax credit. These credits have had a significant effect on the growth and development of renewable energy sources; wind-generated electricity, in particular, is economically competitive as a result of the current production tax credit (Wiser et al. 2007). Under current tax extensions, renewable energy capacity additions are estimated to peak at about 48–53 GW in the 2020s (NREL 2016). A disadvantage of these credits is their short

[25] https://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo12866_10041993.pdf.

duration of typically one year, with uncertainty regarding extensions from year to year, which undermines investor confidence.

Loan guarantee programs to encourage capital investment in non-emitting technologies like nuclear or renewable energy have often been included on their own or as a part of more comprehensive energy policies, such as the Energy Policy Act of 2005 (Pub. L. No. 109–58, Aug. 8, 2005). These programs are designed to overcome the liability and risk associated with deploying less conventional technologies (NREL 2010). Between 2010 and 2015, the DOE issued loan guarantees to 25 projects related to energy manufacturing and generation. The projects include the manufacture of solar PV panels, and geothermal, wind, and solar generation facilities, totaling nearly $22 billion. Between 2013 and 2015, the DOE announced new loan guarantee solicitations for advanced fossil energy ($8.5 billion), renewable energy and energy efficiency projects (up to $4.5 billion), and advanced nuclear energy ($12.5 billion).

The U.S. government also has funded energy technology research, development, and demonstration (RD&D), which has led to advances in all fields of energy, including nuclear, fossil fuels, renewables, and end-use technologies. The Advanced Energy Initiative of 2006 prioritized research areas such as solar power, biofuels, and clean coal research (IEA 2011). The economics literature has shown that firms underinvest in RD&D because they face difficulty in capturing all the benefits from their investments in innovation, such as spillovers from learning-by-doing, as well as market barriers and scale and network effects (e.g., Arrow 1962). Policies that directly target RD&D are designed to overcome these market failures and, if successful, enhance energy security.

III. Assessing Electricity Security for U.S. Allies and partners

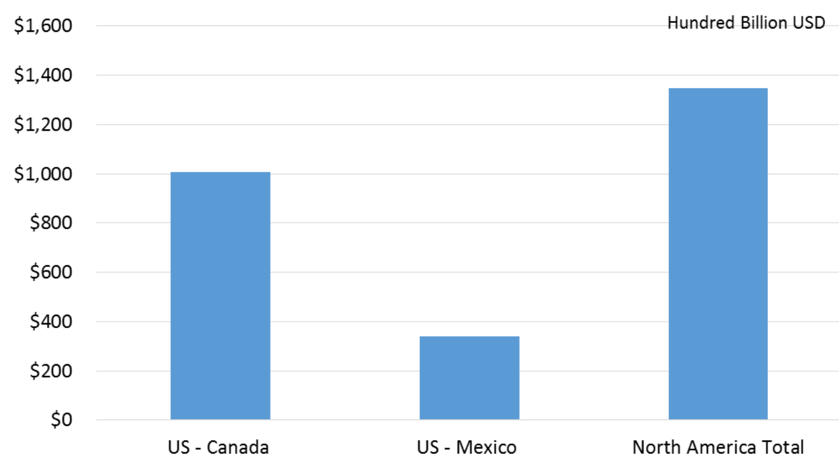
This section provides a brief assessment of the energy security of the electricity systems, according to the G-7 principles, of U.S. allies and partners. For purposes of this study, U.S. allies and partners are defined as those countries in North America, the European Union, the OECD, and the IEA.

Electricity enables nearly every aspect of the U.S. economy and the globalized world, which means that major policies of and challenges faced by U.S. allies and partners may also affect U.S. electricity markets, in terms of their reliability, security, and achievement of clean energy goals.

A. North America

The North American electric power sector is one of the largest, most integrated and reliable power systems in the world (Bradley 2006). The United States and Canada share extensive electricity infrastructure and the responsibility for many of the grid’s operations. U.S. electricity trade with Mexico, on the other hand, is much smaller, with fewer physical connections and shared responsibilities; however, Mexico remains a critical commodity trade partner in North America (see Figure 2.11). Major policy reforms in Mexico are decreasing its reliance on fossil fuels, replacing oil-fueled generation with natural gas-fueled generation ensuring its power grid is resilient to both cyber and physical attacks, and continuing its path toward liberalizing its energy and electric power sectors. These are critical efforts toward ensuring and enhancing the energy security of the United States and North America.

Figure 2.11. Value of North American energy trade, 2015



Source: **EIA Forms EIA-111, EIA-182, EIA-782, and EIA-814.**
Note: Data for crude oil, petroleum products, natural gas, and electricity. Prices calculated using West Texas Intermediate Price.

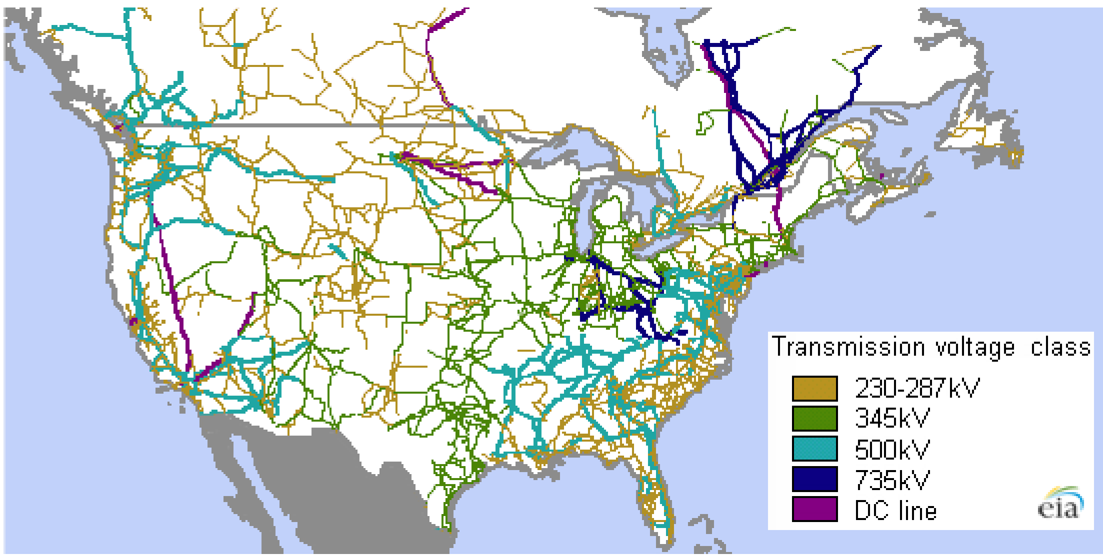
i. Canada

The United States and Canada form the largest integrated energy market in the world. Markets exist for the trade of many fuels, including oil, natural gas, and electricity. The electricity trade is vital to both economies. In 2014, 60 companies in Canada exported over 58.4 terawatt hours (TWh) of electricity into the United States, accounting for 1.6 percent of U.S. electricity sales and 10 percent of Canadian electricity generation. Three of the eight NERC reliability regions span both the United States and Canada, which permits the sharing and coordination of resources.

Electricity trading between the two countries is enabled by 30 power transmission connections (see Figure 2.12). This close interconnection of the United States and Canada is set to deepen with additional high-voltage transmission infrastructure projects. A recently completed 230 kilovolt (kV) transmission project between Montana and Alberta, allowing bidirectional power flow, facilitates use of new wind power capacity over that northern region. A larger 500 kV transmission line is being constructed between Minnesota Power and Manitoba Hydro with the purpose of enabling greater use of renewable wind resources in the upper Midwest. In the Northeast, the Champlain Hudson Power Express transmission is also planned to ultimately provide hydropower electricity from Quebec straight to the New York City metropolitan area, a much-needed potential supply of up to 1,000 megawatts.

Canada's current electricity reliability and regulatory constructs were formed as a result of a blackout in 2003 that affected 50 million people in the U.S. Northeast and Midwest as well as Ontario, Canada. The outage was estimated to have cost the United States between $4 billion and $10 billion. For Canada, gross domestic product (GDP) was down 0.7 percent the month of the disruption, 18.9 million work hours were lost, and shipments of manufacturing goods in Ontario were down about $2 billion (OTF 2004). A joint U.S.-Canada Power System Outage Task Force was formed to investigate the causes of the blackout and recommend actions to minimize the possibility of such incidents recurring in the future. In response to the task force's findings, the U.S. Congress passed the Energy Policy Act of 2005 to provide for the establishment of an electric reliability organization (ERO) to develop reliability standards for the North American bulk power system (Pub. L. No. 109–58, Aug. 8, 2005). In July 2006, NERC was certified as the ERO by FERC (CEA n.d.).

Figure 2.12. North American electricity transmission grid, 2012



***Source*: EIA (2012)**

NERC has taken steps to achieve recognition by the appropriate governmental authorities in Canada. NERC's relationship with these authorities differs from province to province, depending on the particular legislative and regulatory frameworks in place in each jurisdiction. In terms of regulation over the electricity system in Canada, the provincial governments exercise greater authority than does the Federal Government. Provinces have jurisdiction over energy and electricity regulations, based in the Constitution Act of 1982, with some overlapping authority related to environmental protection between federal and provincial entities.

In Canada, a large part of the electricity system is under public ownership, with the majority being municipal ownership. Investor-owned utilities appear in Alberta, Nova Scotia, British Columbia, and Newfoundland. As was the case in the United States, the Canadian system was made up of traditionally integrated utilities covering generation, transmission, and distribution functions. More recently, the Canadian system has undergone changes in several provinces with the objective of inducing wholesale competition for electricity. In the provinces of Ontario and Alberta, the market has transitioned to a full retail competition with the development of independent power producers and providers. There also have been developments in transmission grid management and wholesale market operations, with the responsibility in those two provinces falling to the Independent Electricity System Operator (IESO) in Ontario and the Alberta Electric System Operator (AESO). Currently, the other provinces do not have independent system operators. Nonetheless, the trend for greater wholesale competition in the system continues to increase across the Canadian provinces.

Three-quarters of Canada's electricity comes from clean sources, mostly from hydropower (60 percent) and nuclear (15 percent) (Statistics Canada 2016). In addition, Canada continues to pursue other clean energy generation capacity, especially in the form of wind power. According to the Canadian Wind Energy Association, Canada's wind capacity was 10.4 GW as of September 2015, after a record-setting year of installations in 2014, which saw 37 new wind projects added, totaling 1.9 GW of capacity.

Canada is committed at the national level to supporting the Intended Nationally Determined Contribution (INDC) submission to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the 2015 Paris Agreement. Canada's INDC "intends to achieve an economy-wide target to reduce its greenhouse gas emissions by 30% below 2005 levels by 2030" (Government of Canada 2015). The Canadian Federal Government's principal policy is the Canadian Environmental Protection Act (S.C. 1999), which provides for regulatory action on GHG emissions.

> Since 2006, the federal government has taken the following regulatory action under its responsible sector-by-sector regulatory approach:
>
> 1. transportation sector regulations establish progressively more stringent GHG emission standards for heavy-duty vehicles (model years 2014–2018) and for passenger automobiles and light trucks (2011–2025);
> 2. electricity sector regulations make Canada the first major coal user to ban the construction of traditional coal-fired electricity generating units. These regulations will also lead to the phase-out of existing coal-fired electricity units without carbon capture and storage;
> 3. renewable fuels regulations require that gasoline contain an average 5% renewable fuel content and that most diesel fuel contain an average 2% content. (Government of Canada 2015)

Electricity reliability in Canada is critical to maintaining reliable and quality power in North America. To that end, NERC operates the Electricity Information Sharing and Analysis Center (E-ISAC), which provides security services and expertise to the electric power sector (E-ISAC 2016). E-ISAC members are vetted electricity owners and operators in North America. The organization provides the electricity community, and related sectors and governments, with analyzed information about threats, vulnerabilities, risks, and strategies for preparing for and responding to cyber and physical threats. Further, E-ISAC serves as the primary communications channel for the industry, which includes coordinating incident management.

Parallel to these improvements in reliability, the North American electric power sector is becoming increasingly dependent on IT systems for grid operations, commonly referred to as smart grid. There is concern that these efforts could cause the grid to become more vulnerable to attacks and loss of service. To address this concern, the Energy Independence and Security Act of 2007 (EISA) gave FERC and the National Institute of Standards and Technology (NIST) responsibilities related to coordinating the development and adoption of smart grid guidelines and standards across North America (Pub. L. No. 110-140, Dec. 19, 2007).

ii. Mexico

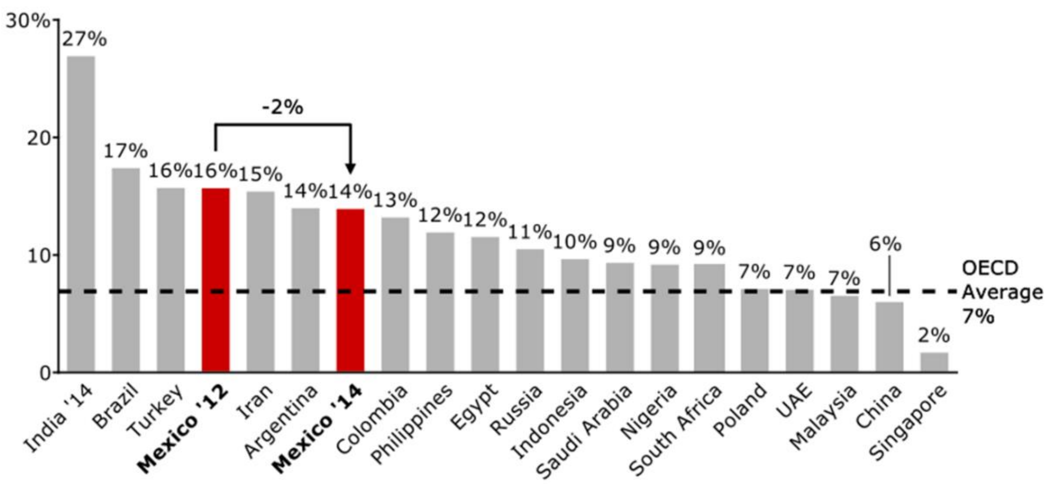
The U.S electric power sector is much less integrated with Mexico than with Canada. With only 10 transmission line border crossings in three states, total electricity imports from Mexico represent less than 1/100 of a percent of U.S. electricity use. More recently, however, a new transmission infrastructure project for a 230 kV line was approved to supply renewable wind power from Mexico into California. Mexico is a net electricity exporter to the United States, sending 7.1 million kWh in 2014 (EIA 2016b). Mexico is in the process of reforming its electric power sector to ensure greater reliability and fairer prices for consumers, as well as to reduce the significant dependence on fossil fuels for generation, which currently provide 78 percent of total capacity. As Mexico is a major partner in trade and regional and border security, these issues all impact the energy security of the United States.

Mexico has passed multiple energy sector reform measures since 2013 to open the oil, gas, and electric power sectors to private sector investment. For years, state-owned vertically integrated monopolies controlled the generation, transmission, and distribution markets. The goals of these reforms include providing more reliable supply at more affordable prices, while contributing to decarbonization goals. Historically, these challenges have been the sole responsibility of the Mexican government-owned Federal Electricity Commission (CFE). The legislation also establishes a wholesale electricity market where power generators will be able to sell electricity to distributors and end users.

Supplying the energy needed to meet economic demand growth is another focus of the energy sector reforms. In Mexico, power consumption has followed GDP growth at about 4 percent annually, and both figures are expected to grow at about 3.5 percent annually over the next 15 years (WEF 2016). However, since 2004, the transmission system has grown annually by only 1.4 percent, well below the growth of demand. CFE estimates that the grid must expand by 17 percent per year through 2026 to keep pace with demand. This will also include expanding access to energy services for the quarter of the population living outside of cities, as well as addressing the high electricity intensity in Mexico, where GDP output per capita requires roughly twice as much electricity than the OECD average in 2009 (CEE and ITAM 2013).

Another issue affecting the energy sector and economic growth is the relatively high loss of electricity in transmission and distribution systems (see Figure 2.13). As of 2012, Mexico's losses were more than double the OECD average because of inefficient infrastructure and grid operations. Operational improvements in recent years have decreased the loss in transmission and distribution.

Figure 2.13. Transmission and distribution losses as share of generation, % (select years)



***Source*: WEF (2016)**

To mitigate these challenges, the power sector is being restructured so that CFE's generation assets are divided into four generation companies, which can sell power into the wholesale market along with independent power producers. (CFE will remain the supplier of retail electricity to customers who do not choose to switch to a competitive retail supplier.) The Centro Nacional de Control de Energía (CENACE) is the independent system operator for Mexico's entire transmission grid. After decades of state control, the new reforms move toward more private sector involvement and open markets, motivated by the objective to increase efficiency, lower the cost of generating electricity, and encourage new capacity investments in low- and nonemitting generation technologies.

As part of the National Energy Strategy, Mexico aims to generate 35 percent of its electricity from clean sources (which include renewable energy, nuclear, efficient cogeneration, and fossil fuels paired with carbon capture and storage) by 2024, up from 14 percent in 2013. (Most existing clean energy is generated from hydroelectric sources.) Additional goals have been set to reach 40 percent by 2035 and 50 percent by 2050. The potential generation capacity from renewable sources in Mexico include 20 GW from wind, 10 GW from geothermal, and 6 GW from solar, with an additional 9.3 GW from small-scale hydro and biomass (SENER 2013). This capacity is necessary to augment and replace the aging current generation capacity of around 54 GW (EIA 2015b). To encourage development of those sources, Mexico plans to launch certificates by 2018 to provide clean energy generators will additional income.

Mexico also submitted its INDC in support of the UNFCCC 2015 Paris Agreement, setting both unconditional and conditional reduction goals (Government of Mexico n.d.). Following is its unconditional goal:

> Mexico is committed to reduce … 25% of its [GHGs] and Short Lived Climate Pollutants emissions (below BAU) for the year 2030. This commitment implies a reduction of 22% of GHG and a reduction of 51% of Black Carbon.
>
> This commitment implies a net emissions peak starting from 2026, decoupling GHG emissions from economic growth: emissions intensity per unit of GDP will reduce by around 40% from 2013 to 2030.

Its conditional goal is stated as follows:

> The 25% reduction commitment expressed above could increase up to a 40% in a conditional manner, subject to a global agreement addressing important topics including international carbon price, carbon border adjustments, technical cooperation, access to low cost financial resources and technology transfer, all at a scale commensurate to the challenge of global climate change. Within the same conditions, GHG reductions could increase up to 36%, and Black Carbon reductions to 70% in 2030.

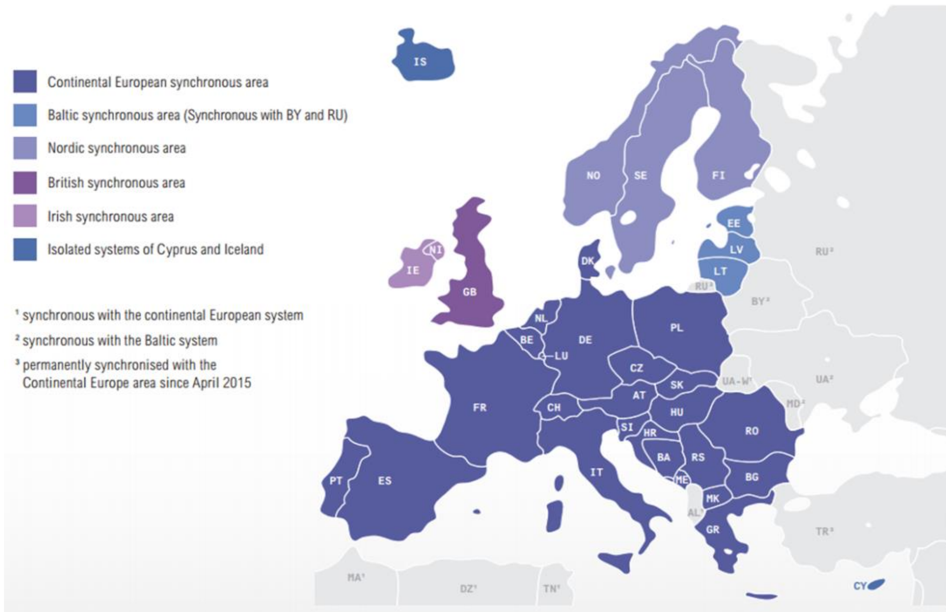
B. Europe

Although no physical electricity connections exist between the United States and the European Union, the shared economic interests, which include trade, travel, finance, and defense, among others—all enabled by electricity—enhance the importance of both U.S. and EU energy security. The EU's continued expansion of its single economic market has included efforts to advance the integration of electricity markets and networks, led by key policy recommendations to ensure the development of common operations and increased energy efficiency and diversity of energy suppliers and routes.

To ensure proper management of bulk transmission systems that span across Europe, transmission system operators participate in the European Network of Transmission System Operators for Electricity (ENTSO-E) (see Figure 2.14). ENTSO-E activities include coordinating system operations, developing operational standards, and protecting critical infrastructure (ENTSO-E 2015). The Agency for the Cooperation of Energy Regulators (ACER) meanwhile regulates the electric power sector with a focus on furthering the common market, integrating intermittent generation, and implementing stable frameworks for the development of new trans-European infrastructure (ACER 2012).

Specific developments in the integration of the European network include the connection of the Nordic country systems and markets, which began in the early 2000s and was completed with the joining of Latvia in 2013. In 2010, France, Germany, Belgium, and the Netherlands formed a combined Central Western European (CWE) market. In Eastern Europe, Hungary, the Czech Republic, and Slovakia established market by 2012. More recently, starting in 2014, 15 countries established a larger North Western Europe (NWE) market by combining the CWE, the Nordic region, and the United Kingdom and Ireland. The continued integration of Europe's electricity markets has helped reduce the disparity in regional wholesale electricity prices and adverse power flows. To keep pace with the market-linking initiatives in Europe, countries also are considering developing common reliability standards and capacity markets (IEA 2016b).

Figure 2.14. ENTSO-E synchronized areas, 2014



***Source*: ENTSO-E (2015)**

Most distribution system operations are still managed at the national level, though the EU makes recommendations to national regulators that have authority over the distribution system operators (DSOs), such as on voltage ranges. DSOs provide a high level of reliability and quality supply throughout the EU. The duration of interruptions in European networks ranged from 15 minutes (Germany) to 400 minutes (Romania) per year. In terms of the market structure, in some countries, including Ireland, Greece, and Lithuania, only one DSO provides 100 percent of distributed power, while in others, including Germany, Belgium, and Austria, the three largest DSOs provide less than 50 percent of distributed power (Eurelectric 2013). Further, the business models of DSOs range significantly across the EU, from privately owned to publicly owned, though most DSOs are owned by organizations domestic to their operational environment. In more than half of the EU countries, the DSO revenues are linked to their performance on continuity of supply and power quality, which has proved to be a successful incentive structure.

Incorporating smart grid technologies into system operations is a priority for EU policies and regulations. In 2009, the European Commission set up a Smart Grids Task Force to develop common standards and technical requirements for the technologies. These efforts have included a focus on hundreds of transnational projects of common interest, which leverage public funds and private investment to further the research and development of smart grids (EPRS 2015). Following reports in December 2015 that Russian hackers penetrated the Ukrainian power network and forced blackouts, concerns have increased in the EU about the vulnerabilities that smart grid technologies present to European power grids (Walters 2016). In July 2016, the EU passed the first explicit cybersecurity rules with the new network and information security (NIS) directive, which established minimum requirements for cybersecurity on critical infrastructure operators. The NIS directive will affect the businesses that supply essential services and operate critical infrastructures in different industries, including energy, transport, banking, and digital services. Companies in these industries are required to be compliant with minimum standards of cybersecurity (Paganini 2016).

The European Commission has funded cybersecurity research through its FP7 ICT Work Programme 2007–2008 Objective 1.7 "Critical Infrastructure Protection," as well as the Horizon 2020 Program (EC 2015a, 2015b). Additionally, the European Union Agency for Network and Information Security (ENISA) has published several reports on ICS-SCADA security that include analysis of cybersecurity maturity levels in critical infrastructure, certification of skills for cybersecurity professionals, and lessons learned and best practices from working groups (ENISA n.d.).

The EU is also committed to various climate change–related goals and the development of clean energy technologies. The European Commission has created many climate-related initiatives since 1991, when it issued the first strategy to limit CO_2 and improve energy efficiency. The EU has set targets for reducing GHG emissions progressively up to 2050, and it has also established a climate mitigation goal, as per its INDC (Latvian Presidency 2015):

> The EU and its Member States are committed to a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990.

Given the economy-wide and multiple GHG emissions coverage, the EU INDC also covers the sector and legislative details underlying the emissions reduction goals:

> Domestic legally-binding legislation already in place for the 2020 climate and energy package. The existing legislation for land use, land-use change and forestry (EU Decision 529/2013) is based on the existing accounting rules under the second commitment period of the Kyoto Protocol. Legislative proposals to implement the 2030 climate and energy framework, both in the emissions trading sector and in the non-traded sector, to be submitted by the European Commission to the Council and European Parliament in 2015–2016 on the basis of the general political directions by the European Council, taking into account environmental integrity.

C. Asia

Much like the European Union, other allies of the United States including Japan, South Korea, and Australia have no physical connections to the United States and its electricity system. However, many issues and challenges faced by their power sectors also affect the

United States, and the reliability, security, and decarbonization of their power sectors are important to the global economy and indirectly to U.S. energy security.

i. Japan

Japan is particularly vulnerable to energy supply disruptions from abroad, as it is dependent on imports for 94 percent of its primary energy supply (FEPC n.d.). To ensure Japan's stable electricity supply, it is critical for the country to establish an optimal combination of power sources that can concurrently deliver energy security, economic efficiency, and environmental benefits.

Following the earthquake in March 2011 and the meltdown of the Fukushima Daiichi nuclear power station, Japan halted operations at all nuclear power stations as a safety precaution (IEA 2016a). Since then, Japan has relied more on coal and natural gas for electricity, both of which are imported from abroad. The shift away from nuclear has contributed to increased prices for electricity; according to data from Japan's 10 major utilities, the average retail electricity price rose for four consecutive fiscal years (2011–2014) (EIA 2016d). To lower prices for its customers, Japan began restarting some of its nuclear fleet, including two reactors at the Sendai plant in 2015. Two additional reactors at the Takahama nuclear plant were restarted in early 2016. However, on March 9, 2016, a court-ordered injunction called for a shutdown of the Takahama reactors. Another reactor, Ikata Unit 3, was restarted in early August 2016.

Believing more competition could ease the price pressure on consumers, Japan initiated reforms aimed at deregulating the electric power sector in three phases. The first phase established an independent system operator to dispatch electricity across the national grid in 2015. On April 1, 2016, regional monopoly control was removed from the utilities so that competition could enter the market and give consumers the choice of supplier. The final steps are removing pricing regulations and unbundling utilities' transmission, distribution, and retail businesses by 2020.

Japan is committed to supporting the INDC submission to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the 2015 Paris Agreement. Japan intends a reduction of 26 percent by 2030 compared with 2013 (UNFCCC 2015c). It is important to note that most developed countries use 1990 or 2005 as their base year, so that Japan's selection of a 2013 base year represents a larger reduction than most other countries. The government also announced a longer-term goal to reduce GHG emissions by 80 percent by 2050 in its next plan. The shutdown of Japan's nuclear reactors left a 30 percent gap in the country's electricity supply that was replaced by imports of LNG, oil, and coal. To meet its goals and reduce its dependence on imports, Japan must further diversify its energy supply to include a higher share of nuclear and renewable energy (NEI 2016a).

ii. South Korea

Like Japan, South Korea relies heavily (98 percent) on imports of fossil fuels for primary energy needs because of insufficient domestic resources (EIA 2015a). Also, the country currently imports all of its nuclear fuel supply and is restricted from reprocessing or enriching uranium based on a cooperation agreement with the United States. Fossil fuels (mostly coal) accounted for 64 percent of electricity generation in 2015, while 31 percent came from nuclear power and 5 percent came from renewables, including hydroelectricity (KEPCO 2016).

The state-owned Korea Electric Power Corporation (KEPCO) controls all aspects of South Korea's electricity generation, retail sales, transmission, and distribution. In early 2016, it was announced that the government will open up parts of its electricity generation market to private companies to improve efficiency, cut debt, and improve transparency (Patel 2016). South Korea last embarked on privatizing KEPCO after the Asian financial crisis of 1997, seeking to increase private holdings of the company's shares to 40 percent. However, transmission and retail services are still monopolized by KEPCO, and South Korea's government holds about 51 percent of the company's shares. Additional restructuring in the electric power sector is likely to occur and will impact the Korean market for years. For example, it was announced in June 2016 that independent firms may import their own LNG by 2025 separate from the natural gas monopoly, Korea Gas Corporation (KOGAS). The overall policy shift appears to downplay coal development and allow more private investment in the energy sector (Lefebvre 2016).

Energy consumption in Korea has continued to increase in line with economic growth. Traditionally energy-intensive industries, such as petrochemicals and steel, consume relatively more energy than in other OECD countries. Electricity consumption has increased five times faster than the OECD average in the last decade (Cheong 2013). The main focus of South Korea's energy policy is to balance increased demand with diversified supplies. On the demand side, Korea has achieved rapid economic growth through compressed development in energy-intensive industries such as the manufacturing industry, which brought about a rapid surge in energy consumption, and energy consumption is expected to remain high in the near term. On the supply side, to achieve higher self-reliance in energy, the government will seek to make new and renewable energy sources more economically feasible through incentives.

