THE CONTRIBUTION OF THE COAL FLEET TO AMERICA'S ELECTRICITY GRID

Prepared for the American Coalition for Clean Coal Electricity

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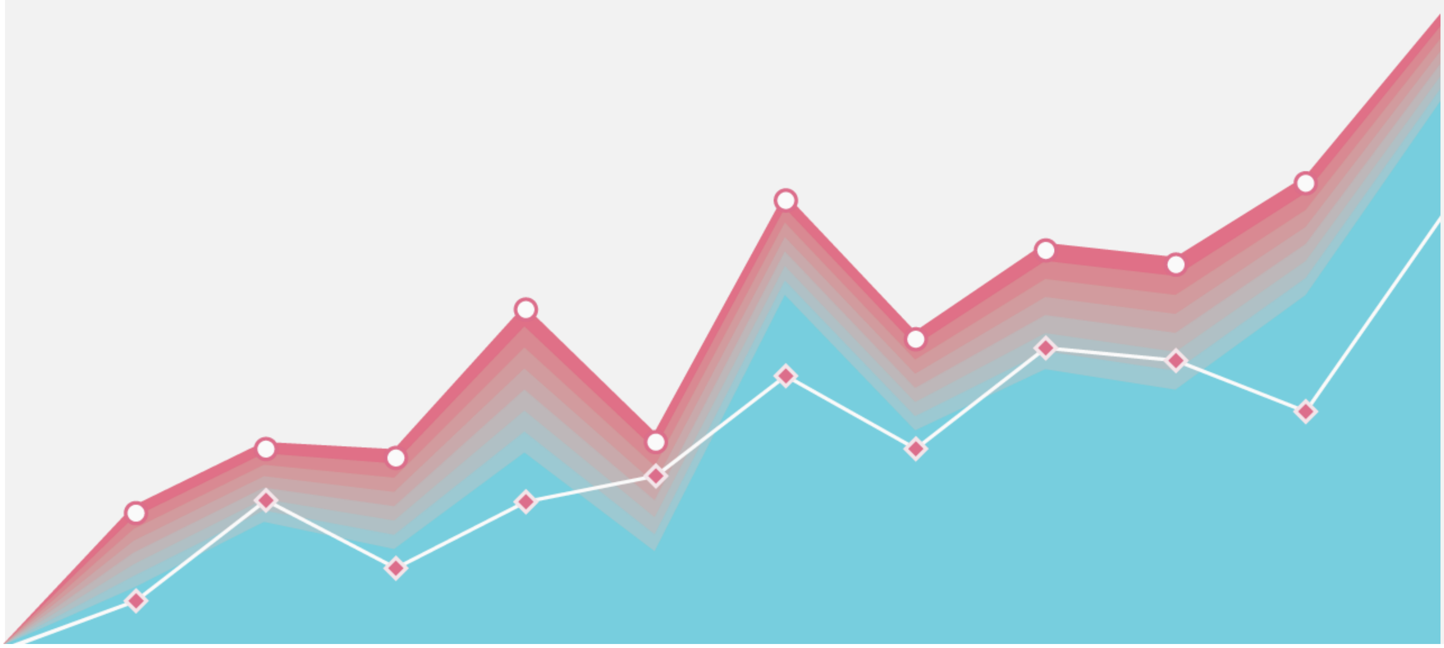

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EXECUTIVE SUMMARY

The U.S. electricity grid is rapidly evolving due to the low-cost supply of natural gas and the increasing penetration of grid-scale and behind-the-meter intermittent renewable generation. Innovation and cost reductions in battery storage and other technologies mean that this pace of change is likely to continue. These changes have sparked a debate over the need for what have historically been referred to as "baseload" electricity generation resources, such as coal-fueled and nuclear power plants. These resources have traditionally operated around-the-clock, continually providing reliable electricity generation at a stable price, as well as contributing to overall grid resilience. As explained in this report, these traditional resources—including coal-fueled generation—provide attributes that will remain critical to the grid as it continues to evolve.

There is broad agreement that the electricity system should be reliable and resilient, and that electricity prices should be affordable. A reliable electric system minimizes the likelihood of disruptive electricity outages, while a resilient system acknowledges that outages will occur, prepares to deal with them, and is able to restore service quickly. In pursuing these commonly-held goals, policy makers, utility executives, and grid operators are required to make decisions that take into consideration both near-term and longer-term economic, policy and technology trends. These decisions ultimately lead to a determination of the most appropriate mix of electricity resources that reflect the diversity of the U.S. electric grid (e.g., different market structures, physical features, and policy preferences).

This report highlights three ways in which the United States' existing coal fleet benefits the electricity system:

> ***Coal-fueled generation provides many attributes that are critical for grid <u>reliability and resilience</u>*.** A variety of attributes are required to maintain a reliable and resilient grid, and no one technology can do it all. Different resources provide these attributes to varying degrees, and coal provides many critical attributes. As the electric sector becomes increasingly reliant on natural gas and as renewable penetration grows, market structure changes may be required to properly price and value the contribution of all types of generation to ensuring both reliability and resilience.

> ***<u>Resource diversity</u> is critical in maintaining a reliable and resilient electricity system*.** The coal fleet plays an important role in helping to maintain resource diversity. The impact of unpredictable low-probability, high-impact events that challenge grid resilience is magnified as the electricity system evolves. For example, natural gas has historically been prone to supply disruptions and price shocks, while intermittent renewable and demand response resources are generally not dispatchable[1] to meet unforeseen fluctuations in electricity demand. The U.S. coal fleet benefits from stable commodity pricing, multiple means of delivery, and an ability to stockpile fuel. Diversity in fuel supply improves the resilience of the grid and mitigates the impact of fuel supply disruptions.

> ***The coal fleet provides <u>stable pricing</u> as a hedge against natural gas price volatility*.** The price of natural gas has an outsized impact on the price of electricity in most markets. Today's natural gas prices are at near-historic lows, which has resulted in natural gas-fired combined-cycle plants being *the* favored technology to replace retiring generation and meet expected load growth. Retaining existing coal-fueled power plants can help insulate ratepayers against rising and possibly volatile natural gas prices.

[1] Dispatchable generation can be scheduled ahead of time, and adjust power output by command (within physical time constraints).

The essential attributes provided by different resources to grid reliability, resilience and affordability are shown in Table ES-1 below. Each attribute is described in Section 1.1. The table is not intended to demonstrate which resource is "better," or to rank the resources. However, the comparison highlights two important facts: (i) all the attributes listed are needed for grid reliability and resilience; and (ii) no single resource by itself exhibits all the attributes needed for reliability and resilience—however, coal-fueled generation provides many of these attributes. Note that the table is not intended to be a complete list of either resource types or attributes, but it illustrates the most common electricity resources.

Table ES-1: Qualitative Comparison of Grid Reliability and Resilience Attributes by Fuel Type[2]

Attribute	Coal	Natural Gas	Wind/Solar	Nuclear	Demand Response
Dispatchability	✓	✓		✓	
Inertia	✓	✓	✓(wind)	✓	
Frequency Response	✓	✓	✓[3]		
Contingency Reserves	✓	✓			✓
Reactive Power	✓	✓		✓	
Ramp Capability	✓	✓			✓
Black Start		✓			
Resource Availability	✓	✓		✓	
On-Site Fuel Supply	✓			✓	✓
Reduced Exposure to Single Point of Disruption	✓		✓	✓	✓
Price Stability	✓		✓	✓	✓

Regulators and policy makers should recognize and appropriately value the attributes of each electricity resource and fuel type, including coal-fueled generation, to maintaining grid reliability, resilience and affordability.

[2] Source: PA Consulting Group analysis.

[3] Although most wind does not provide frequency response, newer vintage wind resources with integrated storage can do so. Some solar depending on the type of inverter also supports frequency response.