The government set specific targets for renewable energy in a four-part plan in 2014. According to the plan, new and renewable energy will provide 11 percent of Korea's total primary energy supply by 2035, up from the current level of around 2 percent. To achieve this target the government will invest in private sector RD&D and test sites, work with industry to ease regulations, expand the value of domestic renewable energy technologies in foreign markets, and improve the renewable portfolio standard (RPS) for large power producers (>500 MW). The revised RPS increased the required share of generation from renewables for each year, though pushed back the final 10 percent requirement from 2022 to 2024. By 2015, the RPS led to the deployment of 620 MW of new renewable energy capacity in Korea (KEA 2015). To put this in context, the country's now defunct feed-in tariff program, which guarantees the price paid by the utility to the owner of the renewable energy facility, created only half as much new renewable capacity over the previous decade.

South Korea has also submitted its INDCs in support of the UNFCCC 2015 Paris Agreement, with plans to reduce its GHG emissions by 37 percent from the business-as-usual level by 2030 across all economic sectors (UNFCCC 2015b). In order to meet its targets, South Korea has stated that a 25.7 percent reduction below BAU will be achieved domestically and the additional 11.3 percentage points of reduction will be achieved by purchasing carbon credits from international carbon markets.

iii. Australia

Australia is rich in natural resources, including fossil fuels and uranium (EIA 2014a). It is one of the few OECD countries that is a significant energy exporter, sending 72 percent of its total energy production abroad in 2014 (Office of the Chief Economist 2015). As a result, 85 percent of Australian electricity generation capacity runs on fossil fuels, mostly domestically produced coal (61 percent). The use of coal-fired generation rose until 2009 but has yielded some share to natural gas, hydroelectric, and other renewable energy in the past few years, though not significantly. Building out clean energy capacity in the domestic electric power sector represents a significant challenge for Australia.

Australia's National Electricity Market (NEM), a wholesale market for the supply of electricity, is the world's longest interconnected power system, running a distance of 3,100 miles. Some assets that constitute NEM's system are owned and operated by state governments, and others are owned and operated under private business arrangements. The Australian Energy Market Operator (AEMO) maintains core responsibility for the system operations, planning, security, and reliability (AEMO 2010). AEMO also provides advice to the government about setting and meeting renewable energy targets, specifically, diversifying the generation mix.

Although other renewable sources (not including hydroelectricity), such as wind, bioenergy, and solar, supplied just 7 percent of electricity in 2014, they have been the fastest-growing renewable sources in Australia since 2000 (Office of the Chief Economist 2015). Wind energy has seen substantial growth since 2007 and accounted for 55 percent of other renewable sources in 2014. Although accounting for only a small portion of the renewable energy generation, solar power experienced the most growth during the past year as a result of the government's promotion of small-scale renewable energy projects and off-grid residential solar use. As part of Australia's Renewable Energy Target, introduced in 2010, a 20 percent share of electricity demand must be met by renewable energy sources by 2020.

Australia submitted its INDC with the goal of an economy-wide target to reduce greenhouse gas emissions by 26 to 28 percent below 2005 levels by 2030. However, in the document officially establishing its INDC, Australia also stated that it "reserves the right to adjust our target and its parameters before it is finalised under a new global agreement should the rules and other underpinning arrangements of the agreement differ in a way that materially impacts the definition of our target" (UNFCCC 2015a).

Chapter 3: Energy Security Applications in Federal Rulemaking

I. Introduction

A wide range of Federal actions can potentially affect energy security, as defined by the G-7 principles. In practice, however, only a limited set of Federal actions have considered the implications of the action on energy security through a quantitative analysis, although other actions have included a qualitative discussion of energy security. This chapter summarizes how energy security is currently incorporated into Federal actions, with a primary focus on benefit-cost analyses prepared as a part of Federal agency rulemaking under Executive Orders 12866 and 13563 (58 Fed. Reg. 51735 (Oct. 4, 1993); 76 Fed. Reg. 3821 (Jan. 21, 2011)). The section reviews the final Regulatory Impact Analyses (RIAs) for the major rules issued over the past 10 years by the Department of Energy, Department of Transportation, Department of Interior, Environmental Protection Agency, Department of Defense, Department of Agriculture, Department of Commerce, Department of Homeland Security, and State Department. Overall, these RIAs have focused on benefit categories associated with the traditional treatment of energy security, rather than the broader set of categories identified in the recent G-7 energy security principles.

In addition to Federal regulatory actions, the U.S. government also considers energy security in other policy contexts such as permit decisions and energy-related Presidential Directives. For example, DOE has the responsibility under Section 3 of the Natural Gas Act to review applications to export LNG.[26] Section 3(a) establishes a broad public interest standard and a presumption favoring the issuance of export authorizations. However, this section does not define "public interest" or provide further guidance on the factors to be considered. To support its LNG decisions, DOE has completed several studies of the effects of LNG exports on the domestic natural gas market, the U.S. economy and the environment. Criteria DOE considers in evaluating the public interest of an application to export natural gas to non-free trade agreement countries includes the effect of the exports on: U.S. energy security, adequacy of the domestic natural gas supply, the domestic natural gas market, the national economy, international trade, and the environment.[27]

Energy-related Presidential Directives and Executive Orders also identify energy security factors.[28] These actions are taken in the public interest, but there is generally little publicly

[26] Under Section 3, the export of natural gas to countries where the United States has entered into a free trade agreement (FTA) for trade in natural gas is deemed to be in the "public interest." For the export of natural gas to other countries (non-FTA countries), DOE must make a determination that the proposed export project is consistent with the public interest. DOE shares the approval responsibility for LNG export projects with the Federal Energy Regulatory Commission (FERC).

[27] See for example, DOE's conditional approval of the export of LNG from the Sabine Pass and Freeport LNG Terminals (DOE 2013, 2016). Similarly, the evaluation process on whether the Keystone pipeline would serve the national interest considered a variety of factors: including, energy security, environmental, cultural, and economic effects; foreign Policy; and compliance with relevant federal regulations and issues (Department of State, 2014).

[28] See, for example, Executive Order 13211, Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use (Executive Office of the President 2001), or Executive Order 13653 from November 1, 2013, Preparing the United States for the Impact of Climate Change (66 Fed. Reg. 28355 (May 22, 2001); 76 Fed. Reg. 3821 (Jan. 21, 2011)).

released information on the underlying analysis. In both examples, energy security is evaluated in ways consistent with some or all of the G-7 definition, but the processes do not include a formal benefit-cost analysis or quantification of energy security.

II. Energy Security Background

A. Oil Price Disruption of the 1970s

After the 1973 oil embargo, consideration of energy security began to enter into the rationale for regulatory rulemaking with a focus on U.S. oil imports and the potential for oil price shocks in the world oil market. President Nixon announced the initiative Project Independence on November 7, 1973, in reaction to the embargo and ensuing oil crisis. The stated goal of Project Independence was to achieve energy self-sufficiency for the United States (Nixon 1973). The Energy Policy and Conservation Act of 1975—including Corporate Average Fuel Economy (CAFE) standards—was enacted to increase United States oil and gas production, reduce U.S. energy consumption and reduce reliance on oil imports (Pub. L. No. 94–163, 1975). In subsequent years, "energy security"—reducing United States reliance on oil imports—was embedded as a keystone of United States energy policy.[29]

As a result, the consideration of "energy security" issues in energy-related RIAs has largely focused on the effects of foreign oil imports.[30] Little attention has been given, for example, in RIAs to foreign import issues in the electricity and natural gas markets. That is probably because the U.S. markets for electricity and natural gas are largely separate from foreign sources. Canada and Mexico are the primary trading partners for these markets, and both countries are stable trading partners that provide a relatively small share of U.S. consumption.

In addition to the exclusive focus on oil, the energy-related RIAs generally do not consider some of the other benefit categories covered under the G-7 energy security principles, such as the diversification of energy supply, promoting development and deployment of clean and sustainable energy technologies, and improving energy system resilience. In many cases this reflects the definition of energy security used at the time.

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[29] For example, President George H. W. Bush in July 1991 set out the following objectives for energy policy: "continued economic growth, increased energy efficiency, strong environmental protection, and then a reduced dependence on foreign oil" (Bush 1991). In launching the development of the National Energy Strategy in 1989, President Bush set out the objectives as follows: achieving balance between "our increasing need for energy at reasonable prices, our commitment to a safer, healthier environment, our determination to maintain an economy second to none, and our goal to reduce dependence on potentially unreliable energy suppliers" (Bush 1989, 1018).

[30] This focus has continued up through recent years. For example, the draft joint technical support document for DOT and EPA 2017–2025 Corporate Average Fuel Economy (CAFE) rule for light-duty vehicles describes energy security as follows: "U.S. energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs or interruptions in energy supplies. Most discussions of U.S. energy security focus on the economic costs of U.S. dependence on oil imports, and particularly on U.S. reliance on oil imported from potentially unstable sources" (EPA and NHTSA 2012, 4-29).

B. Executive Order 13211

On May 18, 2001, President George W. Bush issued Executive Order (E.O.) 13211, Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use, requiring agencies in the executive branch to prepare a statement of energy effects for a significant energy action—that is, an action "likely to have a significant adverse effect on the supply, distribution, or use of energy."[31] Regulatory agencies have routinely included in their rule preambles a section addressing E.O. 13211.

C. Climate Change as New Priority for the Obama Administration

In two memoranda issued on January 26, 2009, President Barack Obama signaled a significant shift in U.S. policy by calling for "the first steps toward energy independence, as we develop new energy, set new fuel efficiency standards, and address greenhouse gas emissions."[32] This renewed call for energy independence broadens the definition of energy security, reflecting concern both for the traditional energy security issues of short run oil disruptions and oil imports, as well as longer term energy use and dependence levels, the need for resilience, and for limiting associated environmental risks.

As a part of the Obama Administration's policy initiative to address climate change, CEA and OMB assembled an interagency workgroup in 2009 to develop an estimate of the social cost of carbon (SCC).[33] The purpose of the SCC estimates is to allow agencies to incorporate the social benefits of reducing GHG emissions into cost-benefit analyses of regulatory actions that have small, "marginal" effects on cumulative global emissions. The interagency workgroup developed a set of SCC estimates by combining the results of three integrated assessment models (IAMs). The Interagency Working Group (IWG) published SC-CO_2 estimates for use in 2010 (IWG 2010), and updated them in 2013 (IWG 2013) to incorporate updated versions of models used in the peer-reviewed literature. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) that are consistent with the methodology underlying the SC-CO_2 (IWG SC-CO2 2016). In recent rulemakings, the addition of a monetized estimate of GHG benefits—using a 3 percent discount rate—typically increases the benefits estimate by 25 percent or less.[34]

Because of the sensitivity of the SC-CO_2 to the choice of discount rate, the workgroup presented SC-CO_2 estimates for discount rates of 2.5 percent, 3 percent, and 5 percent. In

[31] 66 Fed. Reg. 28355 (May 22, 2001), https://www.federalregister.gov/articles/2001/05/22/01-13116/actions-concerning-regulations-that-significantly-affect-energy-supply-distribution-or-use.

[32] https://www.whitehouse.gov/blog/2009/01/26/peril-progress-environment; https://www.whitehouse.gov/the-press-office/2009/01/26/presidential-memorandum-fuel-economy; https://www.whitehouse.gov/the-press-office/2009/01/26/presidential-memorandum-epa-waiver.

[33] The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. The estimates are presented with an acknowledgment of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts. https://www3.epa.gov/otaq/climate/regulations/scc-tsd.pdf.

[34] OMB's A-4 guidelines for RIAs call on the analyst to quantify and monetize all benefit categories (to the extent reasonable given available resources). A-4 guidelines do not set out a laundry list of benefit categories that must be addressed, and the scope and number of benefit categories covered vary depending on the rule and its primary focus.

addition, the workgroup also presented a fourth value to represent the marginal damages associated with lower-probability, but higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. Accordingly, this fourth value is selected from further out in the tail of the distribution of SC-CO_2 estimates; specifically, the fourth value corresponds to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. Agencies use the SC-CO_2 estimate based on a discount rate of 3 percent as a central value, but the workgroup emphasizes the importance of considering all four SC-CO_2 values in regulatory analyses

III. Approach to Reviewing Regulations

As discussed in previous chapters, various studies have identified potential energy security effects associated with oil imports, including macroeconomic disruption caused by price shocks, adverse effects of oil import costs on structural unemployment in the oil and gas industry and on long-term productivity growth, and the cost of policy actions designed to mitigate U.S. vulnerability to oil price shocks, particularly U.S. military expenditures to protect major oil suppliers and the Strategic Petroleum Reserve (SPR). In addition, the value of GHGs has been identified as an important element of energy security.

This evaluation primarily used two data sources to develop information on the estimation of these oil security benefits in RIAs. The first is the annual Report to Congress on the Benefits and Costs of Federal Regulations, prepared by the Office of Management and Budget (OMB). To satisfy its requirements under the Regulatory Right-to-Know Act, OMB submits this report to Congress each year and includes a list of all Federal major rules issued during the previous fiscal year. The second data source is the semiannual Unified Agenda of Federal Regulatory and Deregulatory Actions, compiled each spring and fall by the U.S. General Services Administration and OMB. It contains information about all regulations under development and recently issued by Federal agencies. Appendix C-1 lists these sources.

Using those documents, a database was compiled covering all 301 final major rules issued from DHS, DOC, DOE, DOI, DOT, EPA, and USDA between October 2004 and June 2016.[35] Of these, 115 major rules of potential relevance to energy security were identified (see Appendix C-2). The RIAs for these 115 rules were evaluated for their treatment of energy security benefits and costs. The RIAs potentially relevant to energy security were issued by EPA (43 percent), DOE (25 percent), DOT (23 percent), and DHS, DOI, USDA, and DOC (9 percent).[36]

In identifying potentially relevant rules, 186 major rules were excluded from further review as irrelevant to energy security based on our experience with Federal agency

[35] OMB defines a "major rule" as (1) designated as major under 5 U.S.C. § 804(2); (2) designated as meeting the analysis threshold under the Unfunded Mandates Reform Act of 1995 (UMRA); or (3) designated as "economically significant" under Section 3(f)(1) of Executive Order 12866.
[36] We examined a total of 117 RIAs because EPA and DOT produced separate RIAs for two of the three rules that they issued jointly.

regulation. These rules addressed such areas as healthcare, financial management, agricultural support programs, food labeling, and budget transfer rules (see Appendix C-3).

Data were collected on whether the RIA included a discussion of energy security, provided a qualitative or quantitative discussion of the several oil import premium components, and included any quantitative estimates in the final benefit estimates for the rule. Based on both the more traditional energy security concerns with oil imports and the recent G-7 energy security principles, the following key words were used to extract information for the review:

- ***Oil import premium:*** security, OPEC, reliance, foreign, import, premium, macroeconomic, disruption, monopsony
- ***Greenhouse gases:*** social cost, carbon, methane, greenhouse, climate
- ***Reliability:*** reliability, resilience, 13211, integrated planning model
- ***R&D:*** sustainable, renewable, energy technology, investment, R&D

Finally, the rules were grouped based on their statutory basis, the issuing agency, and the extent of the RIA's treatment of energy security. The first group covers rules that provide the most extensive treatment of energy security. Examples are DOT and EPA RIAs for rules addressing CAFE and Energy Independence and Security Act (EISA) requirements (Pub. L. No. 110-140, Dec. 19, 2007). These provide full discussion of the traditional energy security issues associated with foreign oil imports. Beginning in 2009, these RIAs also present a full discussion—with monetized estimates—of the climate change effects of the rules; DOT's 2006 CAFE rule for light-duty trucks presented only a qualitative discussion of the climate change issue. The second group consists of DOE's energy efficiency rules, many of which are mandated by EISA; these have a less extensive discussion than the first group. The third group includes DOT transportation safety rules and EPA air and water rules directed at environmental issues. Finally, for the "residual group" of rules, most of the RIAs provide a brief—often qualitative—discussion of the rule effects on energy production and/or consumption but do not address any of the components associated with energy security.

IV. Discussion

The discussion below begins with the focused treatment of energy security issues in the CAFE and EISA rules of DOT and EPA. The remainder of the discussion is organized by agency because, given differences in their statutory objectives and targeted sectors, agencies treat energy security in very different ways. Overall, agency RIAs have focused on benefit categories associated with the traditional treatment of energy security, rather than the broader set of categories identified in the recent G-7 energy security principles.

DOT's and EPA's RIAs for rules setting fuel efficiency standards for cars and trucks and implementing the renewable fuels mandate of EISA provide the most complete and extensive discussion of the several elements constituting energy security. The central or core purpose of the authorizing statutes for these rules is to reduce petroleum consumption (and oil imports) and greenhouse gas (GHG) emissions. Not surprisingly, then, the RIAs for these rules present a full analysis of their effect on energy security.

The regulatory analysis for DOE's energy efficiency standards—largely addressing products that use electricity or natural gas—focus on both the potential cost savings of the standards and the compliance costs of producing more efficient products. In the few cases where these rules were projected to reduce oil consumption, the regulatory analysis projected very small changes in oil use and did not evaluate further the energy security effects in terms of a change in oil prices and imports. After the current administration placed a priority in 2009 on addressing climate change, DOE's regulatory analyses for these rules included a monetized benefit estimate for the reduction in GHG emissions (using the interagency SCC). While the preambles for these rules provide a brief qualitative discussion—without any specifics—of other energy security effects, the regulatory analyses do not address further these additional elements.

The RIA benefits analyses for DOT's safety rules focus on reductions in mortality and injury-related risks, and these benefit categories largely account for the monetized benefits. In discussing the fuel consumption effects, five of these eight rules provide quantified estimates; the remaining RIAs offer qualitative descriptions. Three RIAs also discuss at least some aspect of the oil import premium, and four include a discussion of climate change effects—although only one includes a monetized benefit estimate (using the interagency SCC). However, for these rules, energy security is peripheral to their purposes, and the oil consumption effects—positive or negative where quantified—are small. It is not surprising to find that the attention given energy security in these RIAs is typically less extensive (and more likely to be qualitative) than the RIAs for DOT's CAFE and EISA rules. The focus of EPA rulemaking—apart from the rules implementing the EISA GHG emissions and renewable fuel mandates—is on environmental improvement and reducing public health risks and environment-related adverse welfare effects. The energy security aspects of these rules are somewhat peripheral. In fact, in several cases, the effects of these rules conflict with energy security objectives by increasing petroleum consumption and GHG emissions (and at least potentially adversely affecting the reliability or resilience of energy supply systems). EPA's RIAs for rules addressing the electricity generation sector typically address GHG emissions and reliability issues, and in two instances, they offer a qualitative discussion of the deployment of sustainable energy technologies. The RIAs addressing other sectors typically present a brief, mostly qualitative discussion (if any at all).
For most of the rules identified in this review, the agencies determined that the rules would not be "likely to have a significant adverse effect on the supply, distribution, or use of energy." EPA—as the one exception—identified eight of its rules as likely to have a significant adverse effect. Overall, the agencies addressed the E.O. 13211 requirements in a brief one- or two-paragraph statement.

A. EPA and DOT: CAFE and EISA Rules

Congress adopted the legislation mandating CAFE standards in 1975 to reduce energy consumption by increasing the fuel economy of cars and light trucks (Energy Conservation and Policy Act of 1975, Pub. L. No. 94–163, 1975). The intent was to create a more fuel-efficient fleet, thereby improving the nation's energy security and saving consumers money at the pump.

Following the adoption of 2007 Energy Independence and Security Act, which mandated more stringent fuel economy standards and set an aggressive schedule for adding renewable fuels to the fuel supply, DOT and EPA rulemaking have had the dual objective of reducing petroleum consumption (and oil imports) and greenhouse gas (GHG) emissions (Pub. L. No. 110-140, Dec. 19, 2007). Thus it is not surprising to find a thorough discussion of these energy security elements in the post-2007 RIAs that explain how the final EISA and GHG rules will affect energy security, describe the types of energy security effects, and justify their inclusion in the final benefit-cost analysis.[37]

The RIAs for the CAFE and EISA rules estimate the expected reductions in petroleum consumption and oil imports and consider their potential energy security implications. Table 3.1 lists the major rules and the qualitative and/or quantitative treatment of four energy security components.

Table 3.1. DOT and EPA rules to improve vehicle fuel economy, reduce U.S. dependence on petroleum imports, and reduce GHGs

FY	Agency	Title	Macroeconomic Disruption	Military Expenditures	SPR	GHGs
2012	EPA (40 CFR)	Passenger Car and Light Truck Establish 2017 and Later GHG Emissions and CAFE Standards (EISA) for MY 2017 and later Vehicles*	\$8.26/barrel (2010\$) in 2025	Qualitative	Qualitative	\$27/ton of CO_2 (2010\$) in 2020 (\$7–\$84)
2012	DOT (49 CFR)	Passenger Car and Light Truck Corporate Average Fuel Economy Standards MYs 2017 and Beyond (EISA)*	\$8.26/barrel (2010\$) in 2025	Qualitative + sensitivity analysis	Qualitative	\$27/ton of CO_2 (2010\$) in 2020 (\$7–\$84)
2011	EPA, DOT (40 CFR, 49 CFR)	Commercial Medium- and Heavy-Duty On-Highway Vehicles and Work Truck Fuel Efficiency Standards (EISA)	\$7.11/barrel (2009\$) in 2020	Qualitative	Qualitative	\$23.06/ton of CO_2 (2009\$) in 2012 (\$5.28–\$70.14)
2010	EPA (40 CFR, 49 CFR)	Light-Duty Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards (EISA) for MY 2012–2016*	\$7.62/barrel (2007\$) in 2020	Qualitative	Qualitative	\$21/ton of CO_2 (2007\$) in 2010 (\$5–\$65)

[37] President Obama requested that NHTSA establish revised CAFE standards in his memorandum of January 26, 2009, which called for the development of new national policies to prompt sustained domestic and international actions to address the closely intertwined issues of energy independence, energy security, and climate change.

2010	DOT (49 CFR)	Light-Duty Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards (EISA) for MY 2012–2016*	$7.10/barrel (2007$)	Qualitative + sensitivity analysis	Qualitative	$21/ton of CO_2 (2007$) in 2010 ($5–$65)
2010	EPA (40 CFR)	Renewable Fuels Standard Program (EISA)	$6.56/barrel oil + ethanol or $7.08/barrel just oil (2007$) in 2022	Qualitative	Qualitative	$20/ton of CO_2 (2007$) globally in 2013 ($5–$34) and $1.20/ton of CO_2 (2007$) domestically in 2013
2009	DOT (49 CFR)	Passenger Car and Light Truck Corporate Average Fuel Economy Model Year 2011 (EISA)	$4.87/barrel (2007$)**	Qualitative + sensitivity analysis	Qualitative	$33 and $80/ton of CO_2 (2007$) globally in 2007 and $2/ton of CO_2 (2007$) domestically in 2007
2006	DOT (49 CFR)	Average Fuel Economy Standards for Light Trucks Model Years 2008–2011 (CAFE)	$1.89/barrel (2003$)**	Qualitative	Qualitative	Qualitative

Impact categories: A number indicates the impact was quantified; "Qualitative" indicates the impact was qualitatively described—no quantitative estimate was included. For GHGs, the value listed is the social cost of carbon (SCC) estimate for a 3% discount rate. The numbers in parentheses indicate the range of SCC estimates used by the agency, the lower number associated with a 2.5% discount rate and the higher number associated with the 95th percentile of the 3% discount rate. MY = model year.

* EPA and DOT issued a joint rule-making but prepared separate RIAs.

** DOT's estimate of $1.89/barrel in the 2006 light trucks CAFE rule was based on Leiby et al. (1997); its estimate of $4.87/barrel for the 2009 light vehicle CAFE was based on Leiby (2007). The remaining estimates for both EPA and DOT were based on Leiby (2008).

The methodology—including the language and the graphics—for both agencies' RIAs is based on Leiby (2008), although DOT and EPA energy security analyses differ, as discussed below.

i. Macroeconomic Disruption Estimates

EPA worked with Leiby for each of its RIAs related to fuel economy, adapting the energy security premium methodology to incorporate oil price forecasts and energy market trends from the most recent Annual Energy Outlook from EIA.[38] The agency then calculated an energy security premium for each year over the course of the program's expected lifetime.

[38] At the request of EPA, ORNL revised the Leiby (2008) estimates in subsequent years to reflect changes in projected world oil prices (based on the most up-to-date editions of EIA's Annual Energy Outlook). These updates continued to use the peer-reviewed methodology developed in Leiby (2008).

In contrast, DOT used a single year's estimate of the energy security benefits of the rule and did not calculate an oil import premium for each year of the cost-benefit analysis. For example, for the CAFE standards for the 2012–2016 model years (MYs), EPA used the Oak Ridge National Laboratory estimates for 2015, 2020, 2030, and 2040 to calculate a stream of energy security benefits for each year from 2015 to 2040, interpolating values for the intervening years. In contrast, DOT simply used the energy security estimate for 2015 in its benefits calculation.

For its 2010 Renewable Fuel Standard program (RFS), EPA calculated the energy security effects of reducing oil imports and increasing dependence on biofuels. Following similar logic to the macroeconomic effects from disruptions in oil imports, the agency notes the potential for disruption and adjustment costs to the economy if renewable fuel supplies are interrupted by, for example, droughts or floods. This negative effect from an increased reliance on renewable fuels offsets some of the benefits of the decreased dependence on imported oil. Therefore, the RIA presents two estimates for the macroeconomic impact of the rule: the first considers only the effect of reduced oil imports, and the second adds the partially offsetting effect of an increased reliance on biofuels. EPA adopts the second estimate as its primary estimate in the final RIA.

ii. Military Expenditures

Both DOT and EPA provide a qualitative discussion of the rationale for considering military expenditures in developing an energy security–based benefits estimate. However, following Leiby (2008), they do not include an estimate of oil import effects on military expenditures. The agencies note the difficulty of attributing specific military costs to maintaining energy security and explain that military costs do not appear to change with incremental changes in oil imports.

However, for three RIAs, DOT develops a quantitative estimate of the military expenditure component of the oil import premium as a part of a sensitivity analysis. DOT arrives at this estimate by assuming that some percentage of the U.S. military costs for securing Persian Gulf oil, calculated by Delucchi and Murphy (2008), can be reduced in proportion to the reduction in U.S. oil imports from that region. For the 2009 and 2010 DOT RIAs, the agency sensitivity analysis assumes that only half of U.S. military costs will be reduced proportionally (yielding an estimate of $2.10/barrel, in 2007$); in the 2012 rule, the agency assumes that all military costs will be reduced proportionally (yielding an estimate of $5.04/barrel, in 2010$).

iii. Strategic Petroleum Reserve

The SPR is qualitatively described and uniformly excluded from all of these RIAs. There is no distinguishable difference in the treatment of the SPR in these RIAs between agencies or within an agency over time.

Both DOT and EPA provide a qualitative discussion of the rationale for considering SPR costs in developing an energy security–based benefits estimate. However, following Leiby (2008), they do not include an estimate of SPR-related oil import effects. The agencies explain that SPR costs do not appear to change with incremental changes in oil imports. Historically, U.S. SPR policy has not been determined solely by the minimum size necessary to meet IEA obligations given U.S. import levels. So such a marginal variation in SPR size and costs was not deemed an appropriate part of the oil security calculation for incremental import changes. The energy security premium approach in Leiby (2008) does account for the existence of the current SPR and its ability to attenuate price shocks. Any assumed endogenous variation in SPR with imports as part of the energy security premium analysis would also have to account for the implied change in oil shock protection. The RIAs were not addressing the optimal size of the SPR, therefore the energy security costs analyses abstracted from any potential SPR size changes.

iv. Monopsony

Beginning in 2010, DOT and EPA excluded a monopsony premium from their primary benefits estimates for the RIAs for these rules because, from a global perspective, the monopsony effect is simply a transfer payment between U.S. consumers and foreign oil producers.[39] However, the agencies continued to offer a discussion of estimates of the monopsony premium as part of the oil import premium discussion, with estimates ranging from $7.86 per barrel to $12.50 per barrel (2007$). In some instances, DOT included the monopsony premium in sensitivity analyses performed as part of the RIA. For rules issued prior to 2010, DOT included monopsony benefit estimates of $1.85/barrel (2003$) and $11.17/barrel (see Appendix C-4). The monopsony premium component of energy security declines more directly (almost in linear proportion) with projected net import levels, and has therefore been smaller in recent estimates.

B. Department of Energy: Energy Efficiency and Conservation Rules

From 2007 to 2016, DOE issued 29 major rules—many mandated by EISA—setting energy efficiency and conservation standards for both household appliances and commercial and industrial equipment (Table 3.2). These standards cover equipment ranging from clothes and dish washers to commercial icemakers to electric motors and pumps. Most, but not all, of these standards serve primarily to reduce electricity consumption; these rules have little to no effect on oil consumption and imports.

Beginning in 2009, the RIAs for DOE's energy efficiency rules present a quantified, monetized estimate of the climate change effects of the rule using the current estimates of the SCC adopted by the interagency workgroup. The earliest rules listed below were issued before the SCC estimates were developed. Three of these early RIAs provided a qualitative description of the effect of the rule on GHG emissions. For the 2009 Energy Efficiency

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[39] The monopsony effect reflects a pecuniary externality—that is, an externality that operates through the effect of the regulatory action on prices—rather than through a direct resource effect on a third party. A pecuniary externality does not affect resource allocation; in fact, in an otherwise properly functioning market, government action to address the pecuniary externality will further distort resource use instead of improving the allocation of resources and the production possibilities of the economy. However, arguments have been made for including the monopsony effect. The most prevalent argument is that the world oil market is not fully competitive (over 75 percent of global supply is controlled by governments or government-owned corporations, including OPEC, Russia, and others), and prices are strongly influenced by the decision of noncompetitive countries. In that case, the monopsony effect is a market failure of a noncompetitive world oil supply (see, e.g., Greene 2010). Under this view, the monopsony effect reflects the appropriate countervailing exercise of consumer market power in the face of supplier market power, to limit transfer of wealth to foreign oil suppliers.