CONTENTS

1 A DIVERSE MIX OF GENERATION RESOURCES IS IMPORTANT FOR GRID RELIABILITY

In recent years, many industry participants have qualitatively and quantitatively evaluated the benefits of different generation technologies and fuel sources. These findings can be controversial and require the appropriate context and framing. For example, a single type of power generating resource that meets "all" the identified attributes of a resilient and reliable resource cannot alone meet all of the grid's generation needs, since there are system-wide resiliency risks associated with relying on any one technology or fuel type. Such findings tend also to focus on the contributions of various technologies to normal grid operations, while discounting an uncertain future that will invariably feature low-probability, high-impact events (such as the Polar Vortex winter event that occurred in 2014). Planning for a grid that is both reliable and resilient requires a focus on such unlikely events.

This section begins with a discussion of attributes of different types of generation to set the context of how baseload generation (including coal) fits into the current mix of U.S. generation technologies that collectively contribute to a reliable grid and low-cost electricity. It then frames the discussion in the broader context of the regional variations in market structures and policies that shape generation mixes. Chapter 2 will discuss how baseload generation contributes to resilience.

1.1 The attributes of a resilient and reliable electricity grid

A resilient and reliable electricity grid is good for the United States. However, translating this truism into an understanding of the roles different power generation technologies serve within the appropriate fuel mix, including coal, is more challenging. For example, the Brattle Group recently wrote a report suggesting that baseload generation is no longer needed.[4] Such views may oversimplify the complexity and heterogeneity of the modern grid.

Collectively, the mix of generation on the grid needs to provide the following attributes, at a minimum, in order to satisfy the goals of a reliable, resilient and affordable electricity system:

Dispatchability. The operation of baseload power plants can be scheduled well in advance to meet predicted load, with minimal need to forecast factors which affect many other generation technologies. Over shorter time-frames, baseload power can be adjusted to increase or decrease output as necessary, providing flexibility in meeting fluctuations in demand.

Frequency response provides active control to maintain a constant 60 Hz—this is the frequency that must be maintained to keep the grid, and all connected equipment, operating safely and reliably. This can only be provided through active generating resources and fast response storage, which must respond to moment-to-moment dispatch instructions to maintain the grid's frequency. Baseload plants with Automatic Generation Control ("AGC") can provide frequency regulation in all hours of the day, including in overnight hours when wind penetration is typically the greatest. Frequency regulation requirements are increasing in parts of the country where there is significant renewable penetration, as the intermittency of renewables requires frequency adjustment more often.

[4] Advancing Past "Baseload" to a Flexible Grid, The Brattle Group, June 26, 2017

Inertia. By their nature, baseload power plants consist of large electric machines rotating at a frequency of 60 Hz. As the load on the grid increases, the rotation of connected machines begins to slow down, reducing the grid frequency; alternatively, a reduction in load causes faster rotation and an increase in frequency. However, when such load changes occur rapidly in a system with baseload power, the inertia provided by these heavy rotating machines resists the changes in frequency, helping the grid ride through disturbances. Additionally, the short time frame of this inertial response buys time for other grid control systems to take action to address the root cause of such disturbances.

Contingency reserves. Baseload plants are able to provide spinning reserves to provide backup power in case of system disruptions (e.g., a generator tripping offline) at short notice (often ten to thirty minutes). This is accomplished by holding back capacity from the energy market, without the risks associated with starting up from a cold state or a fuel supply disruption. Offline reserves are typically provided by fast-starting peaking plants.

Reactive power. Changing characteristics of load and generation on the grid—even when supplying constant power—can result in fluctuations in the voltage level, which may damage electric loads, generators, or transmission and distribution equipment. Baseload generators can supply reactive power to counteract these fluctuations both on command and through AGC.

Ramp capability. Resources which can quickly increase or decrease their power output—"ramping" up or down—are needed on the grid in order to quickly adjust to system shocks such as momentary increases or decreases in renewable energy output, load spikes, or generator outages elsewhere on the system. Ramp capability is one of the most critical requirements for grid flexibility.

Black start capability. Several types of generators require an active electric connection in order to supply power to the grid, and will disconnect whenever the grid fails or moves outside of set operating limits. After such a failure or a blackout, generators with "black start" capability are necessary to re-start the grid and give other generators a signal to synchronize to. These resources typically include hydro-electric, diesel generators, and combustion turbines.

Resource availability. Generators need to be available to provide a relatively constant supply of electricity when it is needed under a variety of system conditions, seasons, and times of day. Wind and solar resources are by their nature intermittent, while many demand response resources are seasonal. Conversely, coal, natural gas and nuclear generators can run uninterrupted for very long periods of time.

On-site fuel supply. Resources with on-site fuel supply contribute to grid resilience by minimizing the potential for fuel supply disruptions. Natural gas supplies for generating plants are generally scheduled on a daily basis ("just in time"), with almost no opportunity for on-site storage. This leaves them vulnerable to upstream supply issues, whether from pipeline constraints or from supply failures (some are capable of burning oil to insulate against this risk), while hydroelectric generation may have limited "fuel" availability due to reservoir limitations or other natural constraints. During periods when the electricity system is stressed, on-site fuel supply contributes to increased grid resilience.

Reduced exposure to single point of disruption. Many grid resources rely on external systems to ensure they operate reliably. For example, natural gas generators require a constant external fuel supply that is be supplied only by a network of pipelines, compressor stations, storage, and LNG facilities. Resources utilizing "free" fuel supplies, such as the wind and the sun, have reduced exposure to external factors, as do the majority of coal-fueled generating stations, which maintain on-site fuel stockpiles and have multiple means of fuel delivery as a resource class.

- **Stable, predictable pricing.** Generators with stable pricing can be freely dispatched by system operators without the risk of incurring high costs for customers, or operating losses for generators. Because marginal costs are based on variable costs, which largely reflect fuel costs, resources with volatile fuel costs like natural gas can result in unstable power prices. Baseload generation has traditionally had relatively high fixed costs, but low and predictable variable costs.

1.2 The role of baseload generation in supporting grid reliability

Baseload generation typically refers to low-variable cost resources that operate around-the-clock to meet minimum system demand. By its nature, baseload power provides resilience and long-term affordability, while its rotational inertia contributes to ancillary services that ensure essential reliability services, such as frequency control, contingency (spinning) reserves, and reactive power. Arguments that baseload generation is an artifact of traditional resource planning miss two key realities about the current electricity system and the continued relevance of baseload resources within it.

First, while the growth in renewables in some markets drives a need for ramping ability, those attributes provided by baseload generation remain critical to the reliable, resilient and affordable operation of the grid, and in some ways are magnified by the growth in renewables. Second, the pace of change of the electric grid across the United States has not been uniform, and the need for retaining baseload power reflects the various market structures and regional variation in existing generating resources. In short, there is not a one-size-fits-all answer.

Wholesale electricity markets are slowly recognizing that a greater need to value baseload resources for these attributes may be appropriate. For example, PJM is currently considering several reforms to improve price formation and reduce the "pernicious effect" of issues such as negative pricing. PJM states that this need is critical because the distorting price signals "erod[e] revenue streams… of thermal generation, whose continuing operation is needed to meet capacity requirements and provide reliability services to accommodate for the intermittency of renewable generation".[5]

1.3 The lack of market uniformity

The importance of the benefits provided by baseload coal is further highlighted by differences in regional market structures. In the excitement over new technologies and visions for how the future may unfold, it is easy to forget that the grid is not a uniform system. In some regions there have been rapid advances in the integration of new generation technologies, which has spurred new challenges for system operators. In other regions with limited renewable resources, the challenges are largely unchanged from a generation ago. Due to these regional distinctions, solutions that work for one part of the country may not work for another. The two key ways in which regions differ are: (i) current electricity market structures; and (ii) existing regional generation supply. While not the only factors, these two critical factors are often overlooked in the debate regarding the role of existing coal-fueled plants. Policy prescriptions should therefore appropriately reflect the needs and goals of individual regions.