Standards for General Service Fluorescent Lamps and Incandescent Lamps, DOE relied on the range of values from DOT's 2009 CAFE rule for light-duty vehicles as the basis for monetizing the climate change effects.[40]

Apart from the discussion of GHG benefits, the RIAs for these rules do not discuss other specific elements of energy security.[41] For example, as a part of the regulatory analyses, DOE includes a "utility impact analysis" that assesses the effect of the standards on installed electricity generation capacity and on projected annual electricity generation, but does not evaluate the associated effects of projected changes in capacity and generation on the reliability and resilience of the electric utility system.

More broadly, the preambles for these rules provide only a brief qualitative discussion—without any specifics—of the energy security impacts of the energy efficiency standards.[42] The preambles refer to E.O. 13211, reporting that these final rules are not significant energy actions because they are not likely to have a significant adverse effect on the supply, distribution, or use of energy. The RIAs do not provide any further discussion of E.O. 13211 issues.

Table 3.2. DOE RIAs for energy efficiency and conservation standards

FY	Agency	Title	GHGs
2016	DOE (10 CFR §430)	Energy Conservation Standards for Commercial and Industrial Pumps	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §431)	Energy Conservation Standards for Single Package Vertical Air Conditioners and Single Package Vertical Heat Pumps	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §430)	Energy Conservation Standards for Residential Ceiling Fan Light Kits	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)

[40] In its 2009 CAFE rule, DOT adopted the following range of values for the global SCC: \$2, \$33, and \$80 per ton of CO_2. DOE notes that the lower end of this range, \$2, also approximates the possible mean value for domestic benefits (74 Fed. Reg. 34163).

[41] For each of its energy efficiency and conservation standards, DOE prepares a technical support document (TSD) presenting the technical and economic analysis for each rule. Though not titled as RIAs, these TSDs effectively constitute the agency's RIAs.

[42] The preambles to these final rules contain the following language: "DOE also considers the need for national energy conservation in determining whether a new or amended standard is economically justified (42 U.S.C. 6313(a)(6)(B)(ii)(VI)). The energy savings from the adopted standards are likely to provide improvements to the security and reliability of the Nation's energy system. Reductions in the demand for electricity also may result in reduced costs for maintaining the reliability of the Nation's electricity system. DOE conducts a utility impact analysis to estimate how standards may affect the Nation's needed power generation capacity."

2016	DOE (10 CFR §430)	Energy Conservation Standards for Residential Boilers*	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §431)	Energy Conservation Standards for Small, Large, and Very Large Commercial Package A/C and Heating Equipment	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §429, §431)	Energy Conservation Standards for Refrigerated Bottled or Canned Beverage Vending Machines	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §431)	Energy Conservation Standards for Commercial Warm Air Furnaces*	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2016	DOE (10 CFR §429, §431)	Energy Conservation Standards for Commercial Pre-Rinse Spray Valves	\$40.0/ton of CO_2 (2014\$) in 2015 (\$12.2–\$117)
2015	DOE (10 CFR §431)	Energy Efficiency Standards for Automatic Commercial Ice Makers	\$40.5/ ton of CO_2 (2013\$) in 2015 (\$12.0–\$119)
2014	DOE (10 CFR §431)	Energy Conservation Standards for Walk-In Coolers and Walk-In Freezers	\$40.5/ ton of CO_2 (2013\$) in 2015 (\$12.0–\$119)
2014	DOE (10 CFR §429 §430)	Energy Conservation Standards for Residential Furnace Fans	\$40.5/ ton of CO_2 (2013\$) in 2015 (\$12.0–\$119)
2014	DOE (10 CFR §430)	Energy Efficiency Standards for External Power Supplies	\$39.7/ton of CO_2 (2012\$) in 2015 (\$11.8–\$117)
2014	DOE (10 CFR §431)	Energy Efficiency Standards for Metal Halide Lamp Fixtures	\$39.7/ton of CO_2 (2012\$) in 2015 (\$11.8–\$117)

2014	DOE (10 CFR §431)	Energy Conservation Standards for Commercial Refrigeration Equipment	\$39.7/ton of CO_2 (2012\$) in 2015 (\$11.8–\$117)
2014	DOE (10 CFR §431)	Energy Efficiency Standards for Certain Commercial and Industrial Electric Motors	\$39.7/ton of CO_2 (2012\$) in 2015 (\$11.8–\$117)
2013	DOE (10 CFR §430)	Energy Efficiency Standards for Microwave Ovens (Standby and Off Mode)	\$41.1/ton of CO_2 (2011\$) in 2016 (\$12.6–\$119)
2013	DOE (10 CFR §431)	Energy Efficiency Standards for Distribution Transformers	\$22.3/ton of CO_2 (2011\$) in 2011 (\$4.9–\$67.6)
2012	DOE (10 CFR §429, §430)	Energy Conservation Standards for Residential Clothes Washers	\$22.3/ton of CO_2 (2010\$) in 2010 (\$4.9–\$67.6)
2012	DOE (10 CFR §430)	Energy Efficiency Standards for Fluorescent Lamp Ballasts	\$22.1/ton of CO_2 (2009\$) in 2010 (\$4.9–\$67.1)
2011	DOE (10 CFR §430)	Energy Efficiency Standards for Residential Furnace, Central Air Conditioners and Heat Pumps	\$22.1/ton of CO_2 (2009\$) in 2010 (\$4.9–\$67.1)
2011	DOE (10 CFR §430)	Energy Efficiency Standards for Residential Refrigerators, Refrigerator-Freezers, and Freezers	\$22.1/ton of CO_2 (2009\$) in 2010 (\$4.9–\$67.1)
2011	DOE (10 CFR §431)	Energy Efficiency Standards for Clothes Dryers and Room Air Conditioners	\$22.1/ton of CO_2 (2009\$) in 2010 (\$4.9–\$67.1)
2010	DOE (10 CFR §430)	Energy Efficiency Standards for Pool Heaters and Direct Heating Equipment and Water Heaters	\$22/ton of CO_2 (2009\$) in 2010 (\$5–\$67)
2010	DOE	Energy Conservation Standards for Small Electric Motors	\$22/ton of CO_2 (2009\$) in 2010 (\$5–\$67)

	(10 CFR §431)		
2010	DOE (10 CFR §431)	Energy Efficiency Standards for Commercial Clothes Washers	\$20/ton of CO_2 (2008\$) globally in 2007 (\$5–\$56) and \$1/ton of CO_2 (2008\$) domestically in 2007
2009	DOE (10 CFR §430)	Energy Efficiency Standards for General Service Fluorescent Lamps and Incandescent Lamps	\$33/ton of CO_2 (2007\$) globally in 2007 (\$2–\$80) and \$2/ton of CO_2 (2007\$) domestically in 2007
2009	DOE (10 CFR §430)	Energy Efficiency Standards for Commercial Refrigeration Equipment	Qualitative
2008	DOE (10 CFR §430)	Energy Efficiency Standards for Residential Furnaces and Boilers	Qualitative
2007	DOE (10 CFR §430)	Energy Efficiency Standards for Electric Distribution Transformers	Qualitative

Impact categories: "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included. For GHGs, the value listed is the social cost of carbon (SCC) estimate for a 3% discount rate. The numbers in parentheses indicate the range of SCC estimates used by the agency, the lower number associated with a 2.5% discount rate and the higher number associated with the 95th percentile of the 3% discount rate.

* The rule reduces oil consumption, but the RIA does not address the energy security impacts of reduced oil imports.

C. Department of Transportation Safety Rules

DOT issued most rules under its authority to address safety in transportation. The primary, quantified benefits in the RIAs arise from reductions in injury and mortality risk; energy security is peripheral to the rules' purpose, and the oil consumption effects—positive or negative where quantified—were small. Where the RIA provided a quantified estimate of the oil premium, the RIA discussion was typically limited, referring instead to DOT's fuel efficiency rules (Table 3.3).

The RIA for NHTSA's Roof Crush rule presented a quantified, monetized estimate of the rule's climate change effect. The rule increases fuel use because it increases the weight of the vehicle. With the increase in fuel use, there is also an increase in CO_2 emissions; NHTSA monetized this "disbenefit" using then-current estimates of the SCC. Three additional rules provided a qualitative description. The RIAs for these safety rules do not address energy system reliability, the encouragement of R&D, and/or the development of sustainable energy technologies.

In addition to these safety-related rules, DOT also issued a major rule implementing the 2009 Car Allowance Rebate System ("cash-for-clunkers"). Congress adopted the program to support the purchase of new vehicles during the worst months of the Great Recession. DOT's RIA for this rule provided a qualitative discussion of the oil consumption and carbon dioxide emissions effects. However, it did not discuss the effect of the rule on oil imports or any of the associated energy security effects (like economic disruption). The RIA also did not address effects on the reliability of the energy system, promoting R&D, or the development of sustainable energy technologies.

The RIAs typically do not discuss E.O. 13211, but DOT's preamble for a more recent final rule includes a brief E.O. 13211 statement that the rule is not a significant energy action because "it is not likely to have a significant adverse effect on the supply, distribution, or use of energy."

Table 3.3. DOT RIAs for rules affecting oil consumption

FY	Agency	Title	Description of Impact on Oil Consumption	Direction of Oil Effect	Oil Import Premium	GHGs	Direction of GHG Effect
2015	DOT (49 CFR)	Hazardous Materials: Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains	Quantified	Increases consumption	None	None	None
2011	DOT (23 CFR)	Real-Time System Management Information Program	Quantified	Reduces consumption	None	None	None
2010	DOT (46 CFR)	Positive Train Control	Qualitative	Reduces consumption	None	None	None
2009	DOT (49 CFR)	Roof Crush Resistance*	Quantified	Increases consumption	Macroeconomic disruption effect: $5.04/barrel (2007$)	Quantitative: $33 and $80/ton of CO_2	Increases emissions
2009	DOT (49 CFR)	Requirements for Car Allowance Rebate System	Qualitative	Reduces consumption	None	Qualitative (carbon dioxide)	Reduces emissions
2008	DOT (49 CFR)	Regulatory Relief for Electronically Controlled Pneumatic Brake System Implementation	Qualitative	Reduces consumption	None	None	None

2007	DOT (49 CFR)	Electronic Stability Control	Quantified	Increases consumption	Macroeconomic disruption effect**: $1.97/barrel (2005$)	Qualitative (carbon dioxide)	Increases emissions
2005	DOT (49 CFR)	Tire Pressure Monitoring Systems	Quantified	Reduces consumption	Premium reflecting wealth transfer to OPEC: $3.00/barrel (2001$)	Qualitative (carbon dioxide)	Reduces emissions

Impact categories: "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included.

*The RIA also contains a quantitative estimate for wealth transfer of $11.34/barrel (but does not include in primary benefit estimate because monopsony is a transfer, given a global SCC). The RIA also offers a qualitative discussion ruling out any effect of the rule on military expenditures. The SCC estimates are based on the RIA for DOT's 2009 rule setting CAFE standards for MY 2011.

**The RIA also contains a wealth transfer estimate of $5.96/barrel; estimates come from the 2006 CAFE for light-duty trucks.

D. Environmental Protection Agency: Rules Addressing Conventional Air Pollutant Sources

The environmental statutes serve as the basis for most of EPA's major rules. The primary regulatory objectives (e.g., reduction of human health risks) are central to EPA's analyses; some attributes of energy security as defined in this report are peripheral—and in fact, in certain cases the effects of these rules conflict with some aspects of energy security by increasing petroleum consumption. For example, EPA's MARPOL rules addressing emissions from large marine engines are expected to set a sulfur emissions standard that effectively requires ships to replace the use of residual fuel oil (bunker fuel) with ultra-low sulfur diesel. That is expected to greatly increase the demand for and production of diesel, which will in turn increase the production of residual fuel oil because it is a co-product of diesel production. The price for residual fuel oil will fall, which will increase demand from countries where the combustion of residual fuel oil to generate electricity is more cost effective than the combustion of natural gas.

In addition, some of the rules addressing emissions from the electric power sector (at least potentially) could adversely affect the reliability or resilience of energy supply systems. Where these rules would adversely affect petroleum consumption and GHG emissions, EPAs RIAs provided (at least in some instances) a monetized estimate of the associated "disbenefit"—that is, the additional costs of the rule arising from these adverse effects.

Beginning in 2010, EPA's RIAs present quantitative estimates of the effect of rules on GHG emissions and monetize these reductions using the interagency SCC estimate. A few RIAs address—quantitatively or qualitatively—the effect of rules on oil consumption, but with a few exceptions they do not include an explicit discussion of the energy security effects of the rule. The RIAs for rules limiting emissions from electricity generating plants—and for a few other rules—also present a brief qualitative discussion of the effect on energy system reliability and resilience.

EPA's RIAs generally include a brief discussion in response to the requirements of E.O. 13211. EPA reported that eight of its major rules over the period of our review, six of which affect the electric power sector, would have a significant adverse effect on energy use and production. For example, EPA finds that the rules affecting electric utilities will reduce coal-fired capacity and increase electricity prices.[43] For the rules addressing other sectors of the economy, EPA generally finds no significant effect on energy use, production, or distribution. Overall, given the focus of many of these rules on reducing conventional pollutant emissions to protect human health and the environment, it is not surprising that the treatment of the several energy security issues in many of these RIAs—where addressed at all—is brief and refers to the RIAs for EPA's fuel economy rules.

i. EPA Rules Affecting the Electric Power Sector

EPA used ICF's Integrated Planning Model (IPM) to project the effect of its electric power sector rules on generation capacity and annual generation by fuel (e.g., coal, gas).[44] Oil-fired electricity generation units (EGUs) account for a very small fraction of total generation; thus these rules are projected to have almost no effect on the oil market and oil imports.

Commenters raised the concern that many of these rules might adversely affect the reliability of the electric utility system. In response, EPA prepared separate technical support documents. For the Clean Air Interstate Rule, for example, EPA evaluated the ability of the utility industry to marshal the needed labor and control equipment to meet the compliance dates in the rule. In more recent rules, the reliability issue has shifted to the potential effect of the closure of fossil-fueled generation units. To address this concern, EPA has used the IPM to analyze the effects of the projected plant retirements on electric system reliability as measured by the projected reserve margin,[45] and RIAs generally conclude that the rules will not adversely affect reliability.[46]

Beginning with the current administration, all the RIAs addressing the electric power sector included estimates of the rules' effects on the sector's GHG emissions (Table 3.4). The RIAs provide a summary of the interagency workgroup report and monetize the CO_2 reduction estimates using its SCC. Two recent RIAs for rules limiting the sector's GHG

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[43] For example, EPA finds that the Clean Air Interstate Rule (CAIR), Mercury and Air Toxics Standards (MATS), and Clean Power Plan (CPP) would have a significant adverse effect on energy use, production, or distribution. See https://archive.epa.gov/airmarkets/programs/cair/web/pdf/finaltech08.pdf (CAIR); https://www3.epa.gov/ttn/ecas/docs/ria/utilities_ria_final-mats_2011-12.pdf (MATS); and https://www.epa.gov/sites/production/files/2015-08/documents/cpp-final-rule-ria.pdf (CPP).

[44] "IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector" used by EPA to project likely future electricity market conditions with and without the rule in place. The model "provides forecasts of least cost capacity expansion, electricity dispatch, and emission control strategies while meeting energy demand and environmental, transmission, dispatch, and reliability constraints" (EPA 2014). See https://www.icf.com/solutions-and-apps/ipm.

[45] See, for example, EPA's discussion of this issue for the 2012 National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Electric Utility Steam Generating Units (i.e., the MATS rule) in a TSD titled "Resource Adequacy and Reliability in the IPM Projections for the MATS Rule," available in the docket for the MATS rule at https://www.regulations.gov/document?D=EPA-HQ-OAR-2009-0234-19997.

[46] Reliability is treated as an externally imposed constraint (target reserve margin) in each region in the model and is not itself a decision variable. IPM retires capacity if it is no longer needed to provide energy for load or to provide capacity to meet reserve margin during the planning horizon of the projections.

emissions explicitly provide a qualitative discussion of deploying sustainable energy technologies.[47] In the RIAs for these rules, EPA notes that deploying renewable technologies will be a primary method of meeting the standard.

Finally, in the E.O. 13211 section of their RIAs, EPA identified six of these rules as likely to have a significant adverse effect on energy supply, distribution, or use.

Table 3.4. EPA RIAs for rules affecting electric power sector

FY	Agency	Title	Oil Import Premium	GHGs	Reliability	R&D
2016	EPA	Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (40 CFR)	Qualitative (minimal reliance on foreign energy sources)	\$46/ton of CO_2 (2013\$) in 2020 (\$13–\$130)	None	None
2015	EPA	Standards for the Management of Coal Combustion Residuals Generated by Commercial Electric Power Producers (40 CFR)	None	\$43/ton of CO_2 (2007\$) in 2020 (\$12–\$128)	Electric system	None
2015	EPA	Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units (77 FR. 79 FR, 80 FR)	None	\$41/ton of CO_2 (2011\$) in 2022 (\$13–\$120)	Electric system	Deployment of sustainable energy technologies
2015	EPA	Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (Clean Power Plan) (40 CFR)	None	\$40/ton of CO_2 (2011\$) in 2020 (\$12–\$120)	Electric system	Deployment of sustainable energy technologies
2014	EPA	Criteria and Standards for Cooling Water Intake Structures (40 CFR)	Qualitative (minimal reliance on foreign energy sources)	\$45.89/ton of CO_2 (2011\$) in 2020 (\$12.81–\$136.59)	Quantitative (electric system)	None
2013	EPA	Reconsideration of Final National Emission Standards for Hazardous Air Pollutants	None	None	Qualitative (electric system)	None

[47] Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units; Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (Clean Power Plan).

		for Reciprocating Internal Combustion CI Engines (40 CFR)				
2012	EPA	National Emission Standards for Hazardous Air Pollutants from Coal- and Oil-Fired Electric Utility Steam Generating Units and Standards of Performance for Electric Utility Steam Generating Units (40 CFR)	None	\$24.3/ton of CO_2 (2007\$) in 2016 (\$5.9–\$74.4)	Electric system	None
2011	EPA	Cross-State Air Pollution Rule (CAIR Replacement Rule) (80 FR)	None	\$23.4/ton of CO_2 (2007\$) in 2012 (\$5.5–\$71.2)	Electric system	None
2005	EPA	Clean Air Visibility Rule: Best Available Retrofit Technology (BART) (40 CFR)	None	None	Electric system	None
2005	EPA	Clean Air Mercury Rule—Electric Utility Steam Generating Units (70 FR)	None	None	Electric system	None
2005	EPA	Clean Air Interstate Rule (40 CFR)	None	None	Electric system	None

Impact categories: A number indicates the impact was quantified. "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included. For GHGs, the value listed is the social cost of carbon (SCC) estimate for a 3% discount rate. The numbers in parentheses indicate the range of SCC estimates used by the agency, the lower number associated with a 2.5% discount rate and the higher number associated with the 95th percentile of the 3% discount rate.

ii. EPA Rules Affecting the Oil and Gas Sector

Based on runs of the National Energy Modeling System, EPA projected that three recent oil and natural gas sector rules—two from 2012 and one from 2016—will have at most a minimal effect on oil and natural gas production and on oil imports. EPA did not develop production and import estimates for its New Source Performance Standards (NSPS) for petroleum refineries. These three RIAs do not discuss any energy security effects in terms of macroeconomic disruptions or oil import premiums.

The RIAs' estimates for a reduction in GHG emissions used a summary of the interagency workgroup report and the SCC estimates for CO_2 reductions (Table 3.5). The 2012 oil and gas RIA includes a sensitivity analysis with a discussion of the issues in monetizing a social cost for methane reductions. The 2016 oil and gas RIA includes a monetized methane reduction estimate as a part of its primary benefits estimate.

These RIAs do not address energy system reliability, the encouragement of R&D, or the development of sustainable energy technologies.

Responding to E.O. 13211, the RIAs state that these final rules are "not likely to have a significant adverse effect on the supply, distribution, or use of energy."

Table 3.5. EPA RIAs for rules affecting oil and gas sector

FY	Agency	Title	Oil Import Premium	GHGs	Direction of GHG Effect	Reliability
2016	EPA	Oil and Natural Gas Sector: Emission Standards for New and Modified Sources (40 CFR)	None	\$1,100/ton of CH_4 (2012\$) in 2015 (\$490–\$3,000)	Reduces emissions	None
2012	EPA	Petroleum Refineries—New Source Performance Standards (NSPS)—Subparts J and Ja (40 CFR)	None	\$21/ton of CO_2 (2007\$) in 2010 (\$5–\$65)	Reduces emissions	None
2012	EPA	Oil and Natural Gas Sector—New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants (40 CFR)	None	\$25/ton of CO_2 (2008\$) in 2015 (\$6–\$76) \$840/ton CO_2-e for methane	Reduces emissions	None

Impact categories: A number indicates the impact was quantified; "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included. For GHGs, the value listed is the social cost of carbon (SCC) or methane (SCM) estimate for a 3% discount rate. The numbers in parentheses indicate the range of SCC and SCM estimates used by the agency, the lower number associated with a 2.5% discount rate and the higher number associated with the 95th percentile of the 3% discount rate.

iii. EPA Rules Affecting Industrial Sources

The RIAs for rules affecting these three industrial sources report negligible changes in fuel use (Table 3.6). The RIAs do not provide estimates of the effect of these rules on oil markets or oil imports. However, the control equipment required by these three rules will use additional electricity and the RIAs estimate that these rules will have the indirect effect of increasing GHG emissions from the electric power sector. The RIA discussions of climate change effects include a summary of the interagency workgroup report and its SCC estimates for CO_2 emissions.

The RIAs for these industrial sector rules do not address the encouragement of R&D and/or the development of sustainable energy technologies.

For E.O. 13211, the RIAs for these rules state that these final rules are "not likely to have a significant adverse effect on the supply, distribution, or use of energy."

Table 3.6. EPA RIAs for rules affecting industrial sources

FY	Agency	Title	GHGs	Direction of GHG Effect	Reliability
2015	EPA	Brick and Structural Clay Products NESHAP (40 CFR)	\$43/ton of CO_2 (2011\$) in 2018 (\$13–\$120)	Increases emissions	None
2013	EPA	NESHAP for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters; Proposed Reconsideration (40 CFR)	\$21/ton of CO_2 (2007\$) in 2010 (\$5–\$65)	Increases emissions	None
2010	EPA	NESHAP: Portland Cement Notice of Reconsideration (40 CFR)	\$21.5/ton of CO_2 (2005\$) in 2013 (\$5.0–\$65.6)	Increases emissions	Electricity and natural gas

Impact categories: "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included. For GHGs, the value listed is the social cost of carbon (SCC) estimate for a 3% discount rate. The numbers in parentheses indicate the range of SCC estimates used by the agency, the lower number associated with a 2.5% discount rate and the higher number associated with the 95th percentile of the 3% discount rate.

Note: NESHAP = National Emission Standards for Hazardous Air Pollutants.

iv. EPA Rules Affecting Mobile Sources

EPA's RIAs for four rules affecting mobile sources projected small changes in gasoline and diesel fuel use. For three of the rules, the RIAs projected a small fuel economy penalty associated with the additional control requirements. The RIA for large Marine Diesel Engines also projected an increase in GHG emissions commensurate with the fuel economy penalty; however, the reduction in methane and nitrous oxide emissions for EPA's 2014 Tier 3 rule and the reduction in tropospheric ozone with the 2008 locomotive and marine engine rule have potentially offsetting effects and the RIAs for these two rules projected a net reduction in GHG emissions (Table 3.7).

The RIAs do not address energy system reliability, the encouragement of R&D, or the development of sustainable energy technologies.

In response to E.O. 13211, the RIAs state that these final rules are "not likely to have a significant adverse effect on the supply, distribution, or use of energy."

Table 3.7. EPA RIAs for rules affecting mobile sources

FY	Agency	Title	Description of Impact on Oil Consumption	Direction of Oil Impact	Oil Import Premium	GHGs	Direction of GHG Impact	Reliability
2014	EPA	Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards (40 CFR)	Quantified	Increases consumption	None	Qualitative (methane and nitrous oxide)	Reduces emissions	None
2010	EPA	Control of Emissions from New Marine Compression-Ignition Engines at or above 30 Liters per Cylinder (40 CFR)	Quantified	Increases consumption	Macroeconomic disruption effect: $4.74/barrel (2007$)	$8 and $83/ton of CO_2 (2007$) in 2020	Increases emissions	None
2008	EPA	Control of Emissions from New Locomotives and New Marine Diesel Engines Less Than 30 Liters per Cylinder (40 CFR)	Quantified	Increases consumption	None	Qualitative (tropospheric ozone)	Reduces emissions	None
2008	EPA	Control of Emissions from Nonroad Spark Ignition Engines and Equipment (40 CFR)	Quantified	Reduces consumption	None	None	None	None

Impact categories: "Qualitative" indicates the impact was qualitatively described, but no quantitative estimate was included.

E. Other EPA Rules with a Qualitative Discussion of Greenhouse Gas Effects

Other EPA RIAs that contain qualitative discussions of the GHG effects of the rules are listed in Appendix C-5.

F. Residual Rules

Many of the RIAs for the “residual” category of our potentially relevant rules provide at least a brief discussion of electricity and fuel production and/or consumption, but they do not address the rules’ effects on oil imports, greenhouse gas emissions, reliability of the nation’s energy system, or deployment of sustainable energy technologies. The RIAs for rules issued by DHS, DOI, and USDA do not address the various energy security issues. Appendix C-6 lists these residual rules.

Chapter 4: Valuation of Energy Security Benefits in the Oil, Natural Gas, and Electric Power Sectors

I. Introduction

The FAST Act requests DOE to discuss the energy security benefits (or costs, described here as negative benefits) of energy-related policies and actions in the oil, gas, and electric power sectors. That was done qualitatively in the first two chapters. The FAST Act also asks DOE to review the literature for guidance on how to quantify these energy security benefits for use in benefit-cost analysis or other types of reviews conducted by Federal agencies when considering energy-related policies or actions (Pub. L. No. 114-94, Dec. 4, 2015). This chapter reviews the literature relevant to valuation of the benefits of energy security in the oil, gas, and electric power sectors. In some cases, estimates already exist for the benefits of a particular policy. In other cases, quantifying the energy security benefits of a policy may involve the application of previously published methods. And in yet other cases, new methods of accounting for energy security benefits are needed.

In general, benefits can be described as falling into one of two categories: market benefits and non-market benefits. Market benefits are those benefits that are reflected in market prices. They show up as changes in consumer surplus, producer profit, or government revenue, and result from changes in supply or demand of traded goods and services. (Consumer surplus is a measure of the difference between the price paid for a good or service and the value placed on that good or service by the consumer.) Typically, economic models of the economy or particular sectors are used to quantify these values. For instance, during periods of oil supply disruptions, prices of fuels rise, which signals greater scarcity to consumers who then cut back fuel use while producers have greater incentive to produce oil. These forces operate to bring about a new market equilibrium, with consumer surplus lower. This new equilibrium typically entails substantial distributional impacts, including the redistribution of wealth between U.S. and foreign entities. For sudden price shocks, there may also be significant dislocational effects – short-run disequilibria or underemployment of labor and capital inputs. Macroeconomic market models vary in their scope, and may not be sufficient to capture all these effects.

The non-market benefits, or externalities, are those benefits that are not reflected in market prices because they are not traded. That is true for the various externalities that are affected by energy policies. Pollution is the canonical example of an externality; other examples are the many unpriced effects of oil price shocks on the U.S. economy and unanticipated electricity outages. The challenge of valuing non-market benefits that do not have prices is to find out how highly people value them. This is what revealed and stated preference valuation methods are designed to do. Revealed preference methods infer people's value on externalities from data about the trade-offs people make between non-market and market goods. Stated preference methods are based on surveys or experiments that ask people how highly they value something. For example, surveys of customers are used to gather information to estimate the value of reducing the frequency or duration of electricity outages.

A review of RIAs suggests that many aspects of the modern definition of energy security are not qualitatively or quantitatively discussed as rationales for policies or actions that affect energy security. This report recommends below a variety of research agendas that could better support the quantitative inclusion of the energy security benefits resulting from energy-related policies and actions. But in the absence of those quantitative estimates, the following questions are provided as a guide for policymakers to consider when evaluating the qualitative effects of a particular policy on energy security. Answering any of these questions in the affirmative would suggest that the policy or action under consideration provides energy security benefits; conversely, answering in the negative suggests the policy might come with energy security costs. Some policies may, in fact, provide both energy security benefits and costs. A qualitative discussion of energy security benefits and costs, as they relate to the questions below, would improve the consistent treatment of energy security in policymaking.

With respect to ***consumers and the economy***, does the policy or action:

1) Offer consumers of energy more flexibility in the event of a supply disruption, which might include higher energy prices or energy outages?
2) Improve energy efficiency in the demand or supply of energy?
3) Enable energy consumers to respond more quickly to energy price increases?