Different market structures

For most of the last century, the U.S. electricity grid was dominated by vertically-integrated utilities that controlled the majority of the electricity value chain, from the generation of electricity at power plants to its

[5] PJM White Paper, "Energy Price Formation and Valuing Flexibility", June 15, 2017. Available at: http://www.pjm.com/~/media/library/reports-notices/special-reports/20170615-energy-market-price-formation.ashx

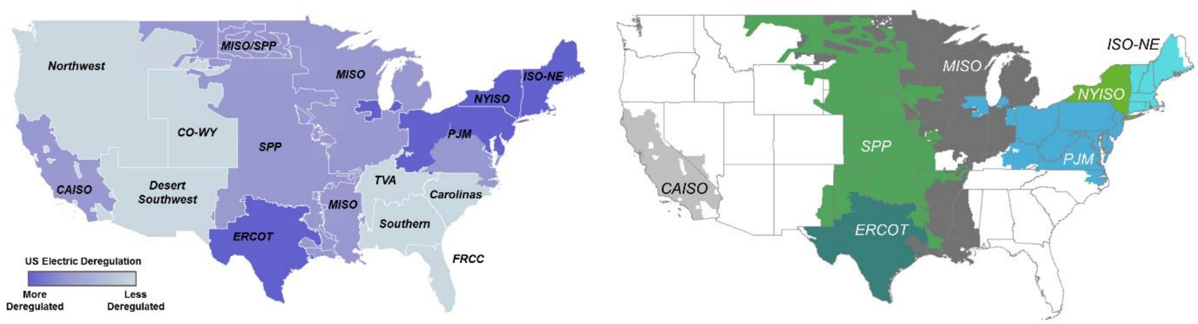
delivery to homes and businesses. These state-regulated monopolies and public power entities were viewed as the most effective way to safely provide affordable and reliable electricity to the public.

However, the paradigm shifted in the mid-1990s and early-2000s, as electric market deregulation swept across the United States. At its core, deregulation was intended to increase competition in the electric sector and thereby lower costs for customers. However, the issue of whether an unfettered competitive market will adequately address policy and reliability goals without regulatory guidance is debatable, along with whether the markets provide appropriate compensation to achieve desired levels of reliability and resilience.

Electric deregulation has progressed differently across the United States, with states in the Northeast, Mid-Atlantic, and Texas generally being the most deregulated, and states in the Southeast and much of the Midwest and West generally being less deregulated. Some regions of the country have evolved further, forming Independent System Operators ("ISOs") or Regional Transmission Operators ("RTOs") (see Figure 1-1), such as PJM, New England, and New York. These regions have created independent oversight of the wholesale markets, and feature more competitive markets when compared with regions such as the Southeast and most of the West (excluding California). In these competitive markets, locational market pricing ("LMP") prices reflect energy, transmission congestion and losses every five minutes at thousands of separate locations on the grid, which accurately inform dispatch signals that reflect least-cost outcomes.

Figure 1-1: United States Deregulation and Electricity Markets[6]

Level of Deregulation | **Major U.S. Electricity Markets**



Today, over half of U.S. states have adopted some form of electric deregulation, with much of the competition occurring within seven distinct electricity markets. In these markets, power plants owned by competitive generators are expected to enter (or exit) the market based on their ability to earn (or fail to earn) a profit. This dynamic shifts the risk associated with changing market forces from the captive electricity customer to the power plant investor.

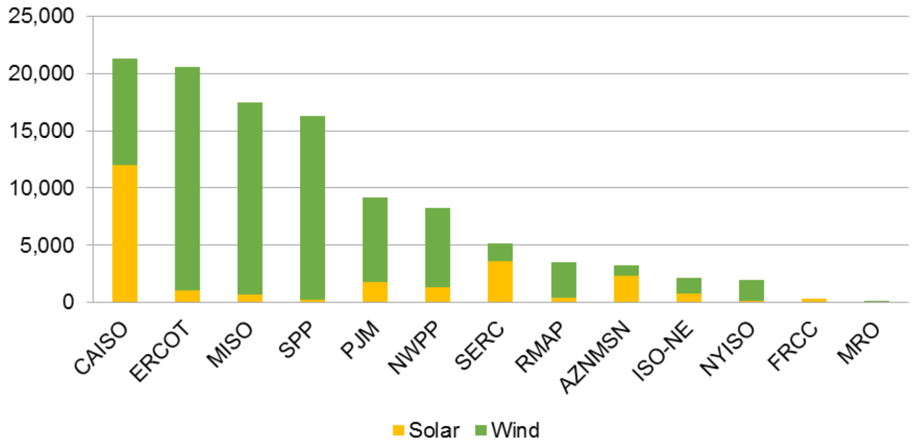
However, outside of these electricity markets (and to some extent within them), vertically integrated utilities under state regulatory control exist. Where such utilities are the norm, changes to market dynamics that impact the cost of electric generation are generally borne directly by the electric customer. As such, vertically integrated utilities and the regulatory bodies governing them typically focus on long-term planning, and carefully weigh how altering the power generation supply may impact customers over the long-term. This includes weighing the financial implications to the customer of prematurely retiring existing generation that provides a natural hedge against future reliability, resilience, and market risks.

[6] Source: ABB's Energy Velocity suite.

Regional variation in generation supply

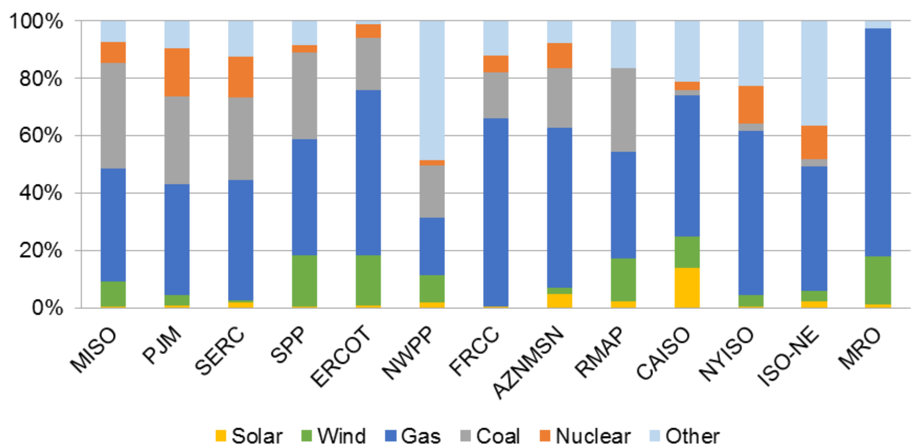
The growth of new energy technologies has not occurred uniformly across the United States. In regions where there has been more adoption of renewables, markets have evolved to accommodate these changes in the resource mix. While this market evolution is necessary in places like California, not all states will reach (or have the potential to reach) high levels of wind and solar penetration as quickly. The uneven geographic distribution of growth in wind and solar capacity (illustrated in Figure1-2) has two principal drivers. The first is state-level policies, including specific renewable energy targets, which have subsidized these resources and disproportionately encouraged growth in certain states. The second is the differing quality and availability of solar and wind resources across the United States.

Figure 1-2. Installed Solar and Wind Capacity (MW) by Electricity Region[7]



Moreover, even in regions that have relatively high intermittent renewable penetration, such as in the ERCOT electricity market of Texas, these newer resources still make up a small component of the overall existing fuel mix (see Figure 1-3).