With respect to ***markets***, does the policy or action:

4) Reduce transaction costs or increase transparency for market participants?
5) Increase competition in ways that lower market prices?

With respect to ***fuel diversity and resilience***, does the policy or action:

6) Support the diversification of energy fuels, sources and routes?
7) Reduce dependence on critical energy-related materials?
8) Improve the responsiveness of domestic supply to disruptions?

With respect to ***national security***, does the policy or action:

9) Promote the modernization of energy infrastructure?
10) Develop fuel reserves or substitute fuels that can be used in an emergency?
11) Support U.S. national security and homeland defense systems?

With respect to ***environment***, does the policy or action:

12) Reduce dependence on or decarbonize the use of fossil fuels?
13) Reduce carbon emissions and other pollution to the air, water, or soil?
14) Support R&D in clean and sustainable energy?

II. Estimating Market Benefits Using Economic Models

Models used to determine the market-based energy security benefits of various policies and other actions fall into two general categories, sectoral models and whole-economy models. Sectoral models are typically detailed representations of a particular sector, in this case, the oil, gas, or electric power sector. Although a few electric power sector models include detailed representations of the natural gas market, energy sector models are usually isolated to oil, gas, or electricity; that is, oil sector models usually do not include detailed representations of natural gas markets or electricity markets. Whole-economy models examine direct and indirect effects between various sectors of the economy, but with a simplified version of each sector. A hybrid model combines a more detailed sectoral model with a whole-economy model.

Any of these three types of models can capture the benefits of energy-related policies and actions that do the following:

- Directly affect energy prices, such as taxes, production subsidies, and end use energy subsidies;
- Indirectly affect energy prices, through quantity limits or performance standards, such as tradable emissions limits, emissions taxes, regulations on pollutants, fuel efficiency standards, and energy efficiency standards;

To a more limited extent, depending on the policy and model, these sectoral or whole-economy models can also capture the benefits of policies that:

- Make markets more transparent and efficient, such as by allowing the export of domestically produced energy, making information more available to customers, facilitating data sharing agreements, and allowing the market to determine prices;
- Encourage diversification of electricity generation, through the use of production tax credits, other subsidies, loan guarantees, and tradable fuel and portfolio standards; and
- Provide the U.S. government with an emergency response system to a supply disruption that can reduce oil or refined petroleum product prices over the short run, such as the Strategic Petroleum Reserve.

Incorporation of these benefits into a model requires an understanding of how the energy-related policy or action affects the relevant equations or parameters that make up the model, for example, the marginal cost of energy supply or energy demand.

A. Sectoral Models

Models of one sector of the economy are also often called partial equilibrium models, because they only explore the effects of policies or other actions on part of the economy, such as the oil, gas, or electric power sector. In practice, actions in the energy sector affect other sectors of the economy that use energy as inputs or that supply inputs to the energy sector, but a partial equilibrium model would not take these broader effects into account.

The advantage of sectoral models is that they can incorporate significant detail about a particular sector, which can be important for representing relevant sectoral conditions and relationships (e.g. logistical, institutional, or infrastructural constraints such as pipeline capacities or storage) and for understanding the implications of a particular policy on that sector. Sectoral models can be very complex but are essentially elaborations of demand, supply, cost functions, and constraints. New policies or actions change these functions, which causes the model to produce new estimates of equilibrium energy price and quantity consumed at each location in the model. From these estimates, welfare can be calculated and compared to the welfare under other policies. Sectoral models can also be either static or dynamic. A static model captures how a single moment in time would change. A dynamic model captures how a market or system evolves over time by representing intertemporal linkages, from either the long-lasting effects of past decisions or outcomes, or from expectations regarding the future or both. For example, some such models in the electric power sector simulate generator investment and retirement decisions over future years.

Although these sector-specific models do not estimate the effects on the rest of the economy, researchers have used various approaches to approximate the effect on the rest of the economy. One very simple way of estimating whole-economy effects is to assume that the benefit (or cost) to the whole economy will be a multiple of the benefit in the sectoral model (Goulder and Williams 2003). For example, Sullivan and Schellenberg (2013) noted that their estimates of sectoral damages resulting from an electricity outage could be multiplied by between 1.2 and 3 to approximate the economy-wide effects. Different types of policies and actions would have different multipliers, but other things being equal, larger disruptions tend to have larger multipliers.

i. Gas Sector Models

Many models are available to evaluate various aspects of the gas sector. For example, EIA and EPA currently uses two proprietary models to analyze natural gas disruption and policy scenarios, assist in the emergency response to energy disruptions, and develop long-term planning for energy infrastructure. The models, developed by ICF International, are the Gas Market Model, which forecasts monthly natural gas activity in Canadian and U.S. markets, and the Daily Gas Load Model, which focuses on daily activity.

These models are fairly aggregated views of the natural gas market. They represent the gas market with 119 nodes and 350 links between the nodes, representing natural gas pipelines. Both models make projections on production, consumption, and storage injections or withdrawals conditional on the pipeline network, storage and distribution infrastructure, and weather. Both use statistical analysis of historical data to estimate gas demand in the residential, commercial, industrial, and power sectors as a function of price, temperature, and seasonal factors. Aggregate forecasts of peak demand are used to assess pipeline and network adequacy. Commercial and residential demands are functions of temperature and seasonal factors but not price. The industrial and power sectors are functions of temperature, seasonal economic factors, and relative prices.

The Energy Information Administration (EIA) at DOE uses several models for predicting natural gas supply and distribution. Using the Oil and Gas Supply Model within NEMS, EIA projects annual oil and natural gas production at a county/play level to build aggregate regional short-term natural gas supply curves. The Natural Gas Transmission and Distribution Model (NGTDM) balances North American natural gas supply and demand via a pipeline network, while simultaneously estimating associated prices. For the

International Energy Outlook, EIA uses an international model that is functionally similar to NGTDM to determine the production and price of natural gas using regional demand modules to determine gas demand. International trade volumes via pipeline and LNG are predicted to balance supply and demand.

There are also a large number of proprietary models used to predict domestic natural gas flows, natural gas pipeline constraints, and international trade. Some of the more popular models are summarized by Busch (2014).

ii. Oil Sector Models

Sectoral models representing the oil sector can capture the supply of oil, the refining of oil, or both. EIA currently uses several models to estimate oil and refining activity. The International Energy Outlook model is an EIA world model that uses "crude-like liquids" to represent world supply and consumption over an extended period (IEO 2016 is through 2040). EIA's Short Term Energy Outlook (STEO) model is an econometric model that projects 2 years of oil and refined product supply and demand based on historical data. In addition, EIA uses several sectoral models for oil and refined product in its National Energy Modeling System (NEMS). On behalf of DOE, Oak Ridge National Laboratory has developed an oil market disruption model they have used for modeling the U.S. Strategic Petroleum Reserve. Models are not well developed for analyzing short-run disruptions of domestic petroleum infrastructure on regional markets and the economy. This is because each disruption event tend to be unique and there is not a large empirical dataset of historical events from which regional or national economic costs could be estimated.

There are many other proprietary sectoral models for estimating the effect of policies or actions on oil and refined products. Prism is a Baker and O'Brien refinery model that estimates crude volumes and product demands by-refinery for the United States, Canada, and Europe. Turner Mason has a similar, proprietary, model that will provide a refinery volume balance given crude supply and product demands for the United States. The EnSys Energy World Oil Refining Logistics and Demand model (WORLD) is another example of an oil sector model that captures the global refining industry in short, medium, and long-term scenarios. The model calculates refinery runs and crude and product flows for refineries worldwide using supply data and a database of crude oil and product transportation routes. These models predict refinery spreads and investments, but do not forecast crude or product prices.

iii. Electric Power Sector Models

Detail in an electric power sector model can be important for its performance at projecting the effects of policies and fuel prices (Shawhan et al. 2014; Mao et al. 2016). Sectoral models representing the electric power sector capture the generation of electricity, transmission of electricity to distribution centers, and distribution to end users. EIA currently uses several electric power sector models in NEMS, the International Energy Outlook, and the Short Term Energy Outlook. Each of these models includes a module that focuses on electricity demand, supply, and distribution as well as the distribution of fuels to various geographically dispersed generators of electricity. Although EIA's models reflect constraints among larger power market regions, they do not currently explicitly capture secondary transmission or local distribution constraints. In addition, DOE in partnership with the national labs and electric utilities, has developed a tool, called Eagle-I, that visually displays the status of electric grid service for more than three-quarters of U.S. electricity customers. It provides near real time updates on the grid to enhance DOE's situational awareness and emergency response capabilities. Regular reports are generated from Eagle-I to assist the decision making of U.S. government leadership, the electric power sector, and emergency responders during energy emergencies.

There are many other economic models of the electric power sector, including E4ST (2016), GE MAPS (GE 2016a), Haiku (Paul et al. 2009), IPM (ICF International 2016), Plexos (Energy Exemplar 2016), ReEDS (NREL 2016), and US-REGEN (EPRI 2016). These models can produce detailed simulations of the effects of policies and other actions on the electric power sector, including effects on generator usage, generator investment, generator retirement, prices, emissions, benefits, and costs, by location. The models differ in their features and strengths. For example, one of Haiku's strengths is its ability to simulate the effects of the details of various air pollution abatement policies and compliance strategies, while one of E4ST's strengths is its combination of detailed physics-based transmission models with comprehensive long-run benefit-cost analysis.

B. Whole-Economy Models

Many energy-related policies or actions are likely to have effects that ripple throughout the economy because changes in the price of any particular energy commodity would affect all the sectors that use that energy commodity. For example, among other effects, an emissions fee on carbon dioxide would decrease the demand, and thus the production of coal. That would decrease coal production in the United States and decrease the coal sector's demand for most of its inputs, which would decrease demand for most of the inputs used by firms that provide the coal sector with inputs, and so on. Similarly, the emissions fee would increase the demand for solar PV arrays, their inputs, the inputs to *their* inputs, and so on. These effects would ripple through the economy, altering the decisions of firms and consumers throughout the economy, as well as profits, consumer welfare, government revenue, and emissions in many sectors. Most whole-economy models do not represent any of the individual sectors, including the energy sectors, in detail. That can cause whole-economy models to miss many of the effects of energy-related policies and actions that require more detailed sectoral depictions to identify. Whole-economy models, also sometimes called regional economic models, include computable general equilibrium models, input-output models, and macroeconometric models.

i. Computable General Equilibrium Models

Computable general equilibrium (CGE) models are designed to simulate how each sector of the economy affects, and is affected by, the other sectors of the economy. A CGE model typically divides the economy into dozens of sectors. The trade-off for including every sector of the economy is that each sector is represented in very simple terms. In CGE models that are specialized for energy policy applications, the major energy subsectors, such as electricity, natural gas, and petroleum, are separated, and the fuels of the electric power sector, such as coal and natural gas, are separately represented. In such a model, each sector is typically represented by a production function that links it with its supplying sectors and a consumer demand function that links it with the sectors that consume its output. Coal and natural gas supplies to the economy are represented by supply functions. One challenge associated with CGE models is that the production, supply, and demand functions are generalized across many sectors and often not based on statistical estimates from historical data specific to each sector (Sanstad 2016).

The interactions between sectors of the economy that are identified in a CGE model can sometimes make a policy that seemed like a net benefit for the economy when using only a sector model, fare worse for the economy once the effects from other sectors are included. For example, under some circumstances, a tradable emissions intensity standard may be more cost-effective than emissions pricing, even though the latter performs better in electric power sector modeling. In addition, for those policies that produce government revenue, such as an emissions tax, a CGE model can incorporate the economic benefits of how that revenue is used. The welfare differences between different means of using the revenue can be as large as the benefits of the policy (Goulder et al. 2016; Goulder and Hafstead forthcoming). This suggests, for example, a very different welfare implication for an emission credit trading system where the credits are initially auctioned from one where the initial allocation of credits is freely granted.

An overview of the use of CGE models for the analysis of energy and climate policies through 2009 is available in the literature (Sue Wing 2009). CGE models specialized for energy policy applications include the Hafstead-Goulder Model (Goulder et al. 2016), GTAP (Aguiar et al. 2016), GTAP-Power (Peters 2016), IGEM (Jorgenson et al. 2013), and some of the models participating in the Energy Modeling Forum (EMF 2015).

ii. Input-Output Models

Input-output models use the same kind of detailed sector-to-sector supply relationship tables used in building CGE models, but they tend to be even simpler representations of the economy. In input-output models, the amount of each input needed to produce one unit of a particular product is fixed based on historical data. For example, an input-output model might assume that producing one unit of legal services requires 0.37 unit of labor, 0.01 unit of electricity, and specified amounts of various other inputs. Thus whereas CGE models use functions to approximately represent input substitutability, most input-output models assume no substitutability between inputs.[48] Another difference is that in input-output models, consumer demand for the output of each sector is fixed. IMPLAN and the Regional Input-Output Modeling System (RIMS II) are two input-output modeling systems commonly used to model policies in the United States.[49]

iii. Macroeconometric Models

Econometric models have been created that capture whole-economy effects. For example, Greenberg et al. (2007) use a macroeconometric model of the New Jersey economy to

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[48] In practice, a few input-out models have incorporated elasticities of substitution other than zero, to allow for some degree of flexibility in key sectors of the economy in response to shocks (e.g., Okuyama et al. 2004, Miller and Blair 2009)

[49] For IMPLAN, see http://implan.com/; for RIMS II, see http://www.bea.gov/regional/rims/.

estimate the effects of a prolonged power outage on state employment and income. They do not describe the model in detail but mention that it is a system of 220 equations estimated from historical data. Arora (2013) provides a discussion of various model types, including macroeconometric and CGE models, and their potential usefulness to the Energy Information Administration.

C. Hybrid Whole-Economy Models

As their name suggests, hybrid models seek to combine the most useful components of whole-economy models and energy sectoral models to provide a more robust estimate of energy-related policies and actions on the U.S. economy. The detailed sectoral component of hybrid models captures complicated feedbacks of the policy within the energy sector and then the whole-economy component captures the implications of those effects on the rest of the economy. Such a combination is called a hybrid model or, sometimes, an integrated model (which is not the same as an integrated assessment model).

A second and simpler approach to capturing the benefits of the two types of models is to use a sectoral model to predict energy security policy implications within the sector and then feed those effects into a model of the whole economy. This simpler option omits the effects of the feedback loop from the whole economy back to the energy sector but may be a better approximation of the market effects of a particular policy or action than just applying a multiplier to the sectoral effects.

The National Energy Modeling System (NEMS) is one example of a hybrid energy-economy model. It was developed and is maintained by EIA of DOE. The macroeconomic component of NEMS is maintained by IHS Global. The model generates projections of production, demand, imports, and energy prices through 2040. The parameters assessed in generating these projections are macroeconomic and financial factors, global energy markets, resource availability, costs, behavioral and technological choices, demographics, and characteristics of energy technologies.

Individual modules of NEMS allow for flexibility in using the methodology and regional coverage that are most appropriate. NEMS incorporates 13 sectoral models:

- four supply modules—oil and gas, natural gas transmission and distribution, coal market, and renewable fuels;
- two conversion modules—electricity market and petroleum refinery market;
- four end-use demand modules—residential demand, commercial demand, industrial demand, and transportation demand;
- one module to simulate the interaction between the energy sectors and the whole-economy;
- one module to simulate international energy markets, linking U.S. petroleum markets to world markets and incorporating global climate change policies; and

- one integrating module,[50] which provides the mechanism to achieve a general market equilibrium.

Another example of a hybrid models include a collaboration between DOE's National Renewable Energy Lab (NREL) and MIT. NREL has developed ReEDS, which is an electric power sector model used to predict the location and type of new electric power generating units in the contiguous United States through 2050. The model finds the configuration of the electric power system that offers the lowest construction and operation costs across a full suite of power generation, transmission, and storage technologies. The model outputs include fuel use, costs, and emissions, but these metrics are only computed for the electric sector with no cross-sectoral interaction. MIT has developed USREP, which is a CGE model of the U.S. economy that balances supply and demand across all production and consumption sectors in the United States while also representing international trade. The linked ReEDS-USREP model inserts ReEDS as the electric sector within USREP, allowing researchers to determine the broader economic impacts of electric power sector policies while taking advantage of a detailed representation of the electricity system. The models iterate until converging on electricity demand, with USREP passing prices of fuel, capital, and labor to ReEDS, while ReEDS returns electric sector fuel use and expenditures to USREP.

D. Next Steps in Modeling Efforts

Various economic models, typically categorized as sectoral, general equilibrium, input-output, or macroeconomic models, can be useful for monetizing energy security benefits, although there is considerable room for improvement in the individual models and in the ability of the models to simulate both the energy sector and its interaction with other important sectors of the economy. Efforts to improve these models are ongoing but could be accelerated to address the needs of those estimating energy security benefits.

III. Valuation of Energy Disruptions on Economic Activity

Unanticipated disruptions in the supply of any particular energy commodity are likely to raise prices, increase price volatility, generate outages, or some combination of those effects. Economic growth in the United States is generally thought to benefit from low and predicable prices of oil, natural gas, and electricity. Although the likelihood of a disruption is not known, the effect of unanticipated higher prices on GDP can be captured by the types of models described in the previous section. This section summarizes the literature regarding the effect of energy price changes on GDP.

[50] The integrating module plays a central role in the generation of projections. It executes the demand, conversion, and supply modules iteratively until supply and demand are equilibrated in all the consuming and producing sectors. To be more precise, the modules are called iteratively until the end-use prices and quantities remain constant within a specified tolerance, indicating convergence for a given year. Equilibration is achieved annually throughout the projection period, currently through 2040, for each of the nine census divisions. The macroeconomic activity and international energy modules are also executed iteratively to incorporate the feedback on the economy and international energy markets from changes in the domestic energy markets.

A. How Energy Price Shocks Affect the Economy

Unanticipated disruptions in the supply of oil can last for days, months, or years and occur at a variety of volumes. Such disruptions would be expected to increase the price of oil as well as goods and services that rely on oil for production or distribution, which causes consumers to purchase fewer goods and services. As demand for these goods and services fall, some workers, production equipment, and other capital are underutilized for a period of time. Thus the price shock tends to reduce the extent to which the economy performs up to its economic potential, diminishing GDP. Kilian (2008) and Bohi and Toman (1996) summarize this and other mechanisms through which petroleum price shocks reduce economic output. Greater volatility in prices also implies larger *downward* changes in prices or costs, but there is an asymmetry in the effects: the economic benefits of price decreases are less than the economic damage caused by price increases (Kilian 2008).

Although higher or more volatile electricity and natural gas prices would be expected to have similar directional effects on GDP following a disruption, a supply disruption in the natural gas or electric power sector would be more likely to create a near-term outage in those sectors instead of just higher prices. This is because electricity and natural gas are more reliant on fixed-capacity infrastructure to deliver energy to regional markets, making it difficult to offset significant supply/demand imbalances. That is, a major technical disruption of the electric system; a quick shutdown of the nuclear generation fleet, as in Japan after the Fukushima Daiichi nuclear accident; a period of extremely cold weather that freezes coal piles or makes natural gas unavailable to buyers without contracts; or disruption of a crucial natural gas pipeline would all likely result in short term electricity outages. If those disruptions were short term, then the outage would also be short term. Estimating the cost of supply outages or shortages, i.e. when markets cannot clear even at higher prices, requires substantially different analytical and modeling approaches than estimating the cost where disrupted markets can rebalance through the price mechanism (see the discussion in section III below).

Gradual price changes also, affect the economy and may be associated with energy security costs. Factors that can cause gradual energy price changes include technological improvements, changes in the availability of fuels and other inputs, resource depletion, changes in market structure, the exercise of political or cartel power over supply, and regulations. When prices are changing, or volatile, the companies involved in making decisions about investment in production and delivery of energy face more uncertainty about future prices. In general, the less accurately and precisely these decision-makers are able to predict future prices, the higher will be the expected cost of meeting consumers' energy needs because the decisions are likely to be farther from what would minimize costs under the actual future prices. One thing policymakers can do to alleviate uncertainty is to make future electricity prices more predictable by announcing future policies farther in advance and adhering to those policies (Hitaj and Stocking 2016). In addition, policies that improve energy efficiency can reduce the vulnerability of consumers and the economy as a whole to energy price variations and unpredictability.

Even in situations where disruptions cause natural gas or electricity prices to increase, there are four reasons why oil price shocks would have a larger effect on U.S. economic activity than natural gas or electricity price shocks:

1. The United States imports a much larger share of its oil than natural gas or electricity, which means a larger share of oil expenditures is transferred to foreign recipients than for other energy expenditures.
2. Oil price increases can greatly reduce sales in the automobile industry, which represents an important sector in U.S. GDP (Kilian 2008).
3. Natural gas and electricity's share of U.S. energy expenditures is less than half of that of refined petroleum products. In 2014, U.S. customers spent $864 billion on refined petroleum products, $390 billion on electricity, and $174 billion on natural gas (EIA 2016c).
4. Oil is priced in a world market, so a price increase affects the entire world economy. Because of the geographically dispersed nature of the electricity and natural gas markets, an outage can at worst affect a regional economy and may be even more localized in its effect.

B. Valuing the Effect of Oil Price Shocks

The original energy security paradigm focused on the economic consequences of U.S. dependence on foreign supplies of oil. It emerged during the late 1970s during the second and third major postwar oil shocks. In 1997, researchers at Oak Ridge National Laboratory released "Oil Imports: An Assessment of Benefits and Costs" (Leiby et al. 1997), which summarized the state of oil supply shock valuation research to that point and provided quantitative estimates for different types of energy security effects. The report was updated in 2007 and 2008 to incorporate changes in oil market conditions as well as projections of oil prices, U.S. oil import levels, behavior of the Organization of the Petroleum Exporting Countries (OPEC), Strategic Petroleum Reserve (SPR) levels, and the likelihood of oil supply disruptions. The most recent update, "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports" (Leiby 2008), is the primary methodological source for agencies that incorporate this aspect of the new energy security definition into their benefit-cost analyses.

According to Leiby (2008), the full economic cost to the United States of importing a barrel of oil includes the purchase price (reflecting forces of supply and demand) as well as an "oil import premium," defined as the marginal oil import costs to the U.S. economy not reflected in the market price of oil (and expected to change with a change in oil imports). In particular, in developing an estimate of the oil import premium, Leiby discusses three energy security effects: (1) the "macroeconomic disruption" cost arising from the increased risk of disruptions in oil import supply to reduce U.S. economic output; (2) the cost to U.S. taxpayers for existing energy security policies, generally identified as the cost of maintaining a military presence in oil-producing regions to ensure a stable oil supply; and (3) the cost of maintaining the SPR. Leiby (2008) excludes from the oil import premium environmental externalities and potential spillover benefits of reduced oil price volatility to other nations.

Leiby (2008) also considers a fourth energy security effect: a "monopsony" premium, which arises because the Nation, as a large purchaser of foreign oil, has the potential to reduce the world price of oil by reducing foreign oil imports. Those lower oil prices represent a transfer in wealth from the producers of oil to the consumers of oil and refined petroleum products (see, e.g., EPA and NHTSA 2012).[51] There is some debate in the literature about the appropriateness of using the monopsony premium in benefit-cost analysis. Brown and Huntington (2010) exclude the monopsony premium "because it is not a security concern and because pursuing these gains would distort global resource use rather than offset an externality." Similarly, the National Research Council report *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (NRC 2010) finds that with respect to the monopsony premium, "no externality in the sense considered in this report exists." As a result, the report does not include the monopsony premium as a part of an estimate of the "unpriced consequences" of energy production and use. And, in fact, since 2010, benefit-cost analyses prepared by the Department of Transportation and EPA have excluded the monopsony premium from the benefits analysis because the focus of the regulation is on the global benefits of reducing greenhouse gases. Arguments for including the monopsony premium stress that energy security, like many security issues, is appropriately viewed from a national welfare perspective, or the perspective of a coalition of cooperating nations such as the IEA. Historically, most regulatory or policy analyses are not based on a global welfare perspective. From this traditional energy security view the monopsony premium, as a transfer of wealth from the U.S. consumers to foreign producers, is a marginal cost of oil imports to U.S. consumers.

In quantifying the oil import premium, Leiby (2008) excludes the cost of existing energy security policies, which would include military expenditures. Military expenditures with the direct purpose of securing reliable foreign supplies of oil are often considered a cost associated with maintaining energy security. However, Leiby (2008) argues that including military expenditures in the oil import premium is complicated by two factors. First, U.S. military activities generally serve a broad range of security and foreign policy objectives, even in regions that supply the United States with substantial amounts of oil. Thus it is difficult to attribute specific costs, missions, or activities of the military as solely directed to enhancing energy security. Second, the costs of energy security–related military expenditures, even if they could be identified, likely do not vary in any meaningful or measurable way with an incremental change in U.S. oil imports. Because the oil import premium is meant to measure the *marginal* energy security costs of oil imports, Leiby concludes that it is not appropriate to include military expenditures in the final calculation.

Leiby (2008) identifies two components affecting U.S. macroeconomic costs associated with oil supply disruptions:

[51] The monopsony premium reflects a pecuniary externality—that is, an externality that operates through the effect of the regulatory action on prices rather than through a direct resource effect on a third party. A pecuniary externality does not affect resource allocation; in fact, government action to eliminate the pecuniary externality will further distort resource use. Addressing a pecuniary externality serves only to affect the transfer of income.

- ***Aggregate contraction*** is the reduction in the U.S. economy's growth path—that is, the growth in potential output of the U.S. economy with a shift in the production possibility frontier when the economy is fully utilizing all available resources. The extent and duration of future oil supply disruptions determine the magnitude of petroleum price increases and, in turn, the magnitude of aggregate contraction.
- ***Allocative or adjustment costs***, in contrast, are incurred when the economy cannot fully utilize all resources available—that is, economic activity falls inside the production possibility frontier. Businesses and households temporarily underutilize available resources as they adjust their petroleum use to a sharp price increase, compared with the smoother adjustment if the same oil price increase takes a more gradual path. Examples of adjustment effects include labor unemployment and idle plant capacity. As long as these resources are underutilized, overall economic output will remain below the potential output level of the economy.

Several private market mechanisms—such as oil futures markets, energy conservation measures, and stockpiles of oil—allow oil consumers to protect themselves from rapidly increasing oil prices and the resulting adjustment costs. However, Leiby contends that imperfect information about risks as well as costs external to private decisionmaking may result in a socially inefficient level of protection from oil supply disruptions. As a result, adjustment costs from oil price spikes may still be incurred, despite these market mechanisms.

To calculate the macroeconomic component of the oil import premium, Leiby estimates the likelihood of a future oil supply disruption, the effect of a disruption on world oil prices, and the effect price shocks on the U.S. economy. Leiby notes that a reduction in U.S. oil consumption would alter the probability or expected size of an oil supply disruption as well as its consequences. Leiby estimated a macroeconomic oil security premium of $4.59/bbl in 2005$ applicable to 2008.

Brown and Huntington (2010) also estimate the oil import premiums in two ways, by using a range of input assumptions about market conditions and by using a range of EIA projections from NEMS. The midpoint estimates of the oil import premium on the consumption of domestic oil increase from $2.15 in 2008 to $4.19 in 2030 (in 2005$ adjusted from 2007$). In contrast, the midpoint estimates for the consumption of imported oil increases from $4.19 in 2008 to $6.42 in 2030 (in 2005$). The difference means that there is greater estimated net social value to reducing the consumption of oil imports than reducing the consumption of domestic oil, although the latter is still estimated to provide an energy security benefit. The import premium for displacing domestic oil production with imported oil without a change in U.S. consumption rises from $2.04 per barrel in 2008 to $2.23 per barrel in 2030 (in 2005$). The actual premium to use depends on the policy being evaluated. The imports-consumption premium, that is the premium for a marginal increase in oil imports as oil consumption rises (domestic supply unchanged) is the appropriate premium relevant for many policy cases. It is the one suited to, for example, CAFE analysis. Various elasticity assumptions generate a considerable range of midpoint values. The results are summarized in Table 4.1:

Table 4.1. Values of oil import premium components, 2008

Energy security impact	Value (2005$/bbl)
Monopsony component (Leiby 2008)	$7.41
Macroeconomic disruption/adjustment component (Leiby 2008)	$4.59
Macroeconomic disruption/adjustment component (Brown and Huntington 2010)	$4.19

***Source*: Leiby (2008) and Brown and Huntington (2010)**

C. Valuing the Effect of Electricity Price Shocks

One approach to managing electricity price shocks is to increase diversity in the geographic locations and fuel sources used by generators. Costello (2005) notes that lower price risk, different long term prices, higher reliability, environmental benefits, and national security benefits could all result from expanded fuel diversity. To assess fuel diversity, Costello (2005) recommends using a portfolio approach that balances price and risk considerations. While some studies have taken this approach, Gotham et al. (2009) suggest that measures generated by it have often been dismissed by policymakers because the results appear unintuitive and oversimplified. Gotham et al. (2009) suggests that this approach could be improved and made more credible if it accounted for the advantages of different fuels in serving different parts of the load cycle. They do this by breaking the load into sections with different load factors.

D. Valuing the Effect of Improvements in Market Operation

Market operation is generally improved by breaking up monopolies, increasing competition, removing subsidies, lowering trade frictions, removing obstacles to buying and selling a product, reducing transaction costs, and reducing barriers for new firms to enter the marketplace. In the absence of countervailing market failures, markets tend to operate more efficiently when they are more competitive, liquid, and transparent. In the event of a supply disruption, markets with those characteristics are probably associated with increased social welfare because the influence any single supplier has on market prices is reduced.