Figure 1-3. Installed Capacity (% of Nameplate MW) by Electricity Region[8]



[7] Source: SNL Energy.

[8] "Other" includes oil, hydro-electric, biomass, and waste-to-energy. Source: SNL Energy.

1.4 The role of coal-fueled generation

Renewable energy has in recent years become an important part of most grids in the United States. Its role has grown in response to state policies, consumer preferences and declining costs. However, intermittent renewable energy by itself cannot create a reliable and resilient power grid, since system operators require dispatchable generation to meet load and provide the aforementioned attributes critical to maintaining the grid. This need highlights a central challenge of wind and solar generation. When the sun does not shine and the wind does not blow, these renewable technologies are unable to provide electricity to the grid. This intermittency is not just limited to predictable factors, such as the rising and setting of the sun, or seasonal variability; there are also localized challenges associated with passing clouds and storm systems that can prevent expected generation from materializing during the day.

To reliably integrate renewables—particularly at high penetrations—regions with significant renewable capacity will increasingly need generation resources providing flexibility attributes which fast ramping natural gas-fired generation supply. Regions that currently have significant existing coal-fueled generation within the fuel mix (especially those with limited levels of renewable generation) do not currently have the same need for flexibility as those with significant amounts of intermittent generation. In such areas, low-marginal cost thermal resources such as coal-fueled generation play an important role in maintaining an affordable, reliable, and resilient electricity grid through the operational and electrical attributes which they provide. Furthermore, even in markets where the need for flexibility is heightened, the attributes provided by baseload resources are still relevant (and in the case of frequency response magnified). Care must be taken to ensure that they are adequately valued.

2 THE IMPORTANCE OF GRID RESILIENCE

Electricity system planners evaluate both reliability and resilience in designing and operating the grid. This helps ensure safety (by maintaining access to critical infrastructure and services), a favorable business and investment climate, and a desirable quality of life. Unlike reliability, which seeks to minimize the likelihood of disruptive outages on the system, "*a resilient system is one that acknowledges that such outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future.*"[9]

Electricity is still difficult and costly to store in most circumstances. As a result, the grid is operated in real-time and requires constant management and adjustment of system operations to ensure this reliable supply. Furthermore, the electric system operates in an environment where equipment failures, extreme weather, natural disasters, malicious attacks, and other events can occur suddenly and unexpectedly. These types of low-probability, high-impact events can significantly compromise reliability and can lead to fuel supply disruptions for electric generators. As such, ensuring fuel diversity is critical to maintaining the resilience of the electricity system.

While natural gas is an efficient fuel that allows for fast-ramping generation, the complex nature of the natural gas production, transmission, and distribution system, "just-in-time" delivery, relatively limited storage capability, and competing high-priority end uses make natural gas-fired generators more prone to supply disruptions. Renewable energy contributes towards fuel diversity and resilience, but due to its intermittent nature, it must often be balanced with thermal (coal, natural gas, and nuclear) generation in order to ensure that load is reliably served. Because of its unique characteristics, including on-site fuel stores and multiple modes of transportation, existing coal-fueled generation has an important role to play in maintaining fuel diversity, reliability, and resilience of the grid.

2.1 The focus on grid resilience

Ensuring grid resilience goes beyond the traditional view of power system reliability. It encapsulates how the power grid as a system will react to large-scale catastrophic events including natural disasters, malicious attacks, and large-scale system failures. With concern about how the grid is changing in an age when new types of threats to the grid are being recognized, NERC and the RTOs/ISOs are paying increased attention to resilience. For example, PJM in its "Grid 20/20" series of stakeholder meetings for 2017 has been examining resilience in terms of fuel mix, diversity of resources, and security.[10] In PJM's recent study examining its evolving resource mix, the grid operator identified fuel risk, fuel assurance, and frequency response as potential issues if natural gas and renewables replace coal in the current generation portfolio mix.[11] Similarly, NERC looks at resilience from a number of perspectives, including single points of disruption and the risks of dependence primarily on natural gas-fired generation.[12]

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[9] Source: The National Academy of Sciences, Engineering, and Medicine, Enhancing the Resilience of the Nation's Electricity System (prepublication copy), 2017, p. 1-6.