In some cases, the benefits of more competitive, liquid, and transparent markets can be partially approximated using economic models, including some of the sectoral and whole-economy models mentioned above. In other cases, the benefits can be statistically estimated using data on market outcomes with and without policies that affect competitiveness, liquidity, and transparency. The most suitable models to quantify the benefits of such policies depend on the specific policy and the benefits to be evaluated.

Increased Market Competitiveness

There are many studies that attempt to quantify the benefits of potential improvements in the operation of oil, natural gas, and electricity markets, as measured primarily through changes in producer and consumer surpluses. For example, a number of analysts conducted studies of the benefits associated with eliminating the ban on U.S. oil exports (see, for example, Baron et al. 2014; EIA 2015). Allowing domestic oil exports improved oil market operations by reducing trade frictions and increasing competition among buyers of U.S. oil. The approach used by many of those studies to quantify the policy benefits was to estimate the additional income producers of oil would earn when they could sell their oil into the global market instead of just the domestic market. The higher prices earned by producers would spur additional domestic production which would put downward pressure on the global price for oil and refined products, benefiting consumers of oil and refined products. The studies used different approaches to estimating the price differentials earned by domestic producers but generally found a net benefit with respect to GDP and social welfare. Such a positive net benefit is not necessarily general to the evaluation of all trade agreements, such as transnational pipelines or free trade agreements. Each should be evaluated on its own benefits to energy security and market efficiency.

A second example comes from the deregulation of natural gas markets in the United States, with the hope of increasing gas production and greater efficiency in the bulk supply of natural gas. Deregulation began with the Natural Gas Policy Act of 1978, with major additional steps taken in the 1980s. A study conducted by DOE's Policy Office attempted to value the early benefits of deregulation (DOE 1981). That study found that the benefits rose to around $2 billion to $3 billion per year by the late 1980s. But it also showed significantly negative impacts on GDP in the initial years after deregulation due to transition costs to the industry. Cooper (1982) was highly skeptical of this study and others predicting large gains from deregulation, but part of the skepticism may have rested on the simplicity of the models and their inability to capture increased flexibility of the natural gas market in response to exogenous shocks, as David Montgomery notes in his rejoinder to Cooper in the same volume.

Reducing Transaction Costs

Transaction costs exist in most markets but can be higher in those markets where, for example, buyers and sellers have difficulty locating each other, products traded in the market are not standardized, or the contract structure limits flexibility. Reducing transaction costs tend to make markets more competitive and economically efficient.

A variety of energy-related policies and actions could affect the size of transaction costs in energy markets. For example, policies that would prohibit some market participants from holding or trading energy commodities such as oil futures contracts or emissions allowances would reduce market liquidity and increase transaction costs (CBO 2010). Alternatively, allowing the export of LNG increases the liquidity of the global LNG spot market by reducing transaction costs for buyers of LNG within that market.

Many of the sectoral and whole-economy models discussed above are technically capable of valuing the benefits of policies and actions that reduce transaction costs, however, most energy models do not currently estimate transaction costs (or the effect of policies that change transaction costs). One way to incorporate transaction costs is to introduce a third party that extracts payment from buyers and sellers to facilitate a completed transaction. That would represent a market where a broker was necessary to facilitate trades between buyers and sellers. For example, following the regulation of limits to sulfur dioxide pollution from electric power generators that burned coal, EPA estimated that early emissions allowance trading was sufficiently illiquid to earn brokers $5 for each allowance traded; those fees fell to $0.50 per allowance several years later when liquidity increased (EPA 2004). In many markets, including the EPA sulfur dioxide market, brokers or traders are necessary for market liquidity and lower transactions costs by matching buyers and sellers. Some policies, however, can reduce brokerage fees including those that would move trading to a centralized and transparent platform (CBO 2010). For many models, introducing a third-party broker would require some additional programming and computational time.

The other challenge with estimating the benefit of reducing transaction costs is that quantifying them is difficult. There are not good estimates for the size of transaction costs in most market and it is equally difficult to project how a particular policy will lower transaction costs in a particular market. Estimating transaction costs is primarily an empirical task requiring the collection of data that is either directly about transaction costs such as time and expense required to arrange a transaction or about market outcomes that allow indirect estimation of transaction costs. Quantifying the effect of a policy or other action on transaction costs would generally require transaction cost data about comparable situations with and without the policy. This is possible if such data exist or if the policy can be piloted to generate the data. When data are not available, asking experts for their estimates, known as *expert elicitation*, may be the best alternative for producing an estimate.

E. Next Steps in Disruption Valuation

Significant literature has been devoted to understanding the implications of higher oil prices on consumers and the U.S. economy, but additional research could be done to elucidate several benefits from energy-related policies:

- ***Oil sector.*** The benefit of reducing oil imports, also called the oil import premium, has been estimated for historical conditions, yet conditions are constantly changing and certainly look different today with respect to oil imports than they did in 2008 or 2010. EPA and DOE have regularly re-estimated the oil import premium for many successive EPA/NHTSA rulemakings over a range of EIA Annual Energy Outlook projected conditions. This premium should continue to be updated using the best available modeling techniques such that the results remain applicable to current and forecasted future conditions.
- ***Oil sector.*** Policies that would encourage or prohibit the extraction of domestic oil have not typically included in their benefit-cost analyses the option value of that domestic oil for use in the future if an oil disruption caused oil prices to spike. Current

models and approaches, such as that used for the oil premium, could be modified to include this potential and the corresponding benefits to GDP from lost or gained future production.

- ***All energy sectors.*** Although more competitive, liquid, and transparent markets are beneficial, there does not exist standardized definitions of these attributes or a standardized approach to quantifying their benefits. Research on a definition and quantification methods would help policymakers evaluate actions or policies that improve market operations.
- ***All energy sectors.*** Changes in energy prices create an incentive for consumers to change their consumption of energy. Some decisions made by consumers, such as what vehicle to purchase, where to live and work, and what energy efficiency level is desirable in large appliances, are costly to change if energy prices change again in the near term. A better understanding of the factors that cause consumers to make energy-inefficient decisions would help policymakers understand the implications of changes in energy prices.
- ***Electric power sector.*** Many policymakers talk about fuel diversity, yet monetized estimates of the value of increasing generation or fuel diversity have not been identified. Moreover, not all increases in diversity are likely to have the same effect. Policies to promote diversity include research and development for new technologies, support for existing nuclear reactors, and renewable portfolio standards. Estimating the value of diversity would enable policymakers to better understand the benefit of these types of policies to weigh against the costs.
- ***All energy sectors.*** The benefits of policies that improve market operation by increasing competitiveness or reducing transaction costs are not currently quantified, even though the benefits can be large. Policymakers would benefit from the development of a consistent approach to benchmarking transaction costs in existing markets and estimating the effect of various types of policies in reducing those transaction costs or increasing competition.

IV. Valuation of Energy Outages and Efforts to Prevent Them

An energy outage occurs when a particular source of energy is not physically available for consumption at any price. The outage could be created by a variety of types of disruptions. In the 1970s, the supply of oil was reduced to the United States when our Arab OPEC oil trading partners instituted an oil embargo on shipments to the United States. In the current globalized and competitive marketplace for oil and refined products, a physical shortage of those commodities is unlikely to occur in the United States.

Two attributes of the oil market make a physical shortage of oil in the United States unlikely. First, nearly 80 million barrels of crude oil are produced every day globally (EIA 2016b). In addition, there are billions of barrels of crude oil and refined product stored underground, in pipelines, tanks, trucks, and ships around the world (IEA 2016). A supply disruption that results in a price increase creates an incentive to release some of the stored crude and petroleum product. Higher prices also incentivize producers to make available new supplies that would otherwise be cost prohibitive. Second, oil and refined product can be transported around the world and United States through multiple means, which further reduce the likelihood that a consumers would be unable to purchase oil. For example, those commodities are currently transported around the United States by pipeline, truck, rail, barge, and ship. During disruptions of supply (e.g., domestic pipeline disruptions), the potential for higher prices provides the market with incentives to use alternative transportation methods. For example, a recent outage in the Colonial pipeline, which provides gasoline to the eastern United States, increased the supply of gasoline delivered to East Coast locations via truck and ship.

Outages are most common in the electric power sector and can have a variety of causes:

- extreme input supply interruptions and shortages, such as those caused by a natural gas pipeline failure, frozen coal piles, or disruption of nuclear plants' Li-7 supply from Russia or China;
- natural disasters, such as hurricanes, tornadoes, wind storms, earthquakes, storm surges, inland flooding, lightning strikes, ice storms, and solar coronal mass ejections (solar storms);
- human errors and other accidents;
- spontaneous electric distribution, transmission, generation, or monitoring equipment failures;
- intentional electromagnetic interference from a high-altitude nuclear explosion or other source; and
- physical and cyberattacks.

The economic effects of an energy outage can be significant, depending on the duration of the outage. For that reason, a variety of types of policies are designed to reduce the duration and extent of an outage, particularly those outages in the electric power sector. The tools used to value the economic benefit of policies that reduce the extent of outages are not the same as those used to estimate the economic effect of changes in energy prices. For businesses, the costs of an outage are primarily lost profit, caused by reduced production ability, equipment damage, raw material spoilage, restart costs, health and safety costs, property crime, increased input prices, reduced demand, or a combination. In addition, a higher risk of future outages can induce firms to undertake expenditures on "backup generators, permanent changes in production schedules, and utility capacity expansion to promote flexibility" to reduce expected future losses (Rose et al. 2007). For households, the results of an outage can include discomfort from lack of space conditioning, damage (e.g., food spoilage), the inability to do certain activities, injuries, property crime, and loss of life. The values of these can be estimated, separately or together. The net cost to society of an outage also has two other names: *damage* and *value of lost load*. Here, damage refers not just to the physical damage but instead to the total cost, from all effects mentioned above.

Numerous authors have summarized the literature on the estimated value of electricity supply outages, including van der Welle and van der Zwaan (2007), Anderson and Taylor (1986), Caves et al. (1990), Lawton et al. (2003), Lehtonen and Lemstrom (1995), Sanghvi

(1982), Sullivan et al. (2009), TERI (2001), Woo and Pupp (1992), Sullivan and Keane (1995), Lijesen and Vollaard (2004), Ajodhia (2006), de Nooij et al. (2007), Schröder and Kuckshinrichs (2015), Miller et al. (2005), NUS (2011) and Billinton et al. (1993). Tollefson et al. (1991) is a comprehensive bibliography of the literature on electricity outage valuation from 1980 through 1990, and Billinton et al. (1983) for the years before 1980. In particular, RAE (2014), Couder (2015), Schröder and Kuckshinrichs (2015), Cheng and Venkatesh (2014), Sullivan and Schellenberg (2013), Ratha et al. (2013), London Economics (2013), SYSTEP (2009), Ozbafli (2012), van der Welle and van der Zwaan (2007), and Rose (2004) are recent publications that comment on the merits and weaknesses of the methods for valuing the effects of electricity supply outages. The methods of valuing electricity supply outages are also addressed in the literature on optimal reliability assessment, including Billinton and Pandey (1999), Chowdhury et al. (2004), Sanghvi (1983), Telson (1975), and Tollefson et al. (1994). CEER (2010), SINTEF Energy Research (2010), and Sullivan and Keane (1995) offer recommendations for what methods to use to value outages.

There is much more limited research evaluating the effect of a physical outage of oil, refined product or natural gas. Kim and Yoo (2012) evaluate the economic cost of a diesel shortage in Korea, and Leahy et al. (2012) estimate the cost of natural gas outages in Ireland. No quantitative analyses of the effects of physical outages were identified for the U.S. market probably because it is unlikely that such an outage would cover a large geographic area, and if it did, it would probably be short-term. This section addresses the literature that attempts to value the cost of an electricity outage to society and the likelihood of that outage occurring. Policies designed to affect those factors are electric sector reliability and resilience.

A. Methods for Valuing Electricity Outages

There are several methods that can be used to estimate the direct costs of electricity supply outages, including surveys about hypothetical situations, blackout case studies, revealed preference methods, and proxy methods.

i. Surveys about Hypothetical Situations

One approach to estimating the value of lost load is to send individuals a survey that asks them to estimate the costs to their companies or households of a hypothetical outage with clearly specified characteristics. The review papers enumerated above list dozens of surveys that attempt to value electricity outages, and in some cases report estimates from some of those surveys. In addition, Sullivan et al. (2015) and Sullivan et al. (2009) present meta-analyses of 34 comparable surveys that were conducted in different parts of the United States. The similarity of methods across the 24 business surveys and across the 10 residential surveys is partially a result of the publication of The Interruption Cost Estimation Guidebook by the Electric Power Research Institute (Sullivan and Keane 1995).

For a business, the survey typically focuses on the expected effects on profit. It may include a worksheet or series of questions that ask the respondent to identify the effects of the outage on the business and estimate the value of each. To enable estimation of the effects on workers, the survey may also ask about layoffs and furloughs of workers. For example, each of the business surveys reported in Sullivan et al. (2009, 2015) first described an outage scenario. Here is an example: "At 1:00 PM on a summer weekday, the electric power serving your business stops without warning. You don't know how long this power interruption will last when it occurs. After one hour your power comes back on" (Sullivan et al. 2009, 93). Each of the surveys then asked the respondent to fill in a worksheet like that shown in Figure 4.1:

Figure 4.1. Simplified representation of outage cost estimation questionnaire for a business

For this interruption, estimate costs from:	
Damage to equipment:	$_________
Damage to materials:	$_________
Wages paid without production:	$_________
Other costs:	$_________
Lost sales (or production):	$_________
Percentage of sales to be recouped: % x Sales lost	$_________
Total sales lost:	$_________
Less:	
Wages saved:	$_________
Energy costs saved:	$_________
Other savings:	$_________
Total Costs:	**$**_________

***Source*: Sullivan et al. (2009)**

Surveys of other non-household entities, such as government agencies and non-profit organizations, can be similar to surveys of businesses. They can ask about net costs to the entity, and perhaps about services not provided to others, as a result of the outage.
For residential customers, a large portion of the costs of an outage may come from discomfort, inability to engage in certain activities, and risk of injury or death. These experiences are not bought and sold, so there are no prices for them that can be used to value them. As a result, researchers typically use non-market valuation methods, developed largely by environmental economists, to estimate the costs to households of a particular potential outage. These surveys, known as "contingent valuation" or "stated preference" surveys, attempt determine the lowest payment a respondent would be willing to accept in order to experience the outage or the most she would be willing to pay to avoid the outage. Some contingent valuation surveys straightforwardly ask such questions. For, example, Sullivan et al. (2009, 94) report that most or all of the U.S. residential surveys they use in their meta-analysis have asked residential customers questions like the following:

> Case #1: On a summer weekday, a power interruption occurs at 3:00 PM without any warning. You do not know how long the power interruption will last, but after 1 hour your household's electricity is fully restored.

Suppose a back-up service was available to handle all of your household's electrical needs during this power interruption. You would be billed by the supplier only for when and for how long the back-up service provided you with electricity. If you were charged a fee for this service only when you decided to use it (by using an on-off switch in your home), what is the most you would be willing to pay for this service each time you used it to avoid this power interruption? (Circle or enter number)

$0	$.10	$.25	$.50	$1	$2	$3	$4	$5	$6	$8
$10	$12	$15	$20	$25	$30	$40	$50	Other: $______		

The outage cost estimates for residential customers might be under-estimates because they are commonly based on questions that ask how much the customer would be willing to pay to avoid an outage, like the question just shown. An alternative is to ask the amount of compensation the customer would need to be paid to be indifferent to the outage. This is called "willingness to accept," and is known to typically be two to ten times as large as willingness to pay (Horowitz and McConnell 2003). Products with highly inelastic demand, such as electricity, tend to be near the top of this range (RAE 2014). It is no more difficult to ask about willingness to accept than it is to ask about willingness to pay.

When stated preference methods are appropriate, typically for residential customers, other surveys, called *choice experiments*, might be a better alternative than standard contingent valuation questions such as the one just shown. They do not ask for explicit dollar valuations but instead ask the respondents to choose from among different outage scenarios, often three, which differ in a few characteristics including how much the respondent would be charged or would save. The other characteristics could be duration of outage and frequency of outages, or some other combination of characteristics.

Respondents' valuation of *improvements* in *each* characteristic can then be inferred from their choices, potentially with a lower-cost set of surveys than would be required if standard contingent valuation questions were used instead (Ozbafli 2012). Using choice experiments may also produce better estimates than using standard contingent valuation questions because the decisions are of a more familiar type (Reckon 2012), may help reduce strategic answers, and may reduce the high incidence of protest answers (RAE 2014). Ozbafli (2012), Carson and Czajkowski (2014), and Hess and Daly (2014) discuss choice experiments. Pepermans (2011), Carlsson and Martinsson (2008), Beenstock et al. (1998), and Ozbafli and Jenkins (2016) offer different examples of choice experiments to value electricity supply outages. Ozbafli (2012) lists others.

ii. Blackout Case Studies

The costs of actual blackouts, typically large, long-lasting ones, have also been used to estimate the value of lost load. Some such studies use surveys similar to those described above, but that ask about the cost of the event that occurred, rather than about a hypothetical event. Such studies may also use records from government agencies, insurance firms, the affected electric distribution utility, and others. Cheng and Venkatesh (2014) assert that "this method provides more detailed and direct cost estimates that include indirect costs not adequately captured in other forms of analysis." The estimates of the effects, and their value, may be more precise than the estimates from surveys about hypothetical events, although future outages will not be identical to past ones, so the net cost of a past event is still only an approximation of the value of avoiding future ones. Corwin and Miles (1978), ELCON (2004), Serra and Fierro (1997), Tierney and Nigg (1995) and Tierney (1997 each report on a blackout case study, of New York City, Ohio, Chile, Des Moines, and two U.S. locations, respectively.

As noted above, surveys are used in both hypothetical valuation studies and studies of actual past outages. Like the other methods, surveys are not perfect, in both kinds of studies. According to Beenstock et al. (1997), "reported outage costs may be exaggerated to impress upon the power company the need for more reliable electricity." Respondents have an incentive to exaggerate their costs if they believe that the reliability-improving potential projects would produce more benefits than costs for them (RAE 2014). In addition, "interviewees may simply be unaware of the costs or unable to devote the necessary time to complete the questionnaire, which is often complex and long, with sufficient care" (Beenstock et al. 1997). Even if the interviewee is highly motivated to provide accurate answers and has full access to the company's records, some important questions may not be answerable from the records, such as how much of the lost production would be, or was, made up after the outage. However, according to Sullivan and Schellenberg (2013), "most hazard loss estimation experts … agree that surveys are the preferred approach for estimating direct costs." Sullivan and Schellenberg add that "this method is relatively uncommon because of" the relatively high cost of conducting reliability valuation surveys.

iii. Revealed Preference Methods

Another approach to estimating the value of an outage is to use market decisions customers have made in the past to avoid or mitigate the effect of outages, such as whether they have installed backup generators. The value of reliability is not equal to the expenditures on adaptation methods but can, under some circumstances, be inferred from customers' adaptation investment decisions and grid outage probabilities. For this method to work in a particular region for a particular group of customers, voluntary adoption of the adaptation methods has to be sufficiently common to allow for a statistically significant estimate of the customers' valuation of outages. Collecting the necessary information may require a survey of customers. There seem to be only a few studies of this type. Beenstock et al. (1997), Matsukawa and Fujii (1994), and Caves et al. (1992) are three of them. Revealed preference studies can be useful as a check on estimates based on other methods, though they may be of less use for understanding the value small customers place on outages because transaction costs may have prevented small customers from installing a backup generation source even if the reliability gain would be worth the price of the system.

iv. Proxy Methods

Proxy methods assume that the value of not being able to carry out some activity as a result of an electricity supply outage is equal to some known, related value. For example, the value per hour that an individual places on an outage is sometimes assumed to be equal to the average wage rate of the individual. Another example is that the ratio of gross regional product to electricity consumed by nonresidential customers is often used as a proxy for the cost to businesses of each megawatt-hour (MWh) not consumed because of an outage.

(Gross regional product is the regional equivalent of gross domestic product.) Anderson and Geckil (2003) is one study that uses this method to estimate the U.S. costs of the 2003 blackout in the Northeast. It is also called a "macroeconomic measures" method. A similar calculation can be done on an industry-by-industry or firm-by-firm basis, in which each industry's or firm's value of production is divided by its electricity use. De Nooij et al. (2007) use it to separately estimate the cost per MWh of outages to each major business sector in the Netherlands.

B. Challenges for Estimating the Economy-Wide Effects of Outages

Models of the whole economy of a country or other region can be used to estimate the economy-wide effects of power outages. Some reseachers have used computable general equilibrium models for this purpose (Rose et al. 2005, 2007; Guha 2005; Rose and Guha 2004). One challenge to this approach is that parameters in CGE models are typically set at levels intended for estimating long-run equilibrium effects. For example, the elasticities of substitution between different production inputs in CGE models are typically designed to reflect the amount of substitution that can occur over a period of a year or more. In a power outage, however, firms are limited to the substitutions they can make quickly. For some types of substitutions, for example switching from electricity to natural gas for heating, the CGE model is likely to overestimate the amount of substitution that would occur and thus underestimate the cost to the economy from the outage. Similarly, production functions in CGE models are typically estimated from long-term data and are therefore likely to overestimate the amount of adjustment that would occur in response to an outage. That, too, is likely to cause CGE models to underestimate the cost to the economy from the outage.

CGE models could be adapted to better estimate the effects of resilience on the costs of power outages. Production functions could be adjusted to represent the adaptation strategies possible within several days or weeks following sudden, short-duration shocks such as power outages. Rose et al. (2007) and some earlier papers do this. Likewise, parameters such as the substitution elasticities and input supply elasticities could be adjusted to reflect the short-term nature of substitution options. However, it appears that at present, no empirical estimates exist of short term substitution elasticities or production functions that capture the effect of short-term shocks. Rose et al. (2007) report, "Unfortunately, we are not aware of any studies that have estimated elasticities for the kind of 'very short run' that we consider." As a result, Rose et al. (2005, 2007) assume that short term elasticities are 10 percent as large as the elasticities in a standard CGE model (before adjusting them upward from that level by 10 percent to represent the adaptation strategies by indirectly affected firms).

Another approach to estimating economy-wide effects of an electricity outage is to use input-out models (MacKenzie and Barker 2012; Anderson et al. 2007; Rose and Lim 2002; Rose et al. 1997; Chen and Vella 1994). The Federal Emergency Management Agency also has an input-output-based simulation tool for estimating the indirect effects (FEMA 2015). Typical input-output models assumes that a fixed amount of each input is needed to produce the output of each sector, so it effectively assumes that all elasticities of substitution are zero. The real elasticities of substitution within days or weeks are closer to zero than are the real elasticities of substitution within years, so this assumption of fixed input requirements may be less of a weakness in simulating a power outage than in simulating longer-lasting phenomena.

A final approach is to use a macroeconometric model such as Greenberg et al. (2007) do. However, as in CGE models, the estimates of relationships in such models are generally long-run relationships, while the economy-wide effects of an outage usually result from short-run relationships.

Standard CGE, input-output, and macroeconometric approaches do not account for costs other than lost production, and in accounting for lost production, assume that the amount of production lost is equal only to the amount that would have occurred during the time of the outage. This is true of proxy methods as well. In fact, there are other costs, and production may be disrupted for longer than the outage lasts. Sanstad (2016) further discusses how to improve whole-economy modeling of the effects of outages.

C. Methods of Incorporating Adaptation to Electricity Outages

Methods of adapting to outages allow firms and households to reduce their losses from outages through changes in their standard operation. For example, during a power outage, firms may be able to use backup generators, find input substitutes, rely on inventory instead of new production, and reschedule production outside the affected area or postpone it to a later date (Rose et al. 2007). Adaptation by firms and households whose service is interrupted reduces the direct costs of a power outage. Firms and households that are only indirectly affected can also implement adaptation strategies—for example, by using inputs in inventory in place of inputs from a supplier that has lost power—thereby reducing the indirect costs of the outage. Accurately estimating the costs of outages requires accounting for these adaptation strategies, which would lower the economic cost of an outage on society.

The effect of adaptation strategies on the cost of an outage are at least partially captured by survey methods for valuing outages because respondents may naturally take adaptation strategies into account in formulating their answers, or may be asked to do so. Similarly, revealed preference methods inherently take into account adaptation strategies, to the extent that electricity customers take into account adaptation options when deciding whether to trade off money for reliability, for example by buying a back-up power supply. In contrast, incorporation of adaptation strategies does not automatically occur when applying proxy methods or when using typical CGE, input-output, or macroeconometric models. Thus some prominent studies of the economic cost of outages have not taken into account adaptation strategies. For example, some of the published studies valuing the 2003 northeastern blackout—at least Anderson et al. (2007) and Anderson and Geckil (2003)—appear to have not accounted for adaptation.

Rose et al. (1997, 2005, 2007) and Rose and Lim (2002) illustrate methods of accounting for adaptation when using CGE and input-output models to estimate the economy-wide costs of a power outage. Rose et al. (2007) consider a hypothetical 2-week power outage in Los Angeles. Using a CGE model and numbers that are intended to represent the adaptation capabilities of businesses, this study estimates that strategies including back-up power supplies, the ability to produce some output without electricity, the ability to substitute other inputs for electricity, and electricity conservation together reduce the cost of a power outage by approximately 41 percent. Downstream and upstream businesses' and consumers' response to the price changes wrought by the outage reduce the remaining costs by approximately 5 percent. Catch-up production after the outage reduces the remaining cost by approximately 77 percent. In total, the authors estimate that adaptation strategies reduces the cost of the power outage by 87 percent, to approximately 13 percent of what it would be without those adaptation strategies (59 * 95* 23 = 13 percent). However, the estimates of the numbers that represent the adaptation capabilities of businesses in these studies are very crude and at times, decades old. Better data on the adaptation capabilities of businesses would enable better estimation of the effects of adaptation on the costs of electricity supply outages. Researchers could design surveys to elicit the data necessary to estimate such capabilities.

D. Estimates of the Cost of Outages

The estimates of the cost of an electricity supply outage that applies to a cross-section of U.S. customers vary widely. For example, for outages lasting at least 16 hours and affecting a cross-section of U.S. customers, the estimates of the costs in credible U.S. studies range from a high of approximately $126 per unserved kWh to a low of approximately $1.70 per unserved kWh. The reason for much of the vast difference between these estimates is difficult to determine.

i. Estimates of the Cost of Short Outages

Sullivan et al. (2015) present a meta-analysis of 34 power interruption cost surveys of customers conducted by utilities between 1989 and 2012, noting that "to the knowledge of the authors, this dataset includes nearly all large power interruption cost studies that have been conducted in the U.S." (16). The surveys and some of their basic characteristics are shown in Table 4.2 below. "Number of Observations" refers to the number of companies or households surveyed.

Table 4.2. Characteristics of surveys of customers conducted by utilties, 1989–2012

Utility Company	Survey Year	Number of Observations			Min. Duration (Hours)	Max. Duration (hours)
		Medium and Large C&I	Small C&I	Residential		
Southeast-1	1997	90			0	1
Southeast-2	1993	3,926	1,559	3,107	0	4
	1997	3,055	2,787	3,608	0	12
Southeast-3	1990	2,095	765		0.5	4
	2011	7,941	2,480	3,969	1	8
Midwest-1	2002	3,171			0	8
Midwest-2	1996	1,956	206		0	4
West-1	2000	2,379	3,236	3,137	1	8
West-2	1989	2,025	5		0	4
	1993	1,790	825	2,005	0	4
	2005	3,052	3,223	4,257	0	8
	2012	5,342	4,632	4,106	0	24
Southwest	2000	3,991	2,247	3,598	0	4
Northwest-1	1989	2,210		2,126	0.25	8
Northwest-2	1999	7,091		4,299	0	12

= Recently incorporated data

***Source*: Sullivan et al. (2015)**

The methods used in the 24 business surveys are "nearly identical" to each other, as are the methods used in the 10 residential customer surveys (Sullivan et al. 2015). Sullivan et al. pooled the data, then fit regression equations to it. Table 4.3 shows the estimated average cost per kWh as a function of customer class and outage duration, calculated using the fitted regression equations. In it, "C&I" means commercial and industrial. (The value per kWh is high for a 5-minute outage because the number of kWh not served in 5 minutes is relatively small, but some negative effects of a supply interruption do not depend on the length of the interruption.)

The authors conclude that the estimated outage cost per kWh tends to decline as outage duration increases. In addition, per kWh of lost service, businesses with low electricity consumption tend to place a much higher value on uninterrupted service than do businesses with high electricity consumption, who in turn value it much more highly than do residential customers.

Table 4.3. Estimated interruption cost per kWh, by customer class and duration of outage, 2013$ per kWh not served

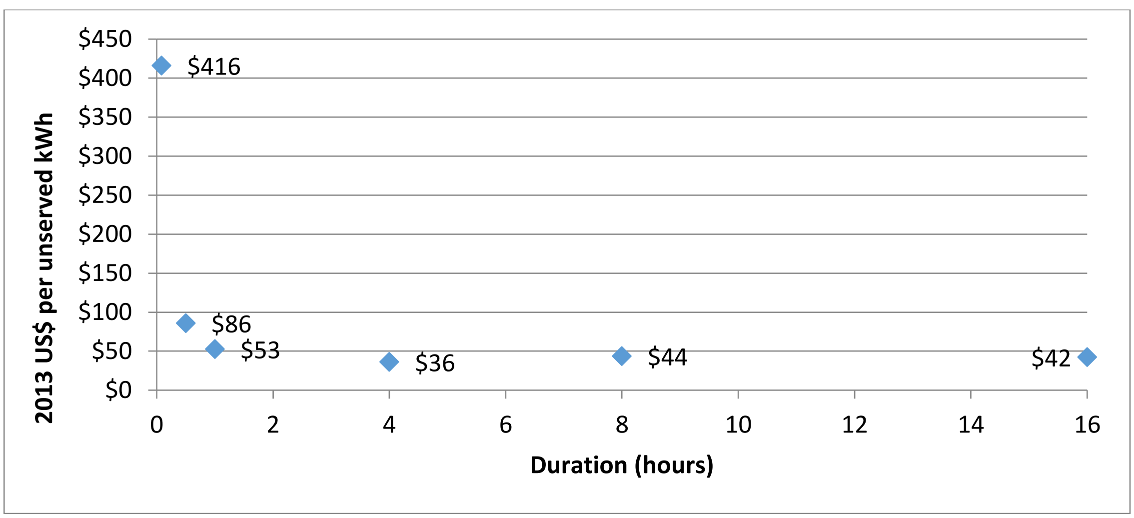
Outage Cost per kWh	Outage Duration					
Customer Class	5 Min	30 Min	1 Hr	4 Hr	8 Hr	16 Hr
Medium & Large C&I (>50,000 Annual kWh)	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (<50,000 Annual kWh)	$2,254	$474	$295	$214	$267	$258
Residential	$30.9	$5.9	$3.3	$1.6	$1.4	$1.3

***Source*: Sullivan et al. (2015)**

According to these outage cost estimates, though small C&I customers account for approximately 14 percent of U.S. electricity consumption (FERC 2009; EIA 2016a), they experience 82 percent of the costs of an average 4-hour outage (not counting economy-wide ripple effects). Residential customers account for approximately 37 percent of U.S. electricity consumption (EIA 2016a), but experience just 2 percent of the costs of an average 4-hour outage (not counting economy-wide ripple effects). Here, "average" means that it affects the three different customer classes in proportion to their shares of U.S. electricity consumption.

Using these shares of U.S. electricity consumption (37 percent residential, 14 percent small C&I, 49 percent large C&I) and the outage costs per kWh from Table 4.3, it is possible to calculate the approximate cost per kWh of an average outage, as a function of its duration (see Figure 4.2).

Figure 4.2. Estimated average direct cost of U.S. electricity supply outages, per kWh, as function of outage duration



***Source*: Sullivan et al. (2015)**

***Note*: Average of costs by customer class weighted by their shares of U.S. electricity consumption.**

To account for the cost associated with indirect effects throughout the rest of the economy, one could use a sophisticated whole-economy model or could use the simpler approach of applying a multiplier. Sullivan and Schellenberg (2013) assume that the appropriate multiplier is between 1.5 and 3. Applying those multipliers to Sullivan et al.'s (2015) estimate, the economy-wide cost of a 16-hour outage would be \$63 to \$126 per unserved kWh. This estimate, \$126, is the top of a range of credible estimates of the cost per unserved kWh of U.S. outages lasting at least 16 hours.

In addition to depending on duration and how much large and small business load is affected, and how much residential load is affected, the cost per unserved kWh also varies based on other factors. It varies greatly from one customer to another even within a customer class, depending on how valuable their uses of electricity are and how sensitive those uses are to interruption. The cost per unserved kWh also depends on when the outage occurs, on the weather, and on whether there is advance notice. De Nooij et al. (2007) cite an older study to illustrate how the cost to customers of an outage can vary according to when it occurs:

> Day and Reese (1992) note that, while interviewing people in the USA about power interruptions in the previous year, many people recalled an interruption that had occurred five years earlier. This interruption happened shortly before the Thanksgiving dinner. Some of the victims became so angry that they drove to the electricity company and threw their half-cooked turkeys at the office building.

The outage costs per kWh from Sullivan et al. (2009, 2015) have been used to create an Interruption Cost Estimate Calculator.[52] To calculate the estimated annual cost of outages for a particular set of customers, a user of the site can enter the share of load consumed by large C&I customers, small and medium C&I customers, and residential customers; the state or states in which the outage occurs; the number of outages per year; the average duration of outages; when the outages occur; and the share of customers with back-up generation. The calculator provides user-modifiable default values of some of these variables from past studies. The calculator then outputs the estimated cost of those outages.

ii. Estimates of the Costs of Long Outages

Using outage data from 1995 through 2003, LaCommare and Eto (2006) estimated that the cost of all U.S. electric outages was approximately \$79 billion per year and that two-thirds of the annual cost resulted from outages lasting less than 5 minutes. However, long outages may be considered more germane to energy security and the G-7 principles. Furthermore, the Executive Office of the President (2013) recently estimated that the cost of U.S. weather-caused outages lasting more than 5 minutes averaged \$18 billion to \$33 billion per year from 2003 to 2012, and that those costs were dominated by 14 long-duration outages.

[52] The Interruption Cost Estimate Calculator is available at http://www.icecalculator.com/.

iii. A Hypothetical Long Outage in San Francisco

Sullivan and Schellenberg (2013) offer an instructive survey-based study of the estimated costs of a long electricity supply outage. It is similar to the short-term work of Sullivan et al. (2009, 2015), but considers outages lasting 1 day to 7 weeks. In collaboration with the local electric utility company, Sullivan and Schellenberg's team surveyed businesses in downtown San Francisco to estimate the value of adding a transmission line to make that area less vulnerable to a prolonged outage in the event of an earthquake. The researchers asked how much revenue the businesses expected they would lose, and how much they expected their out-of-pocket costs would increase, as a result of outages of four lengths (see Table 4.4). Sullivan and Schellenberg then assumed, based on prior studies in the hazard loss literature, that adding the indirect costs elsewhere in the economy would cause the total cost of the outage to be between 1.5 and 3 times the cost to the businesses that would experience the outage.

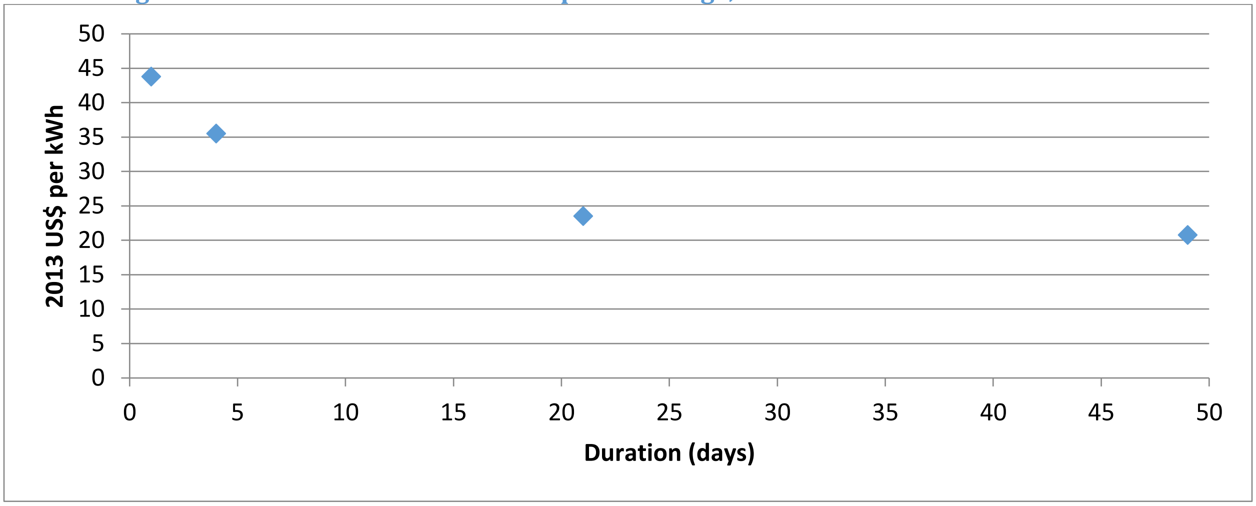
Table 4.4. Total estimated direct and indirect costs of hypothetical San Francisco outages, by duration (millions of U.S.$)

Outage Duration	Total Direct Outage Cost	Range of Total Indirect Outage Costs	
		Low (Direct Cost x 0.5)	High (Direct Cost x 2.0)
24 hours	$125.7	$62.9	$251.4
4 days	$407.4	$203.7	$814.8
3 weeks	$1,417.0	$708.5	$2,833.9
7 weeks	$2,922.6	$1,461.3	$5,845.2

***Source*: Sullivan and Schellenberg (2013)**

Figure 4.3 graphically shows the estimated costs, per kWh not served, for the businesses surveyed by the study. The shape of the relationship between outage duration and cost per unserved kWh is similar to that in the short run analysis: The shortest outages have the highest estimated cost per unserved kWh. The estimated cost per kWh is approximately half as large in a 7-week outage as in a 1-day outage.

Figure 4.3. Downtown San Francisco power outage, direct cost to affected businesses



***Source*: Sullivan and Schellenberg (2013)**

To compare these with the values in Figure 4.2 for durations up to 16 hours, we need to adjust them for the fact that Figure 4.3 considers only businesses. If residential customers constituted 37 percent of the load in San Francisco and their outage cost were $1.3 per kWh (the value for a 16-hour outage from Table 4.3), then the average direct cost per unserved kWh would be $28 for a 1-day outage, which is roughly similar to Sullivan et al.'s (2015) estimated direct cost per kWh of a 16-hour outage of $42, as shown in Figure 4.2.

iv. Other Estimates of the Costs of Long Outages

Table 4.5, from the literature review section of Schellenberg and Sullivan (2013), reports the estimated costs of various other real and hypothetical outages, from various studies. In it, "I/O" stands for "input-output" and "PE" stands for "partial equilibrium." Most of the studies include only nonresidential customers because of the belief, based on some past studies, that the cost of power outages to residential customers is typically much smaller than the cost of power outages to the businesses in the same area.

Table 4.5. Estimated costs of actual and hypothetical U.S. blackouts of various durations

Study	Population Studied	Region Affected	Outage Duration	Outage Date	Hypothetical / Actual	Method	Population Affected	Total Cost Estimate (2011 $)*	Cost per Capita (2011 $)*		Notes
									Total	Per Day	
Corwin and Miles 1978	Non-residential	New York City	Up to 25 hours	Thursday, January 13, 1977	Actual	Reports from businesses and agencies	9 million	$1.3 billion	$144	$144	Much of cost from looting and arson, not representative of most outages
Rose and Lim 2002	Non-residential	Los Angeles (LADWP territory)	Up to 36 hours	Monday, January 17, 1994	Actual	I/O model with ex post resiliency adjustments	3.5 million	$8 - 158 million	$2 - 45	$1 - 30	Resiliency adjustments: electricity importance (-16%), production rescheduling (-84%) (may not be possible for a long duration outage), and time of day of usage (-94%); method is biased underestimate; population number from LADWP
Gordon et al 1998	Non-residential and commuters	Los Angeles County	Up to 36 hours	Monday, January 17, 1994	Actual	Survey and I/O model	9.1 million	$4.4 billion	$484	$323	Impacts: 51% impact zone, 20% rest of LA county, 29% region and world; population affected is LA County, so total impacts ($6.5 billion) have been scaled to it; additionally, 63% of cost is attributed to loss of utilities, so estimate is further scaled; method is biased overestimate; population number from Census
AUS Consultants 2001	Private sector	California	20 effective hours	June to September 2001	Hypothetical	Survey, macroeconomic measures, and I/O model	34.6 million	$31.2 billion	$900	$69	Rolling blackouts, so 20 hours is in 60-90 minute blocks over several months; method is biased overestimate; population number from Census
Anderson Consulting 2003	Non-residential	Northeastern U.S.	Between 16 and 72 hours	Thursday, August 14, 2003	Actual	Macroeconomic measures and indirect effects multiplier	45 million	$5.5 - 10.1 billion	$122 - 224	$61 - 112	Population number from Wikipedia
ICF 2003	Non-residential	Northeastern U.S.	Between 16 and 72 hours	Thursday, August 14, 2003	Actual	Unserved kWh cost from prior studies	45 million	$8.3 - 12.6 billion	$184 - 280	$92 - 140	Population number from Wikipedia
Brattle Group 2003	Non-residential	Northeastern U.S.	Between 16 and 72 hours	Thursday, August 14, 2003	Actual	Unserved kWh cost from prior studies	45 million	$7.3 billion	$162	$81	Estimate is considered a lower bound; population number from Wikipedia
Ohio Manufacturers' Association (ref in ELCON 2004)	Manufacturing sector	Ohio	Between 16 and 72 hours	Thursday, August 14, 2003	Actual	Survey	11.4 million	$1.3 billion	$114	$57	Limited to impact on Ohio; Represents double the Anderson estimate for the state; population number from Census
Anderson et al 2007	General	Northeastern U.S.	Between 16 and 72 hours	Thursday, August 14, 2003	Actual	I/O model with inoperability	45 million	$8 billion	$178	$89	Population number from Wikipedia
National University System 2011	General	San Diego	Up to 13 hours	Thursday, September 08, 2011	Actual	Extrapolation from prior outages	2 million	$97 - 118 million	$49 - 59	$49 - 59	Estimation is considered a lower bound
Moore II et al 2005	General	Los Angeles & Orange Counties	One month	Summer mid-2000s	Hypothetical	Spatial I/O model	11.8 million	$14.4 billion	$1,220	$41	Relies on data from 1990s; population data from Census
Rose et al 2007	General	Los Angeles County	2 weeks	Summer mid-2000s	Hypothetical	CGE model with ex post resiliency adjustments	9.8 million	$3 - 14.2 billion	$306 - 1449	$22 - 104	Resiliency primarily from production rescheduling; population data from Census

* Values adjusted to 2011 dollars using CPI-U.

***Source*: Schellenberg and Sullivan (2013)**

The second-to-last column shows the estimated cost per person per day, in 2011 U.S.$. The lowest is $22 per person per day, which translates to $1.70 per kWh.[53] This estimate is

[53] One study produced a lower estimate, but the authors of Table 5 describe it as biased. The $1.70 per kWh calculation assumes that (1) average electricity use per capita was the same in the affected area as it was in California as a whole; (2) businesses accounted for 63 percent of all electricity use in the affected area; (3) the value of lost load for residential use in the area was $1.30 per kWh (Sullivan et al. 2015); and (4) the indirect cost multiplier was the same for residential customers as for businesses. We derive the estimate from the estimated cost to businesses, at $22 per person per day divided by the 2007 California average of 20 kWh per person per day, or $1.10 per kWh. However, this estimate ignores costs to residential customers. That can be

from Rose et al. (2007), which was described above in the modeling section. It is based on a CGE modeling analysis, and uses estimates of the extent to which firms are able to reduce the impact of the outage through adaptations (resilience). This estimate, $1.70, is the bottom of a range of credible estimates of the cost per unserved kWh of U.S. outages lasting at least 16 hours.

The highest cost per person per day in Table 4.5 is $144 from Corwin and Miles (1978). [54] It translates to $12 per kWh, but most of that is a result of what the authors of the estimate call "indirect costs," primarily from the arson and looting that occurred. Without that, the estimate would be $1.95 per kWh. Of that, just over half is the estimated losses of the securities and banking industries, which would be much smaller in most cities. Without those, the estimate would be $0.97 per kWh. However, the authors emphasize that their accounting of costs in the affected area is not comprehensive. In addition, it is from a time when incomes were lower, and it does not include the indirect economic effects throughout the rest of the U.S. and world economies.

Van der Welle and van der Zwaan (2007) reviewed the literature on the cost per kWh of electricity supply outages in high-income countries including the United States and concluded that it is almost certainly between $4 and $40 per kWh. However, they did not include Rose et al. (2007) or Sullivan et al. (2009, 2015) in their review. In addition, they do not specify the durations of the outages to which their range applies.

Cheng and Venkatesh (2014) include a list of estimated values of load from 18 studies in 13 high-income countries. Assuming that residential customers represent 37% of load and C&I customers the rest, most of their estimates fall in the range of $4 to $40 per kWh, though the estimates of Bliem (2008) and Tiedemann (2004a, 2004b) are substantially higher than $40 per unserved kWh.

Reckon (2012), too, reports a variety of estimates from the literature, mostly for high-income countries in Europe. Most of those estimates are consistent with the $4 to $40 per kWh range.

v. Possible Reasons for the Wide Range of Estimates

For outages lasting at least 16 hours and affecting similar cross-sections of customers, the estimated costs per unserved kWh include $1.70, based on Rose et al. (2007), and $126, based on Sullivan et al. (2015). The former is for a 2-week outage, while the latter is for a 16-hour outage. Based on Table 4.4, the average cost per unserved kWh of 2-week outage might be approximately half of that of a 16-hour outage, so we can approximately halve the $126 estimate to $60 to make it directly comparable with the $1.70 estimate. These two estimates, $1.70 and $60, are both estimates of the cost per unserved kWh of a 2-week outage. There are no obvious differences in the outages that account for the differences in

factored in by adding 0.37 residential share of load * $1.30 direct cost per kWh not served to residential customers * 1.24 whole-economy multiplier from Rose et al. (2007), or $0.60 per kWh.

[54] One study produced a higher estimate, but the authors of Table 4.5 describe it as biased.

the estimates. Further, it is not clear that either estimate is based on unreasonable methods or assumptions.

Differing estimates of economy-wide indirect effects explain part of the difference between these estimates: The $1.70 value is based on a CGE analysis that estimated that the multiplier to convert from direct cost to total economy-wide cost is 1.24. The $60 value is based on the assumption that the multiplier is 3. Removing those multipliers yields the respective estimates of direct costs only, which are $1.37 per kWh calculated using results from Rose et al.'s (2007) CGE analysis with adaptation and $20 per kWh using results from Sullivan et al.'s (2015) meta-analysis of outage value surveys.

One possible explanation for the difference has to do with an assumption in Rose et al. (2007) and the studies that use gross regional product as a proxy for losses. They assume that the cost to businesses of an outage, before counting the cost-reducing effects of adaptation measures, equals the profits the business would have earned during the time of the outage if there had been no outage. If the cost to businesses were actually much higher, that would be reflected in the $20 estimate based on surveys but not in the $1.37 estimate based on Rose et al.'s (2007) CGE analysis.

Another possible explanation for the difference is that the businesses that choose to complete the surveys have a higher outage cost than the ones that do not. The ones with higher outage costs could be more motivated to complete the surveys.

A third possible explanation for the difference is that some survey respondents overstated the cost to them of outages, intentionally or unintentionally. As mentioned above, respondents who believe that a reliability-improving utility investment would produce more benefits than costs for them have an incentive to intentionally overstate their estimates of the costs to them of outages, with the exaggeration limited only by the possibility of their reply being discarded as an implausible outlier.

A carefully designed survey of businesses could elicit information that could shed light on each of the possible explanations just mentioned. Specifically, the survey could ask the respondents about their average profit per day, and could also ask the usual questions in the surveys used by Sullivan et al. (2015). The region's profit per day could be estimated from the responses and then compared against the known annual profit of the businesses in the surveyed area. If it yielded an estimate of profit higher than the actual profit earned by the businesses in the area, then it would indicate that the surveys are overstating profits, consistent with the second and third possible explanations of the difference in outage cost estimates. In addition, the answers to the question about average profit per day could be compared with the answers to the questions about total cost of the outage, to determine whether the reported cost per day of an outage is much larger than the reported usual profit per day. That would be a test of the first possible explanation for the large difference in the estimated outage costs.

Another type of experiment could shed additional light on whether some customers are overstating the value to them of reliability. The experiment could ask hypothetically about the value of a backup energy source, like in past surveys, but then actually offer that backup source at a low price, perhaps in conjunction with a state's battery storage incentive program. This is known as a *field validity test*, and Vossler et al. (2003) provide an example. A fourth possible reason is that the estimates used by Rose et al.'s (2007) of the ability of businesses to reduce the cost of an outage through adaptation may be too large, or businesses might understate their adaptation capabilities because they might not be aware of how much they could make up missed production or sales, or how much they could adapt in other ways. Additional questions to help both businesses and researchers better quantify the businesses' resilience capabilities could better inform the resilience assumptions in outage cost modeling.

A fifth possible reason is that the surveys, usually commissioned by utilities, might lead the respondents to overstate the cost of outages to them. The regulated rates of return that electric utilities are allowed to earn on their investments tend to be higher than the cost of capital, so it can be in utilities' interest for their methods of estimating the cost of outages to produce high estimates, so that new reliability investments are more likely to be approved by regulators. This would be an example of what is known as the Averch-Johnson Effect (Sherman 1985). Survey design, such as the answer choices given and the wording and order of questions, can significantly affect the outcomes. This issue could be checked by having some surveys designed by researchers who do not receive industry funding. More broadly, the literature about valuation of non-market goods in general and environmental quality in particular has examined the effects of various details of the methods, and how to produce estimates that match real outcomes (e.g., Vossler et al. 2003). The lessons of that research could be more extensively applied to the further refinement of outage cost study methods and to decisions about which values from the literature to use when a new study cannot be conducted.

E. Valuing Reliability of Electricity Supply to Critical Military Equipment

Estimating the value of making the grid sufficiently reliable to meet the needs of critical military facilities at times when continual deterrence is needed, or conflict occurs, is difficult. In most cases, the required level of reliability is extremely high so the least-cost solution is likely to be to add backup electricity generators at military facilities. As a result, the main valuation needed for reliability of supply to critical military equipment is not just a valuation of the reliability of the civilian grid. Rather, it is a valuation of the supply to the mission-critical equipment, where that supply comes either from the civilian grid or from the backup sources.

The apparent lack of publicly available literature on such valuation may be because, in the words of Czumak and Woodside (2014), "some could argue that from a qualitative perspective the quantitative cost of energy security is irrelevant, because the potential unfavorable consequences of underinvesting in energy security are greater than the expenditures to secure against them."

However, some literature has made a case for valuation of greater reliability of supply to critical military equipment. Rinaldi et al. (2001) mention that the California blackouts of 2000 and 2001 crippled California's defense systems. Giraldez et al. (2012) report some reasons for further consideration of the reliability of the electric power supply to U.S. military facilities in times of conflict or potential conflict:

> One of the reasons to increase the sufficiency of energy security in DOD installations is that they are almost completely dependent upon the commercial power grid.
>
> Most DOD installations have contingency plans in the event of a grid failure that can provide backup power to critical loads using, in most cases, diesel-powered building generators. However, the expected duration for these contingency plans is not well defined; diesel generators are not designed to run for weeks at a time, and fuel storage capacities vary widely. Additionally, the preventative maintenance for these diesel generators does not always prepare the generators for 100% availability; they have a low probability of 60% to start when needed.

Not all of the Nation's critical military facilities are in the United States: "America has more overseas military bases than any other nation: nearly 800 spread through more than 70 countries" (Economist 2016). Sharon Burke, former Assistant Secretary of Defense for Operational Energy Plans and Programs, has discussed a benefit of valuing reliability to critical equipment (2016):

> Let's say you're talking about a base that has cockpits that are flying unmanned systems in combat, and is running intelligence operations, and is part of defense support to civil authorities if something were to happen in the homeland, they're mission critical in three different ways, and their electricity is a critical enabler for all of those missions. How do you put a price on that? On whatever measures they should take at the base? You have to put a price on it or you can't compete for the dollars, because when you sit around a budget table for a large organization like that, and someone says, "I need money for a really important gun" [and someone else says] "I need money for this brigade to deploy," if you say, "I need money to put backup power on my base," I can tell you who's going to lose. So until you can put a dollar value that has a military effectiveness metric behind it, you won't win in those kinds of discussions.

According to Chisom and Templeton (2013), "The Marine Corps has failed, in policy terms, to determine the economic value of energy security. Therefore, the Marine Corps remains vulnerable to electrical grid interruption."

F. Estimating the Probability and Extent of Electricity Outages

Valuing the effects of policies, grid investments, and some other actions on reliability and resilience requires not just valuing outages, but also estimating the effects of the action on the probabilities of outages. Ideal modeling of the effect of action on the probability of an electricity supply outage requires modeling of the grid's operation along with stochastic modeling of four sets of factors: sudden grid component failures, generator availability, customer demand, and any potential outage triggers that are external to the grid. Whether an external trigger causes an outage, and the extent of that outage, often depends on the system's status at the time, which in turn depends in part on the first three factors. It also requires estimates of the effects of the action on the probabilities of these four sets of factors.

Conventional reliability analysis, such as that using GE MARS (GE Energy Consulting 2016b), considers all four factors. However, it emphasizes normal operation and the weather extremes that recur in a high proportion of years. In the U.S, the actions usually modeled are those under the control of electric distribution utilities, transmission system planners, public utility commissions, and the Federal Energy Regulatory Commission. Conventional reliability analysis does not usually include thorough consideration of uncommon natural disasters and malicious human actions, and usually does not include thorough consideration of policies other than reliability policies. As a result, the methods of estimating the probabilities of most kinds of disasters, attacks, and non-reliability policies, and of estimating their effects on grid component failures and generator outages, are less developed. There are multiple types of policies, multiple types of attacks, and multiple types of disasters. Each type may require somewhat different methods. There is current research on some types, including hurricanes (e.g., Staid et al. 2014) and solar coronal mass ejections. Most of the necessary methods involve statistics, and some involve physics and physics-based engineering as well.

To quantify the effects of a policy or other action on the cost associated with electricity outages, the probability of outages and cause of outages must be modeled. If potential outages have unpredictable causes external to the power system, such as natural disasters and intentional attacks, then the probability modeling must address those events rather than just the power system. Some parts of this are now done well, such as predicting the extent of outages resulting from impending and potential future hurricanes (e.g., Staid et al 2014), but others are not yet. Simulation modeling, statistical analysis, and expert elicitation may each be useful.

Most large outages in the U.S. are cascading outages that typically result from the failure of a single component of the transmission system, but can also result from an event that disables multiple components simultaneously. Vaiman et al. (2012) summarize the main approaches to assessing the risk of cascading outages. They recommend "validation of all methods against observed real data; improvement in methods of sampling cascades; and a re-evaluation of the cascade mechanisms that need to be modeled and the modeling detail that is required. Given the scale of the effort required and the enormity of the challenges ahead, collaboration among policy makers, utilities, vendors and research organization is essential to solve this challenging problem."

Wang et al. (2016) summarize the literature about predicting the effects of storms on system outages and report a need to better predict how system hardening investments will affect outage probabilities:

> Future research on forecast models is needed in two directions: 1) Enhancing the accuracy of the forecast by developing new statistical and simulation based models. This may require more data analytical models to be incorporated, as well as more open source data to be provided by the utilities. 2) Establishing models that link the forecast and the hardening investment guidance. For example, Brown (2009) provides some insights on the cost-benefit analysis of the infrastructure upgrades based on increasing

NESC standard requirements. Such analysis may also be used in other types of hardening techniques, guided by the more accurate statistical and simulation models.

When designing the hardening and resilience programs, utilities typically do not use systematic and rigorous optimization techniques. A common way of deploying the investment is to upgrade the previously damaged facilities, or choose certain techniques based on experience. Therefore, the identification and allocation of the budget may not be the most efficient. More research on how to optimize the hardening program investments could potentially save a large amount of money, as well as increase the resilience of the program.

This section has discussed the valuation of outages and the estimation of the effect of actions on outage probabilities. Larsen (2016a) is one example of a study that does both. It presents a comprehensive method to quantify the costs and benefits of undergrounding distribution and transmission lines, incorporating both effect on outage probabilities and the monetary value of avoided outages. De Nooij et al. (2010) is another example. It presents a framework for benefit-cost analysis of a reliability action. It then applies that framework to the rule that the grid in the Netherlands must always be robust to the failure of any component even during a maintenance situation. These are examples of value-based reliability planning, which Larsen (2016b) reviews at length.

G. Next Steps in Outage Valuation

A significant amount of literature is devoted to estimating the value of avoiding electricity outages, although it is primarily about very short-term outages, and large variation exists in the estimates for any given time period. To generate values that could be used by policymakers in future cost-benefit analysis, additional research is warranted, as follows:

- ***Electric power sector.*** More refinement is needed of methods and data for valuing the direct and indirect costs of long term electricity supply outages. The wide range of estimates might be reduced if researchers used and further developed best practices with respect to survey and model design. In addition, the effect of adaptation measures available to various sectors on the societal value of an extended outage is not well understood. That is particularly true as it relates to nonlinearities in adaptation strategies that may, for example, provide significant protection to a sector from a week-long outage but much less protection from longer outages.
- ***Electric power sector.*** Some sectors of the economy, such as military, healthcare, and public utilities, are critical lifeline sectors of the economy. Understanding both the resilience of those sectors to outages and the adaptation measures they have adopted or could adopt would enable policymakers to better understand the types of policies that would reduce the cost of extended power outages to the U.S. economy.
- ***Electric power sector.*** The probabilities of various types of outages are not well understood. To estimate the value of any resilience or reliability investment, one must weigh the costs against expected benefits, which depend on the effect of the investment on the probability of future outages. More research on how policies,

technology, and investment change the probability of outage-inducing events for various parts of the country would facilitate better benefit-cost analyses.

- ***Oil and gas sectors.*** We were unable to identify any recent research on the economic cost of a gasoline, diesel, or natural gas outage (i.e., the physical shortage of those products at any price), which is probably because the likelihood of such an outage is low and its duration would be short. Better understanding such outages and the relationship between natural gas and refined petroleum product prices and economic growth would benefit policymakers when, for example, considering additional federally funded storage of these fuels.

V. Valuation of Diversification and Resilience in the Oil and Gas Sector

Given the economic costs of disruptions that increase oil or natural gas prices, many policies are designed to reduce price volatility or the probability that disruptions occur. Those might include policies that increase diversity of fuels, sources or routes, such as efforts to increase alternate fueled vehicles in the fleet. Or they might include policies to improve the resilience of energy infrastructure or the U.S. economy against disruptions such as policies that create standards for refinery resilience or the maintenance of strategic government stocks. Quantifying the extent to which diversification or resilience can reduce the effect of a disruption on the U.S. economy or reduce the probability of a disruption is difficult. This section discusses the current state of research on those topics.

A. Diversification of Fuels, Sources, and Routes

Measuring diversification of fuels, sources and routes can be done through a variety of means, as discussed below, however, the benefit of such diversification have not been monetized in the literature, so they cannot be included in the benefit-cost analysis of policy or actions that affect diversification. Diversification of the sources of oil and gas may be used to protect a country against supply risks.[55] For example, obtaining fuel from different sources may lessen the risk that a single supplier could disrupt fuel prices and availability.[56] By contrast, increasing the type of fuel that can be used (e.g., by having vehicles that can run on oil or electricity) may lessen the harm to the overall economy resulting from a change in the price and availability of a single fuel. Increased diversity in other aspects of fuel use, such as the transport routes, and the types of import contracts, may similarly contribute to oil and gas security, but are not often included in measures of diversification (Vivodo 2009; Dirks 2006).

Most methods of quantifying diversification are taken from the financial industry. Portfolio diversification metrics, for example, may be used to develop diversification indices (Helm 2002). For quantifying fuel diversification risks associated with sources of supply, the

[55] This approach may be less comprehensive than a probabilistic approach, such as modern portfolio theory. However, as noted by Blyth and Lefèvre (2004), the risk associated with each supplier is often difficult to estimate, given the complexity of the oil and gas markets and the confounding effect of market liberalization in historical examples. Therefore, an approach focusing on diversification alone may be more appropriate.
[56] Lefèvre (2007) adopts the description of energy security presented by Bohi and Toman (1996), who define energy security as a loss in welfare resulting from a change in price or availability of energy. These two components have varying importance based on whether prices are allowed to adjust.

Herfindahl-Hirschmann Index, which sums the squares of the market share of each supplier, is perhaps the most common of these metrics. The Hirshmann-Herfindahl-Agiobenebo Index and the Shannon-Wiener Index, which are two approaches that weigh the impact of smaller suppliers more heavily than the Herfindahl-Hirschmann Index, have also been used to measure diversification in these studies (Cohen et al. 2011; Vivoda 2009). The measure of diversification presented by Blyth and Lefèvre (2004) adjusts the market share of a supplier of each studied fuel by the political risk of the supplier countries and the market liquidity experienced by the importing country. The authors define market share by the net potential to export to the given market. Cohen et al. (2011), on the other hand, use net positive imports, arguing that potential exports may not reflect short-term threats. Similarly to Blyth and Lefèvre (2004), Gupta (2008), and Neumann (2004, 2007), however, Cohen et al. (2011) account for political risks. The most commonly used measure of geopolitical risk is provided by the Political Risk Services group and reported in the International Country Risk Guide, with risk rated on a scale from 0 to 100 (Cohen et al. 2011).

In addition to geopolitical risks and market liquidity (Blyth and Lefèvre 2004; Cohen et al. 2011), transportation risk, proxied as the distance between countries (Le Coq and Paltseva 2009; Cohen et al. 2011), is used in diversification measurements. Domestic supplies are assumed to pose no geopolitical risk (Blyth and Lefèvre 2004). To the extent that domestic supplies may be interrupted, additional adjustments related to weather or infrastructure may also be necessary. This may be especially true for evaluating the security of markets of fuels that have largely been regional, such as natural gas.

Cohen et al. (2011) first examine trends in diversification on a global scale; their index indicates that diversification in oil supplies increased between 1992 and 2000 but has since leveled off. By contrast, diversification of natural gas sources appears to have increased in recent years.

To create diversification indices for each country, Cohen et al. (2011) rely on the formula

$$CSI = [\textstyle\sum_i \frac{NPI_i}{C}^2 * 100] \qquad (1)$$

where C represents fuel consumption in country *j*, and NPI_i represents net positive imports from country *i* to country *j* ($NPI_i = \max\{0, M_{ij} - X_{ij}\}$).

As noted earlier, Cohen et al. (2011) also adjust for political stability, consumption in a given country relative to total global consumption, and transport distance. In each case, a term representing these adjustments is multiplied by the summed terms in equation (1). The political risk rating term, POL_i is defined as

$$POL_i = \left[100 - \frac{ICRG_i}{100}\right].$$

To account for the relative consumption of each country, the variable *SIZE*, defined as the ratio of global fuel consumption to consumption in a given country, is incorporated into the summed term of equation (1) by multiplying that term by $e^{(\frac{1}{SIZE})}$.

Finally, the variable D_i is used to represent distance between the consuming and importing countries. D_i is set equal to 1, 2, or 3, depending on whether the distance between the countries is less than 1,500 kilometers (km), between 1,500 and 4,000 km, or greater than 4,000 km, respectively. The summed term in equation (1) is multiplied by each of these three adjustments individually to create three additional diversification indices for each country. All three adjustments are included in a final index.

Although Cohen et al. (2011) calculate diversification indices for oil and natural gas separately, they also create a combined index for each country by weighting the oil and gas indices (including political and consumption-based adjustments) by the share of each country's fuel consumption from each fuel. Two weighted indices are created. The indices calculated for the United States by Cohen et al. (2011) are shown in Table 4.6.

Table 4.6. Diversification indices for the United States

	1990	**1995**	**2000**	**2008**
CSI (oil)				
Basic	2.14	3.23	4.30	4.89
POL	0.82	0.96	1.27	1.17
SIZE	4.28	5.62	7.29	8.19
Dist.	5.38	7.26	9.59	9.97
All adj.	6.08	5.94	8.67	9.85
CSI (gas)				
Basic	0.16	0.11	0.28	0.11
POL	0.13	0.08	0.23	0.08
SIZE	0.25	0.15	0.35	0.13
Dist.	0.18	0.18	0.34	0.18
All adj.	0.21	0.17	0.37	0.21
CSI (oil, gas, *POL*, *SIZE*)				
Normalized				5.69
Unadjusted				3.33

***Source*: Cohen et al. (2011)**

The first five rows of indices in Table 4.6 reveal a trend of decreasing oil security over time. Most of the countries studied appear to be less secure in 2008 than in 1990 when the basic CSI index is used. Cohen et al. (2011) suggest this is because imports account for a larger portion of consumption. However, when the CSI index with all adjustments is used, security appears to have improved for most countries, although not for the United States. Accounting for political risk leads to an improved U.S. oil security index. Again, this trend is consistent across almost all countries studied. In contrast to these trends, adjusting for consumption (*SIZE*) has little effect on all other countries except the United States, where the adjustment reveals a less secure picture of U.S. oil supplies. Accounting for distance has a much smaller effect on the U.S. index.

Across the countries studied, natural gas indices appear to be more heterogeneous, and the adjustment for political risk has a greater effect (Cohen et al. 2011). The U.S. index, however, reveals a relatively secure natural gas supply, and this result appears to be robust to adjustments to the index.

When establishing their indices, Blyth and Lefèvre (2004) note the importance of clearly defining the market based on the infrastructure available to transport various fuels from different suppliers. In contrast to import dependence measurement, measures of diversification within a market assume that a country may be vulnerable to a supplier's price changes even if the country does not import fuel from that supplier, because one supplier's actions affect prices across a market.

Brown and Huntington (2013) have a different take on source and route diversification. They maintain that because oil is fungible and has relatively low transportation costs, it is infeasible for U.S. consumers or policymakers to distinguish among sources of foreign oil. This means that oil security in the United States depends on the overall security of the mix of global suppliers of oil and the U.S. total consumption of oil (domestic and foreign). If U.S. production increases, the mix of global suppliers becomes more stable, but the United States still remains vulnerable to unstable suppliers, even if it cannot identify a direct link between those suppliers and U.S. consumption. Generally, Brown and Huntington (2013) assume that an increase in U.S. consumption would be met with an increase in production from unstable sources.

Measuring the diversification of energy sources is not a new exercise, but indices have become more comprehensive in recent years with consideration of additional factors, such as those noted by Cohen et al. (2011): political risk, relative size of consumption, and transport distance. However, indices of diversification have not yet formally included factors such as supply routes or fuel diversity within a particular sector, and risk factors have continued to focus largely on geopolitical factors. Perhaps most significantly, diversification indices for oil and gas have not been quantified in terms of their effect on GDP or social welfare, and thus have not been used in benefit-cost analyses of policies that would increase diversification.

B. Resilience to Oil Supply Disruptions

Some energy-related policies or actions are designed to improve U.S. resilience to an unanticipated shock to the oil and gas market. That could be done by preventing or lessening the severity of a shock by modernizing existing infrastructure, establishing emergency response systems, and facilitating the development of an oil and gas market that is less prone to large shocks from disruptions.

Extreme weather, human error or accident, and terrorist attacks are three specific threats to oil and gas energy security for which steps to improve resilience would prevent or reduce the damage caused by the threat. Hurricanes on the U.S. Gulf Coast have caused significant damage to refinery and pipeline operations, causing both price shocks and short-term physical supply shortages. Human error and accidents may similarly disrupt production or distribution of fuel. In addition, terrorist attacks may threaten specific sites of U.S. production or distribution of fuel. Modernizing infrastructure to withstand extreme weather, implementing measures to prevent human error and make systems less vulnerable to attacks, diversifying transportation routes and domestic suppliers, and relying on sources of energy located in areas less threatened by disasters all would improve the resilience of the U.S. oil and gas markets.

To determine how much resilience is enough and not too much, cost-benefit analysis is needed. This section examines what the literature has to say about the value of additional resilience, in terms of the damages avoided in the event of some major disruption from weather or other incident.

i. Extreme Weather

Extreme weather has caused major disruptions to U.S. oil and gas markets. The Gulf Coast in particular has experienced frequent hurricanes that have threatened and damaged production and refining operations. Offshore production in the Gulf accounts for 17 percent of total U.S. crude oil production. In addition, the Gulf Coast has more than 30 refineries, which account for 45 percent of the total U.S. refining capacity and 51 percent of total U.S. natural gas processing plant capacity (EIA n.d.). Every year, there is a 56.4 percent chance that a hurricane will make landfall in the region and a 26 percent chance it will be a hurricane of category 3 or greater. Even category 2 hurricanes can lead to product losses exceeding 2.5 million barrels per day (DOE 2011). Other types of extreme weather, such as severe cold or heat spells, can also strain markets as producers attempt to supply enough heating or cooling fuels to consumers in a short amount of time to meet demand. This can result in higher prices for the commodity.

In 2005 and 2008, for example, refineries in the Gulf lost about 50 percent of their capacity because of hurricanes (DOE 2011). In 2005, hurricanes in the Gulf of Mexico region shut down oil production operations and many refineries that process crude oil into petroleum products; petroleum product prices then increased sharply as supplies to the market dropped. Other types of extreme weather, such as severe cold or heat spells, also strain markets as producers and distributors attempt to supply enough heating or cooling fuels to consumers in a short amount of time to meet demand. This can result in higher prices for energy commodities, mostly natural gas or electricity.

Several studies have attempted to quantify and value the damages of hurricanes on U.S. oil and gas markets. Crowther et al. (2007) use an inoperability input-output model to analyze the effects of Hurricanes Katrina and Rita on the oil and gas extraction sector, as well as the petroleum and coal products manufacturing sector. They find a total economic cost in the Gulf Coast region of $5.1 billion for the first month after the storm. Although this number is large, the study points out that it is the expected losses before an event that matter for benefit-cost analysis, and the low probability of such an event would make the number insufficient for justifying added resilience. Forecasting the probability of such rare events with greater accuracy would enable better comparisons of the costs and benefits of preparations.

Kirgiz et al. (2009) focus on calculating losses in refinery profits as a result of Hurricane Katrina. They elaborate on an important aspect of measuring the costs of such interruptions, and therefore the benefits of resilience. The study calculates the business losses due to the hurricane by capturing what the operations and margins of the refiner would have been if the hurricane had not happened at all. Some analysts, in estimating these damages, use observed spot prices, which increase following storms, and therefore overestimate what the businesses' profits would have been. Kirgiz et al. (2009) instead use a model to calculate price spreads, which they find were affected for 2 weeks after Hurricane Katrina. Taking a refinery with a capacity of 152,000 barrels per day and a utilization rate of 93 percent, the business interruption loss would be $20 million, using a model to predict prices in the absence of the hurricane. The losses at this same refinery, using observed prices, would be an estimated $56 million.

Refineries have taken actions to harden infrastructure, decreasing the likelihood that they will be damaged in a hurricane. They have raised equipment and instrumentation and control rooms above the flood zone and purchased portable generators to prepare for future storms. The lack of personnel available to operate refineries during evacuations, however, is a major challenge to continuing operation during storms. The rapid return of employees after evacuations is thus of great importance (DOE 2011).

The establishment of regional storage systems of refined fuels has also been proposed as a way to mitigate regional shortages. Although the SPR was designed to offer assistance during market disruptions, it lacks refined products and therefore cannot adequately respond to shortages of refined product caused by extreme weather.

In a 2011 report, DOE looks at the potential costs and benefits of a refined petroleum product reserve (RPPR) that would involve some regional storage and some cavern storage. This reserve would mitigate shortages and price increases. To estimate the benefits of the reserve, DOE uses a simulation model that accounts for the risk of a hurricane, the variability in product prices, and the estimated damages to refineries based on the strength of the storm and the distance refineries are from it. The 2011 model does not adjust for existing or future hardening, which would tend to overestimate benefits of such a reserve. The model also does not consider benefits from the reserve during other types of disruptions, such as terrorist attack or cyberattack; inclusion of those benefits would tend to increase the benefits of an RPPR.

DOE (2011) estimates that the benefits of the reserve, in terms of consumer costs and GDP, would be $4 billion to $6.5 billion for an RPPR of 10–50 million barrels. These benefits would be concentrated primarily in the Gulf Coast region, but price effects would also benefit consumers in other regions, albeit to a less extent. The analysis estimates that an RPPR would cost much less than the estimated benefits; a storage capacity of 10 million to 50 million barrels is estimated to cost $1 billion to $2.1 billion (in 2008$). Because the 2011 analysis did not include the effects of refining resilience investments, DOE has considered conducting a revision to the 2011 report, but has not completed any additional analyses.

Other less direct methods of resilience may also improve the ability of preparing for and responding to natural disasters. For example, improvements in storm forecasting may make decisions to cease operations and evacuate more precise, mitigating damages both from storms and from cautionary actions that prove unnecessary. In one study, for example, Considine et al. (2004) estimate the benefits of improving hurricane forecasts in the Gulf of Mexico as related to oil and gas production. Once one considers better forecasting as a resilience strategy, the benefits side must account with errors that involve the missed prediction of a hurricane and the prediction of a hurricane that does not occur. In the latter case, producers may cease production or evacuate drilling rigs or both in response to the threat of a hurricane, thus delaying production and incurring economic costs even if a hurricane does not hit. But failing to take these actions also results in economic costs if a hurricane does damage operations.[57]

ii. Human Error or Accident

Although human error and accident typically do not result in long-term disruptions, they cannot be ruled out. For this reason, examining the ban on Gulf of Mexico production following the Deepwater Horizon oil spill may be instructive. Following the April 2010 spill, the Department of the Interior issued a 6-month moratorium for offshore deepwater drilling, enacted May 30, 2010, and freezing both production and drilling from 33 wells.

Testimony from Rebecca Blank, Under Secretary for Economic Affairs, U.S. Department of Commerce (Blank 2010), reports the department's estimates that a 6-month moratorium resulted in a loss of 2,000 rig jobs directly, and 8,000 to 12,000 regional jobs indirectly, in the Gulf Coast region, though it notes that most jobs would return once drilling resumed. An Inter-Agency Economic Report also notes that because the moratorium affected such a small amount of production, about 31,000 barrels per day, it most likely would not have a discernible effect on oil prices (DOC 2010). The effects of the moratorium were smaller than originally anticipated because most deepwater drilling operators kept their employees on payroll (DOC 2010).

Other estimates at the time ranged from 12,000 to over 23,000 job losses nationally (Mason 2010; Power and Eaton 2010). These early analyses, using a very simple economic model with employment multipliers, overestimated the costs for several reasons, as reported by Aldy (2014). First, they assumed the Gulf Coast economies at the time of the moratorium represented the general economic environment that summer. However, spill response resources were being poured into the area, provided offsetting income and employment. The multipliers also assumed rigs would relocate and lay off all their workers, but this did not occur.

Aldy (2014) reports that Louisiana coastal parishes, even those that are oil-intensive, saw net gains in employment and economic activity, whereas Florida Gulf Coast counties saw a

[57] Considine et al. (2004) use a nonstandard value of a statistical life (VSL) estimate. For this reason, and because security benefits are not separated from other benefits, we do not include their valuation of forecasts.

net decrease in both. The study finds that the net effect of the spill, response, and moratorium resulted in an increase of 6,400 to 20,000 jobs in coastal Louisiana. The oil-intensive parishes saw an 11 percent increase in economic activity relative to the inland parishes. These somewhat counterintuitive effects are likely due to the spill response. Though Aldy (2014) does not separately estimate the effects of the moratorium on economic activity specifically, the study does show that the negative effects were small enough to be largely outweighed by cleanup activities. Nevertheless, an opportunity cost of the diversion of economic activities is associated with the cleanup. Thus the losses from a massive and lengthy supply disruption could be larger than Aldy suggests.

iii. Terrorism

Similarly to Crowther et al. (2007) for weather disruptions, Mueller and Stewart (2014) conduct a cost-benefit analysis using the probability of a terrorist attack to analyze the cost-effectiveness of a mitigation approach, setting the cost of a measure equal to its benefit:

cost = (probability of a successful attack) × (losses sustained in the attack) × (reduction in risk)

The U.S. government treats the valuation of risk mitigation for natural disasters and for terrorism attacks differently. The Department of Homeland Security uses state-of-the-art risk models based on extensive data for natural hazards, but is far more risk-averse regarding terror attacks. Some analysis suggest that not even the most risk-averse social welfare functions are able to support some decisions made by the U.S. government in regards to terror attacks (Mueller and Stewart 2014).

Robinson et al. (2010), however, points out that the value of a statistical life might be higher for terrorist attacks than for mortality risks from pollution: the former may be seen as more involuntary and frightening than workplace risks, which often serve as the basis for the value of a statistical life in studies of pollution. If the value of a statistical life is significantly higher for evaluating resilience against terrorist attacks, that would justify greater resilience measures.

C. Next Steps in Diversification and Resilience Valuation

Although some tools exist to model the benefits of diversification and resilience, this review did not identify any approaches to quantifying these benefits in ways that could be used in benefit-cost analyses of energy-related policies and actions.

- ***All energy sectors.*** Diversification indices for oil, gas, and by extension, electricity exist but have not been monetized or linked to effects on GDP or social welfare, and thus they have not been used in benefit-cost analyses of policies that would increase diversification. This includes diversification of sources of fuel, routes of fuel transport, or types of fuel.
- ***Oil and gas sectors.*** The benefits of measures taken to increase resilience against disruptions have not been quantified in the literature. That is in part because it is difficult to forecast the probability that a disruption occurs and the damages

resulting from that disruption. Development of methods for quantifying such benefits would improve the efficient investment in resilience.

VI. Valuation of Reductions in Greenhouse Gas Emissions

In 2014, the electric power sector produced 2,039 million metric tons (MMT) of U.S. CO_2 emissions, which represents about a third of net U.S. GHG emissions (EPA 2016a). In the United States, the sector contributes very few emissions of other GHGs.

The oil and gas sector produces very little direct CO_2 emissions (42 MMT for natural gas systems and 30 MMT for petroleum systems and production, both in 2014). Methane losses throughout the value chain of both fuels raise this contribution another 244.3 MMT in terms of CO_2 equivalence (CO_2e) because methane is around 30 times more powerful a greenhouse gas than CO_2 when measured over a 100-year timeline. Adding CO_2 emissions from burning natural gas and fuel oil for electricity generation (468 MMT), transportation (1,732 MMT), industry (81 MMT, including some coal), and residential and commercial uses (respectively 345 MMT and 232 MMT, mostly natural gas) yields 3,174 MMT from the oil and gas sector, of a total GHG inventory of 6,870 MMT gross emissions.

Valuation of CO_2 emissions requires an estimate of the social cost of carbon (SC-CO_2), commonly defined as the net present value of the effects of emitting one additional ton of carbon dioxide in a given year. Estimates of the SC-CO_2 can be used in evaluating the net climate change cost or benefit of actions affecting the CO_2 emissions resulting from economic activity—in this case, the oil and gas sector and, depending on the policy being investigated, the burning of oil and its refined products and natural gas down the value chain and in sectors such as transportation, power, industry, and residential and commercial heating.[58]

Estimating the SC-CO_2 requires four stages:

- modeling the effects of an additional emitted ton of carbon dioxide on the composition of Earth's atmosphere for hundreds of years into the future;
- modeling the effects of those compositional changes on outcomes that matter to humans;
- valuing those outcome changes in each future year; and
- computing the net present value of those future outcome changes.

EPA (2016b) describes the process for estimating the social cost of GHG:

> The SC-CO_2 estimates were developed over many years, using the best science available, and with input from the public. Specifically, an interagency working group (IWG) that included the EPA and other executive branch agencies and offices used three integrated assessment models (IAMs) to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions

[58] For more on the social cost of carbon, see Tol (2007)

of each IAM. The 2013 update did not revisit the 2010 modeling decisions with regards to the discount rate, reference case socioeconomic and emission scenarios, and equilibrium climate sensitivity distribution. Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and published in the peer-reviewed literature. The 2010 SC-CO_2 Technical Support Document (2010 SC-CO_2 TSD) provides a complete discussion of the methods used to develop these estimates and the current SC-CO_2 TSD presents and discusses the 2013 update (including recent minor technical corrections to the estimates).[26]

One key methodological aspect discussed in the SC-CO_2 TSDs is the global scope of the estimates. The SC-CO_2 estimates represent global measures because of the distinctive nature of the climate change, which is highly unusual in at least three respects. First, emissions of most GHGs contribute to damages around the world independent of the country in which they are emitted. The SC-CO_2 must therefore incorporate the full (global) damages caused by GHG emissions to address the global nature of the problem. Second, the U.S. operates in a global and highly interconnected economy, such that impacts on the other side of the world can affect our economy. This means that the true costs of climate change to the U.S. are larger than the direct impacts that simply occur within the U.S. Third, climate change represents a classic public goods problem because each country's reductions benefit everyone else and no country can be excluded from enjoying the benefits of other countries' reductions, even if it provides no reductions itself. In this situation, the only way to achieve an economically efficient level of emissions reductions is for countries to cooperate in providing mutually beneficial reductions beyond the level that would be justified only by their own domestic benefits. In reference to the public good nature of mitigation and its role in foreign relations, thirteen prominent academics noted that these "are compelling reasons to focus on a global SCC" (Pizer et al. 2014). In addition, the IWG recently noted that there is no bright line between domestic and global damages. Adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health and humanitarian concerns.[27]

The 2010 SC-CO_2 TSD also noted a number of limitations to the SC-CO_2 analysis, including the incomplete way in which the IAMs capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Currently IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research.[28] The limited amount of research linking climate impacts to economic damages makes the modeling exercise even more difficult. These individual limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates, though taken together they suggest that the SC-CO_2 estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (2007), which was the most current IPCC assessment available at the time of the IWG's 2009–2010 review, concluded that "It is very likely that [SC-CO_2 estimates] underestimate the damage costs because they cannot include many non-quantifiable impacts." Since then, the peer-reviewed literature has continued to support this conclusion. For example, the IPCC Fifth Assessment report (2014) observed that SC-CO_2 estimates continue to omit various impacts, such as "the effects of the loss of biodiversity among pollinators and wild crops on agriculture."[29] Nonetheless, these estimates and the discussion of their limitations represent the best available information about the social benefits of CO_2 reductions to inform benefit-cost analysis. The new versions of the models offer some improvements in these areas, although further work is warranted.

Accordingly, the EPA and other agencies continue to engage in research on modeling and valuation of climate impacts with the goal to improve these estimates. The EPA and other agencies also continue to consider feedback on the SC-CO_2 estimates from stakeholders through a range of channels, including public comments on Agency rulemakings that use the SC-CO_2 in supporting analyses and through regular interactions with stakeholders and research analysts implementing the SC-CO_2 methodology used by the IWG. In addition, OMB sought public comment on the approach used to develop the SC-CO_2 estimates through a separate comment period and published a response to those comments in 2015.[30]

After careful evaluation of the full range of comments submitted to OMB, the IWG continues to recommend the use of the SC-CO_2 estimates in regulatory impact analysis. With the release of the response to comments, the IWG announced plans in July 2015 to obtain expert independent advice from the National Academies of Sciences, Engineering and Medicine to ensure that the SC-CO_2 estimates continue to reflect the best available scientific and economic information on climate change.[31] The Academies then convened a committee, "Assessing Approaches to Updating the Social Cost of Carbon," (Committee) that is reviewing the state of the science on estimating the SC-CO_2, and will provide expert, independent advice on the merits of different technical approaches for modeling and highlight research priorities going forward. While the Committee's review focuses on the SC-CO_2 methodology, recommendations on how to update many of the underlying modeling assumptions will also likely pertain to the SC-CH4 estimates. EPA will evaluate its approach based upon any feedback received from the Academies' panel.

To date, the Committee has released an interim report, which recommended against doing a near term update of the SC-CO_2 estimates. For future revisions, the Committee recommended the IWG move efforts towards a broader update of the climate system module consistent with the most recent, best available science, and also offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO_2 estimates. Specifically, the Committee recommended that "the IWG provide guidance in their technical support documents about how [SC-CO_2] uncertainty should be represented and discussed in individual regulatory impact analyses that use the [SC-CO_2]" and that the technical support document for each update of the estimates present a section discussing the uncertainty in the overall approach, in the models used, and uncertainty that may not be included in the estimates.[32] At the time of this writing, the IWG is reviewing the interim report and considering the recommendations. EPA looks forward to working with the IWG to respond to the recommendations and will continue to follow IWG guidance on SC-CO_2.

The four SC-CO_2 estimates are: $13, $45, $67, and $130 per metric ton of CO_2 emissions in the year 2020 (2012 dollars).[33] The first three values are based on the average SC-CO_2 from the three IAMs, at discount rates of 5, 3, and 2.5 percent, respectively. Estimates of the SC-CO_2 for several discount rates are included because the literature shows that the SC-CO_2 is sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). The fourth value is the 95th percentile of the SC-CO_2 across all three models at a 3 percent discount rate. It is included to represent lower probability but higher impact outcomes from climate change, which are captured further out in the tail of the SC-CO_2 distribution, and while less likely than those reflected by the average SC-CO_2 estimates, would be much more harmful to society and therefore, are relevant to policy makers. The SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as economies grow and physical and economic systems become more stressed in response to greater climate change.

[26] Both the 2010 SC-CO_2 TSD and the current SC-CO_2 TSD are available at: <https://www.whitehouse.gov/omb/oira/social-cost-of-carbon>

[27] See Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, July 2015, p. 31, at <https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-response-tocomments-final-july-2015.pdf>

[28] Climate change impacts and social cost of greenhouse gases modeling is an area of active research. For example, see: (1) Howard, Peter, "Omitted Damages: What's Missing from the Social Cost of Carbon." March 13, 2014, http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf; and (2) Electric Power Research Institute, "Understanding the Social Cost of carbon: A Technical Assessment," October 2014, www.epri.com.

[29] Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

[30] See <https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf>.

[31] The Academies' review will be informed by public comments and focus on the technical merits and challenges of potential approaches to improving the SC-CO_2 estimates in future updates. See <https://www.whitehouse.gov/blog/2015/07/02/estimating-benefits-carbon-dioxide-emissions-reductions.

[32] National Academies of Sciences, Engineering, and Medicine (2016). *Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near-Term Update*. Committee on Assessing Approaches to Updating the Social Cost of Carbon, Board on Environmental Change and Society. Washington, DC: The National Academies Press. doi: 10.17226/21898. See Executive Summary, page 1, for quoted text.

[33] The current version of the SC-CO_2 TSD is available at: <https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf>. The TSDs present SC-CO_2 in \$2007. The estimates were adjusted to 2012\$ using the GDP Implicit Price Deflator (1.0804). Also available at: http://www.bea.gov/iTable/index_nipa.cfm. The SC-CO_2 values have been rounded to two significant digits. Unrounded numbers from the 2013 SCC TSD were adjusted to 2012\$ and used to calculate the CO_2 benefits.

In August 2016, the IWG issued revisions to the SC-CO_2 Technical Support Document (TSD) and issued damage estimates for two other GHGs—methane and nitrous oxide—for use in Regulatory Impact Analyses. The revisions to the TSD include an enhanced presentation and discussion of quantified uncertainty around the current SC-CO_2 estimates, as a response to recommendations in the National Academies' interim report mentioned above. Specifically, the revised TSD includes an expanded presentation of the SC-CO_2 estimates that highlights a symmetric range of uncertainty around estimates for each discount rate, new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty, and a detailed explanation of the uncertain parameters in two of the models used to estimate that SC-CO_2. In addition, the full set of SC-CO_2 estimates, which have previously been available upon request, are now available on OMB's website for easy public access. The revision does not revisit the interagency group's 2010 methodological decisions or change the SC-CO_2 estimates themselves.

Estimating the social cost of other greenhouse gases, such as methane, involve the same stages as described above for the SC-CO_2. The main differences between the social cost of various GHGs stem from differences among the gases in their potential to absorb infrared radiation over a given time frame, in the temporal pathway of their impact on radiative forcing, and in some physical impacts other than temperature change that vary across gases in ways that are not captured by their global warming potential.

The IWG (2016b) damage estimates for methane and nitrous oxide are based on a study by Marten et al. (2014, 2015) which provided the first set of published estimates of the social cost of methane (SC-CH_4) and social cost of nitrous oxide emissions (SC-N_2O) that are consistent with the methodology and modeling assumptions underlying the IWG (2013, 2015, 2016a) SC-CO_2 estimates. The 2016 Addendum to the SC-CO_2 TSD (IWG 2016b) summarizes the methodology and presents the social cost estimates from Marten et al. as a way for agencies to improve analysis of actions that are projected to influence emissions of CH_4 and N_2O in a manner that is consistent with how CO_2 emissions changes are valued. The IWG presented the estimates of the social cost of these gases with an acknowledgement of the limitations and uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts, just as the IWG committed to do for SC-CO_2. The IWG SC-CH_4 and SC-N_2O estimates are shown in Table 4.7.

Table 4.7. Social cost of methane and nitrous oxide (2007$ per metric ton)

	SC-CH_4				SC-N_2O			
Year	5% Average	**3% Average**	2.5% Average	High Impact (3% 95th)	5% Average	**3% Average**	2.5% Average	High Impact (3% 95th)
2010	370	**870**	1,200	2,400	3,400	**12,000**	18,000	31,000
2015	450	**1,000**	1,400	2,800	4,000	**13,000**	20,000	35,000
2020	540	**1,200**	1,600	3,200	4,700	**15,000**	22,000	39,000
2025	650	**1,400**	1,800	3,700	5,500	**17,000**	24,000	44,000
2030	760	**1,600**	2,000	4,200	6,300	**19,000**	27,000	49,000
2035	900	**1,800**	2,300	4,900	7,400	**21,000**	29,000	55,000
2040	1,000	**2,000**	2,600	5,500	8,400	**23,000**	32,000	60,000
2045	1,200	**2,300**	2,800	6,100	9,500	**25,000**	34,000	66,000
2050	1,300	**2,500**	3,100	6,700	11,000	**27,000**	37,000	72,000

***Source*: IWG (2016b)**

A. Next Steps in GHG Emissions Valuation

As described above, the National Academies of Sciences, Engineering, and Medicine is currently reviewing the latest research on modeling the economic aspects of climate change to inform future revisions to the SC-CO_2 estimates. While the Academies' review focuses on the SC-CO_2 methodology, recommendations on how to update many of the underlying modeling assumptions will also likely pertain to estimating the social cost of other GHGs, such as SC-CH_4 and SC-N_2O. While we await the Academies' recommendations (expected in early 2017), the IWG continues to recommend the use of the current social cost of greenhouse gas estimates as the best scientific information on the impacts of climate change available in a form appropriate for regulatory analysis.

VII. Valuation of Policies to Reduce Other Types of Pollution

Consistent with the G-7 energy security principles, low-polluting technologies are preferred on energy security grounds to higher-polluting technologies, if they are equal in other ways. The oil, natural gas, and electricity sectors all consume large quantities of water, often in places where water is not abundant. In addition, the sectors release a variety of pollutants to the air, soil, and water, described below as operational pollution. The sectors, and in particular the oil and natural gas sectors, are also prone to large discharges of pollutants during a disruption, such as an accidental release, described below as episodic pollution.

A. Operational Pollution

For the oil and natural gas sector, burning oil, its products, and natural gas results in air pollution of sulfur dioxide, nitrogen oxides, particulate matter, volatile organics, and other substances, many of which can cause damage to human health and the environmental, with both market and non-market costs. Water pollution occurs at various stages of the value chain, such as in the refining stage for oil and the extraction stage. Solid wastes are also generated, particularly in the extraction stage.

For the electric power sector, burning fossil fuels to generate electricity causes air pollution and the use of cooling water can have ecological impacts. Disposal of coal ash, in particular, is a solid waste problem.

Valuing those effects is complicated—and geographically differentiated by the number of people who are exposed, the emissions source, and meteorological conditions. But there is a long history of successful, accepted valuation of air pollution reductions from environmental regulations. In such exercises, the value of reducing mortality risks dominates the benefits over all health and environmental pathways estimated, an approach that puts the value of statistical life on center stage. There also are extensive survey-based examples for valuation of cooling water damages to fish populations (see Johnston et al. 2013).

Estimating the net benefits of energy-related policies or actions that affect pollution involves four steps:

- emissions: predicting the effects of the policy or action on emissions;
- transport, fate, and exposure: modeling the effects of the change in emissions on pollutant concentrations and the exposure of people, crops, and other pollution "receptors" to pollution;
- consequences: estimating the negative effects of exposures at the modeled concentrations; and
- valuation: valuing the benefit of avoiding those negative effects.

Step 1. Emissions. The effects of the policy or other action on emissions are estimated, often with the help of models, such as IPM or NEMS.

Step 2. Transport, fate, and exposure. The effects of the emissions on the concentrations of pollutants in the air and water are estimated in locations that matter to people and for exposures of people or other "receptors," such as crops and water bodies. Calculating the effects on concentrations often calls for a fate-transport model to calculate how the emissions are transported and chemically transformed. This step sometimes also calls for exposure models, to calculate how concentrations translate into the actual exposure (or "doses") of people or other receptors. Fate-transport models range from simple models that simply disperse a pollutant over time and space, such as CALPUFF, to chemically and spatially sophisticated models, such as Community Multi-Scale Air Quality (CMAQ). Williams et al. (2010) briefly discuss the EPA's use of fate-transport models and exposure models.

Step 3. Consequences. Negative effects stemming from exposure and modeled concentrations are then quantified. These effects may include changes in the yields of crops, forests, and fisheries, morbidity and other health effects, or premature deaths. Researchers commonly use concentration-response or dose-response functions that estimate the effect of pollution. The Environmental Benefits Mapping and Analysis Program (BenMAP) is a state-of-the-art software package used for estimating health outcomes of changes in air pollution concentrations in EPA's and other agencies' RIAs. The appendices of the BenMAP manual provide and discuss many of the commonly used exposure-response functions for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide in ground-level air—data that come from the research literature, normally from peer-reviewed research journal papers. The "unit impacts" from the foregoing calculations are then multiplied by the affected population, such as the elderly, all humans, or crop acres.

Step 4. Valuation. Finally, the societal welfare value of the impacts is determined. The principles of valuation apply, such that valuation for firms is based primarily on changes in profit. For individuals and households, some outcomes, such as health changes and risk of premature death, require non-market valuation methods to determine how much those changes are worth to the people subject to them. The methods of non-market valuation are explained in, for example, Freeman et al. (2014) among other commonly available sources. Typically, the most critical valuation elements are the rate of discounting the future and the value of a statistical life (VSL). VSL receives much research attention and has evolved over time, but different jurisdictions (including countries) use different values. The key dose-response function for mortality from air pollution has been shown to more logically link to a value of statistical life-year (VSLY) concept (Rabl 2003), but the evidentiary basis for this switch is poor.

BENMAP and Muller's AP2 model (Muller 2016; Muller et al. 2011) are two major and popular models that implement steps 2, 3, and 4 of the process of valuing emissions. For example, Jaramillo and Muller (2016) use the AP2 model to estimate the non–climate change damages of some of the emissions of U.S. power plants. They calculate that the emissions caused approximately 20,000 premature deaths in the U.S. in 2011, the latest year for which they had sufficient data. The estimated damages in 2011 were approximately $170 billion in 2016$, or an average of 6.3 cents per kWh of electricity generated in the U.S. This is slightly more than twice as large as the estimated eventual social cost of U.S. power plant CO_2 emissions in 2011, using the IWG's (2015) social cost of carbon.

In Jaramillo and Muller's results, the average marginal damage per ton emitted by power plants in 2011 was $33,000 for sulfur dioxide, $4,400 for nitrogen oxides, and $38,000 for fine particulate matter ($PM_{2.5}$), in 2016 U.S.$. Most of the estimated damage is from premature deaths, with the value per death being approximately $8.2 million. The mortality-$PM_{2.5}$ relationship dominates the impacts.

B. Episodic Pollution

For the oil and gas sector, episodic pollution occurs primarily at the wellhead (the Deepwater Horizon disaster being a recent large episode) and through pipeline and tanker accidents or terrorism. Valuing such events in RIAs requires estimates of the probability of an event, the vulnerability of the system under threat, the physical consequences of the event, and the value of avoiding such consequences. To the extent that there is individual or social risk aversion (rather than risk neutrality), such that the expected value of avoiding the event is less than the WTP to reduce event risk, a more nuanced approach to estimating the benefits of episode avoidance would be needed.

A robust literature addresses some aspects of this valuation challenge, such as Carson et al. (2003), who estimated the willingness to pay to avoid the *Exxon Valdez* oil spill; Carson et al. (2004), who studied California's Central Coast; and Alvarez et al. (2014), who valuated lost recreational fishing in the Gulf of Mexico due to the 2010 Deepwater Horizon oil spill. Under the natural resource damage assessment provisions of the Oil Pollution Act (OPA), compensation for damages from oil spills must be sought. Government- and industry-sponsored studies have been mounted to estimate the WTP to reduce the probability of major oil spills, both from the well and from tanker accidents. The studies have taken survey-based nonuse value approaches to measuring ecological damages, and revealed preference, hedonic estimation approaches to measuring recreational losses.
Carson et al. (2003), for example, report the results of the contingent value survey performed under the OPA for the *Exxon Valdez* oil spill. The original report provided an estimate of $2.8 billion (1990$) for the lower bound of lost passive-use value, but improvements in estimating nonparametric and more flexible parametric models of the WTP distribution bring this figure up to $4.87 billion or even $7.19 billion. This type of study is controversial and contentious, but it has been improved upon and applied in many major oil spill cases under the OPA since the *Exxon Valdez*, including the Deepwater Horizon spill.

C. Next Steps in Other Pollutant Valuation

A rich literature exists for methods to estimate the value of pollution that is emitted from the extraction, transport, and use of energy. These values are not always incorporated into benefit-cost analysis. For example, morbidity and mortality damages stemming from some types of air pollution typically are included in benefit-cost analysis, but the benefits of reduced water use or water pollution are generally not included. Thus two next steps would be as follows:

- ***All energy sectors.*** Benefit-cost analyses do not currently capture the benefits associated with all types of air, water, and solid waste pollution. Nor do they capture the benefits associated with reduced water use, particularly in the arid regions of the country. Benefit-cost analysis would benefit from the development of an inventory of the pollution and other natural resource–related externalities produced from each source of energy during extraction, transport, and use. This inventory could be compared with standard benefit-cost analyses to identify which types of pollution or other externalities are not currently captured. The externalities with the largest expected benefits could be identified for inclusion in future cost-benefit analysis.
- ***All energy sectors.*** Some traditional estimates of pollution control benefits are subject to controversy even as the science base improves. A particular area for meaningful analysis would be to evaluate the use of a value of statistical life-year estimate to monetize reduced death risks from energy-related policies and actions instead of using the value of statistical life. Research would be needed to develop credible VSLY estimates.

VIII. Analysis of Policy Benefits

The foregoing sections discussed and evaluated the literature that values various benefits of energy-related policies or actions. This section provides a few examples of analyses that estimate the benefits of particular energy-related policies, namely holding oil reserves for emergency responses to disruptions and promoting clean and renewable technologies through R&D.

At the end of this section, we provide an example of an energy security model developed by the IEA that can be used to develop metrics for evaluating alternative energy security policies. Unfortunately, this IEA model does not monetize the energy security metrics and no other models were identified that creates and monetizes metrics. As a result, the IEA model facilitates the ranking of alternative policies for energy security benefits, but does not allow those benefits to be quantified such that they can be used to demonstrate that they exceed the costs for a particular policy.

A. The Strategic Petroleum Reserve and Other Energy Reserves

Since 1975, the United States has maintained the Strategic Petroleum Reserve to protect against price volatility resulting from natural events or intentional actions by other countries or groups. Several states also maintain oil reserves to buffer against price shocks. Determining whether the Nation should maintain a reserve, and what its size should be, requires weighing the costs, such as physically expanding and maintaining the reserve, against its benefits, such as minimizing damage to GDP from disturbances and deterring potential embargoes from oil cartels (Leiby and Bowman 2000; Balas 1981). In 2016, DOE published a Long-Term Strategic Review of the Strategic Petroleum Reserve (DOE, 2016). Areas examined in the report include:

- The state of the SPR's surface and subsurface infrastructure;
- Bottlenecks in the North American midstream infrastructure that impact the SPR's ability to move oil to the market;

- Costs and benefits of SPR options;
- SPR modernization requirements for infrastructure life extension and the addition of dedicated marine terminals; and
- Issues with the SPR's authorizing legislation, the Energy Policy and Conservation Act (EPCA).

The SPR is a U.S. government-owned stockpile of crude oil designed to be used as a supplement to commercial supplies to reduce the economic damage associated with price spikes. The costs of maintaining the SPR are basically fixed. Therefore, Leiby (2008) argues that it is not appropriate to include SPR maintenance costs in the calculation of the oil import premium. But the costs of obtaining the oil and placing it into storage are included. Leiby argues, correctly, that his estimate of the macrodisruption premium incorporates the effect of the SPR to the extent that it has been used historically to buffer oil price shocks. The marginal value of the SPR is the additional value of expanding the SPR by one barrel of oil. The marginal value can also be understood as the benefit of making it easier or faster to draw down the SPR.

Several studies have estimated such values. Leiby and Bowman (2000) evaluate the economic benefits of increasing the SPR as well as the drawdown capability. The study uses a Monte Carlo simulation of the global oil market, with and without additional U.S. stocks to compare the costs (storage) and benefits (avoided disruption) of expanding the reserve. The study, which considered the causes and likelihood of disruption, how existing stocks would be used, the cost of an oil disruption, and the ability of additional stocks to mitigate this, finds that an SPR of 700 million to 850 million barrels would be the efficient size and would yield a net benefit of about $1.87 billion to $2.24 billion (in 2005$ adjusted from 1996$). The marginal value of an additional barrel at an SPR size of 700 million barrels is $14.94 (in 2005$). Thus to estimate the energy security benefit conferred by a larger reserve requires knowing the probability, size, and cost of a disruption, such as that provided by the oil security premium, as well as information on how the reserve would be used and how rapidly and completely additional supply would mitigate the disruption.

Balas (1981) takes a very different approach and incorporates the "embargo-deterrent aspect" of a large SPR when calculating the benefits of having or expanding the reserve. That is, he considers the probability of a purposeful disruption to be endogenous to the size of the reserve, or the ability of the United States to offset the intended effect of an engineered reduction in pumping.

The study uses game theory to analyze a potential conflict between a cartel and the United States as a "bimatrix game," where the objectives are expressed as two payoff functions: the cartel wants to inflict damage on the United States, and the United States wants to minimize the total cost of such a conflict. The study solves for more than 100 scenarios, using such parameters as the U.S. daily petroleum demand, sensitivity to a cutback in in petroleum, the cartel's urgency in its pursuit of goals as well as its own losses, the United States' capacity for economic retaliation, and U.S. imports from the cartel at the time. The study finds that, for an import level of 4.2 million barrels per day from the cartel, an optimal SPR would range from 750 million barrels to 1,450 million barrels (much larger than Bowman and Leiby's reserve), depending on the parameters. The marginal benefits of this reserve decrease as its size increases until it hits 930 million to 960 million barrels, where the marginal benefits increase by almost $3,630 per barrel (in 2005$ adjusted from 1975$). This is the "critical" amount—the point at which the cartel no longer pursues an embargo strategy.

Oren and Wan (1986) note that this type of static analysis does not address limitations on the SPR's rates for fill-up or drawdown and attempt to correct for this deficiency. They use a dynamic model and perform sensitivity analysis under variation in key parameters, which the earlier model had been unable to do. This approach captures uncertainty in the duration of interruptions and uncertainty in the time between interruptions, in addition to considering such parameters as the magnitude of interruptions, demand elasticity, and the fill-up and drawdown rates.

The Oren and Wan (1986) study makes two assumptions: the environment is stationary (both supply and demand are independent of time), and the fill-up and drawdown rates are constant. The study considers the supply for oil to be inelastic and uncertain, with two levels—normal and disrupted—using a stationary, continuous time Markov process for the transition time between states. Base case results show that the optimal reserve capacity is 1.57 billion barrels of oil, and the expected reserve is 1.34 billion barrels of oil.

Though studies focusing on state-level uses of strategic reserves may be less informative for measuring the national benefits, Ford (2005) makes an interesting point about the size and frequency of disruptions in supply. Ford looks at California's proposed strategic fuels reserve, which was considered following gasoline price volatility in 1999 and the early 2000s. Using a systems dynamic model of stocks and flows, he finds that in a simulated large disruption—a 15-day outage of 150,000 barrels per day—the benefit exceeds $400 million. Simulations for smaller disruptions, however, resulted in small negative benefits. However, small disruptions have occurred with greater frequency. Both Oren and Wan (1986) and Ford (2005) note that national and state strategic reserves reduce incentives for private entities to hold their own reserves and therefore may have little or no effect on mitigating disruptions, which would depend on the total amount of oil taken from private, state, and Federal reserves, not the amount taken from any one of these reserve types.

Lastly, Ellison et al. (2006) simulate the usefulness of a natural gas strategic reserve. Though the authors do not quantify whether such a reserve would be efficient, they do raise questions regarding the Nation's natural gas infrastructure and vulnerabilities—specifically in the context of Hurricanes Katrina and Rita. They point out that such a reserve would address different issues than would an oil reserve: a spike in oil prices affecting U.S. consumers benefits foreign exporting nations, whereas a spike in natural gas would benefit domestic producers. Additionally, the United States does not import almost any natural gas and its domestic supply is diversified among several regions and many producers. The main purpose of such a reserve would therefore be to dampen natural gas prices following a natural disaster, terrorism, or other disruption. The authors estimate that creating reserves of 750 billion cubic feet would require about 30 storage facilities and cost about $14 billion. Those estimates allow policymakers to evaluate whether such a reserve is socially beneficial based on how much the country values low natural gas prices following a natural disaster.

B. Promotion of Energy Efficiency and Renewable Energy R&D

Many technological advances in clean, sustainable energy have been driven by government regulations and subsidies. Such advances, in turn, may have significant effects on oil and gas security if they lead to increased energy efficiency or greater diversity in fuel types. To estimate the security benefits of these programs, several studies have explored the relationship between policies that incentivize technological innovation and the resulting changes in the energy market.

Studies of the energy security benefits of clean and sustainable technologies and policies promoting these technologies require multiple estimates. First, the effect of the policy or technological innovation must be estimated. Then the resulting changes in the way the oil and gas markets respond to disruptions must be analyzed. The link between changes in consumption and estimated oil security benefits has already been studied in the context of the oil import premium and the SPR. However, the policy studies presented here offer new approaches to assessing the benefits of other market changes, such as changes in elasticities. In addition, they introduce methodologies that involve using energy market models and policy projections to evaluate the energy security benefits of specific policies.

Greene and Leiby (2006) develop a model to quantify the security benefits of technologies resulting from DOE's Energy Efficiency and Renewable Energy R&D programs. They do so by combining two models. The first, the VISION model, simulates the effects of programs on oil demand and the market shares of alternative fuels. It is calibrated to EIA's Annual Energy Outlook projections, then run using the estimated technological results of DOE's programs and the estimated market penetration of the technologies resulting from those programs. Changes in the price elasticity of oil are also estimated given the projected cost of the technology.

The estimated change in U.S. oil consumption, costs and fuel economy of the technologies, and changes in price elasticity of oil demand and light-duty vehicle motor fuel are then incorporated into a simple model of the world oil market. This second model is used to simulate the effect of oil supply shocks on the U.S. economy in the presence and absence of the new technologies. Although security benefits also include nonmonetary political, strategic, and military benefits, the authors focus on monetary security benefits, including avoided transfer of wealth, loss of economic surplus, and macroeconomic disruptions.
To calculate the gross security benefits of DOE technologies, the three components of oil security are estimated for undisrupted and disrupted world oil markets. In each market condition, two estimates are made, one with the technologies and one without them. Net security benefits are then calculated by subtracting the difference between the with- and without-technology costs during undisrupted market conditions from the difference in costs during disrupted market conditions. These benefits are calculated assuming two possible responses by OPEC to a change in U.S. oil demand: OPEC either maintains the quantity of oil produced or the price of oil.

To illustrate how the model can be applied to an actual technology, Greene and Leiby (2006) estimate the oil security benefits of an advanced technology for light-duty hybrid vehicles. This technology is expected to reduce gasoline consumption in light-duty vehicles by 0.1 percent by 2006, 10 percent by 2022, and 14 percent by 2030. In total, the technology would reduce U.S. petroleum consumption by 6.2 percent by 2030. The net security benefits are estimated to be between $35 billion present value and $58 billion,[59] depending on whether OPEC maintains quantity or price in response to a change in U.S. demand. It is noteworthy that these benefits apply to a single technology that increases the energy efficiency of only light-duty vehicles.

Another study (Yeh et al. 2012) analyzes the energy security implications of a national low carbon fuel standard (LCFS) for short- and long-term energy costs and related macroeconomic effects. Such a nationwide program does not exist in the United States, but a review of their approach is relevant to a discussion of energy security valuation. The Transportation Regulation and Credit Trading model was used to estimate the fuel changes resulting from an LCFS. The authors then estimated the energy security impact of the fuel changes using an approach similar to the one used by Leiby (2008). Unlike the renewable fuel standard (RFS), an LCFS requires a reduction in a fuel's average carbon intensity over its life cycle and covers all transportation fuels. Such a performance standard is more effective at stimulating innovation throughout the supply chain of a fuel and is more economically efficient, since the policy provides more flexibility in compliance.

However, the study notes that by restricting the carbon content of fuels, an LCFS could potentially prevent the domestic use of more reliable, higher-carbon sources, such as Canadian oil sands or domestic shale oil, which would then be exported to other countries, resulting in CO_2 leakage and lower net reductions. According to Yeh et al. (2012), the mean security benefits of an LCFS in 2035 would be "$5 per barrel if domestic alternative fuels substitute for Canadian oil sands; $12 per barrel if all sources in the base U.S. mix of petroleum are decreased proportionally; and $22 per barrel if imported crude oil demand is decreased." Overall, the study finds that the energy security benefits of an LCFS would be greater than those of the RFS.

C. Modeling Energy Security Benefits of Policies

Energy security valuation would benefit from having a modeling tool that could embody the various elements of energy security and that could take inputs associated with a new policy to create its monetized energy security benefits. Such a model would be analogous to EPA's BenMAP model that takes air quality changes from a proposed or final policy as input and calculates the health impacts and their corresponding monetized value. Unfortunately, such a model does not exist for energy security. Instead, The International Energy Agency has developed the Model of Short-term Energy Security (MOSES) to evaluate the energy risks and resilience capacities of its member countries. This model is designed to provide metrics associated with energy security at the country level, but its metrics are neither aggregated into a single index nor monetized for aggregation.

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[59] Because net benefits are calculated as the difference in gross benefits between disrupted and undisrupted markets, the incremental costs cancel. All estimates are made in 2004$.

The current version of MOSES analyzes the short-term security of supply for individual primary energy sources and secondary fuels. The approach is intended to be used to identify energy security priorities. MOSES follows an energy systems approach, dealing with all parts of the energy system from supply to transformation, distribution, and end-use energy services. For energy security, this means understanding how the vulnerabilities of different parts of the system may affect energy services. Taking crude oil security as an example, the model groups countries into five categories of security profiles, depending on the percentage of crude oil imported, supplier diversity, amount of crude oil storage, and number of oil ports and pipelines.

MOSES classifies energy security in four main dimensions, represented in a two-by-two matrix (Table 4.8). Two dimensions are geographic: external and domestic. The remaining two dimensions are risk and resilience. The first cell, accordingly, is the exposure to external risk associated with the disruption of energy flows from abroad. The domestic risk exposure arises from the production and transformation of energy supplies and their distribution to end users. Once a disruption occurs, resilience captures an energy system's responsiveness, which depends on the size, duration, and speed of recovery from the energy shock. For an external disruption, the ability to turn to other sources of imports, switch to other suppliers, avoid chokepoints in transportation, and access spot markets reduces vulnerability. For a domestic disruption, pipelines and transmission networks that continue delivering fuels—oil, other petroleum products, natural gas, and electricity—to markets and end users, the degree to which fuels can be substituted, and the size and drawdown capability of strategic reserves determine the country's ability to adapt and recover.

Table 4.8. Dimensions of energy security addressed in MOSES

	Risk	*Resilience*
External	**External risks:** risks associated with potential disruptions of energy imports	**External resilience:** ability to respond to disruptions of energy imports by substituting with other suppliers and supply routes
Domestic	**Domestic risks:** risks arising in connection with domestic production and transformation of energy	**Domestic resilience:** ability to respond to domestic disruptions in energy supply, such as fuel stocks

***Source*: Jewell et al. (2011)**

MOSES uses energy, economic, and infrastructure indicators to construct energy security measures capturing the components of the system. For example, in the natural gas sector, the indicators are net import dependence, diversity of suppliers, number of entry points, domestic pipeline and distribution network, natural gas intensity, and market competition. These indicators, classified as high, medium, and low, are combined to present energy security profiles by IEA countries. MOSES is designed to evaluate the security of supply of individual sources and fuels (see Table 4.9).

The model has a few limitations. It focuses on short-term physical security of primary sources and secondary fuels, electricity generation, transmission, and distribution, and energy networks but does not address energy security goals more relevant to medium- or long-term perspectives, such as the environmental effects of energy systems, growing demand for energy services, and the depletion of natural resources. In addition, it does not examine the "economic" or "affordability" dimension of energy security, such as the level and volatility of energy prices.

The security of an energy system depends not only on the state of its infrastructure (the main focus of MOSES) but also on the effectiveness of government policies and regulations, the market structure, and the investment climate. These governance, institutional, and investment factors are important for energy security but are difficult to measure and quantify. Thus they are imperfectly captured in MOSES.

D. Next Steps in Policy Valuation

This chapter does not attempt to provide valuations for any particular policy, with the exception of this final section. Instead, the chapter focuses on identifying methodologies that can be used to value the generic benefits that derive from a variety of policies. The policymaker can then combine the valuation methodologies for all of the benefits created by a particular policy. In keeping with that objective, this final section suggests that the development of an energy security model that aggregates energy security benefits and monetizes them might be warranted to better value the energy security benefits of energy-related policies and actions.

Table 4.9. Risk and resilience (res.) indicators used in MOSES

Energy Source	Dimension		Indicator	Source(s)
Crude oil	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
			Volatility of domestic production	IEA
		Res.	Average storage level	IEA
Oil products	External	Risk	Oil product net import dependence	IEA
		Res.	Diversity of suppliers	IEA
			Entry points (ports, rivers and pipelines)	IEA
	Domestic	Risk	Number of refineries	IEA
		Res.	Flexibility of refining infrastructure	IEA
			Average stock levels	IEA
Natural gas	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (LNG ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
		Res.	Daily send-out capacity from underground and LNG storage	IEA
			Natural gas intensity	IEA, World Bank
Coal	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and railways)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of mining that is underground	Various national sources
Biomass and waste	External	Risk	Net import dependence	IEA
	Domestic	Res.	Diversity of sources	IEA
Biofuels	External	Risk	Net import dependence	IEA
		Res.	Entry points (ports)	IEA
	Domestic	Risk	Volatility of agricultural output	IEA
Hydropower	Domestic	Risk/ Res.	Annual volatility of production	IEA
Nuclear power	Domestic	Risk	Unplanned outage rate	IAEA
			Average age of nuclear power plants	IAEA
		Res.	Diversity of reactor models	IAEA
			Number of nuclear power plants	IAEA

Energy Source	Dimension		Indicator	Source(s)
Crude oil	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
			Volatility of domestic production	IEA
		Res.	Average storage level	IEA
Oil products	External	Risk	Oil product net import dependence	IEA
		Res.	Diversity of suppliers	IEA
			Entry points (ports, rivers and pipelines)	IEA
	Domestic	Risk	Number of refineries	IEA
		Res.	Flexibility of refining infrastructure	IEA
			Average stock levels	IEA
Natural gas	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (LNG ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
		Res.	Daily send-out capacity from underground and LNG storage	IEA
			Natural gas intensity	IEA, World Bank
Coal	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and railways)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of mining that is underground	Various national sources
Biomass and waste	External	Risk	Net import dependence	IEA
	Domestic	Res.	Diversity of sources	IEA
Biofuels	External	Risk	Net import dependence	IEA
		Res.	Entry points (ports)	IEA
	Domestic	Risk	Volatility of agricultural output	IEA
Hydropower	Domestic	Risk/ Res.	Annual volatility of production	IEA
Nuclear power	Domestic	Risk	Unplanned outage rate	IAEA
			Average age of nuclear power plants	IAEA
		Res.	Diversity of reactor models	IAEA
			Number of nuclear power plants	IAEA

Source: Jewell (2011)

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