[10] "Grid 20/20: Focus on Resilience (Fuel Mix Diversity & Security)." PJM, April 19, 2017.

[11] PJM looked at a number of alternative scenarios including where 25%, 50%, 75%, and 100% of the existing coal fleet is retired. *PJM's Evolving Resource Mix and System Reliability*, PJM Interconnection, March 30, 2017.

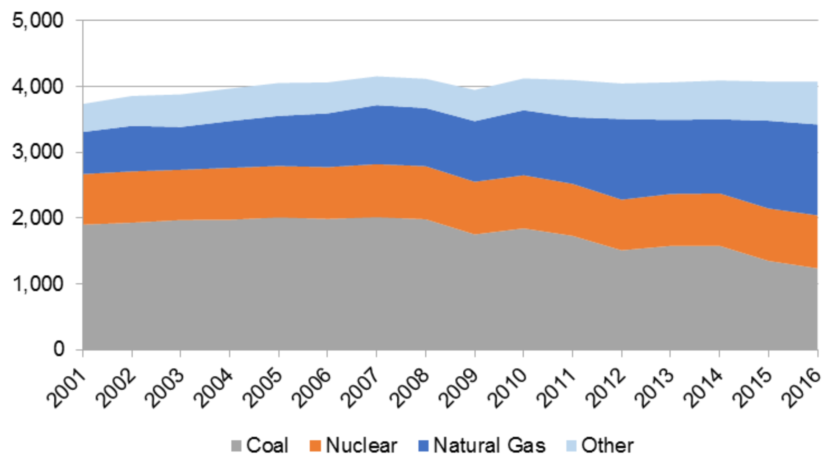
[12] *State of Reliability 2017*, North American Electric Reliability Corporation, June 2017.

2.2 Fuel mix and diversity of resources contributes to resilience

It is not possible to protect the electric system against every possible disruption, and outages are bound to occur. This feature is noted by the National Academy of Sciences, who state that "*While utilities work hard to prevent large-scale outages, and to lessen their extent and duration, such outages do occur and cannot be eliminated.*"[13] Because of the inevitability of low-probability, high-impact events, electric system planners increasingly seek resilience alongside reliability.

Two components that contribute to electric system resilience are: (i) diversification of the fuels used, and (ii) ensuring adequate and consistent fuel supply to electric generators. The fuel supply mix has shifted over the past fifteen years. Coal and nuclear generation today provide approximately half of total utility-scale electricity generation (down from 72% in 2001), while natural gas-fired generation has risen to nearly 34% (up from 17% in 2001). From 2001 to 2016, natural gas-fired generation grew from 639 TWh to 1,380 TWh, a 116% increase, while total electricity generation grew by only 9%.[14] See Figure 2-1.

Figure 2-1. U.S. Electricity Generation by Fuel Type, 2001-2016 (TWh)[15]



There is no single "perfect" fuel upon which to rely for a reliable and resilient electricity system. Rather, a diversity of fuels helps the system maintain reliability and quickly bounce back after low-probability, high-impact events by allowing operators to maximize the benefits of each individual fuel type while offsetting each fuel's drawbacks. As a fuel with unique reliability and resilience benefits, coal plays an important role in this diverse generation mix.

The electricity system is more resilient when generation is sourced from a variety of fuels and technologies. A common argument made in favor of state-level renewable portfolio standards ("RPS") is that these standards help ensure fuel diversity on the grid. For instance, the Council of State Governments has noted that one of the main objectives of state RPS is "*to diversify the state's electricity supply*,"[16] and most states allow a variety of renewable energy technologies (e.g., wind, solar, biomass, waste-to-energy, etc.) to qualify for renewable energy credits. This acknowledges that there is an inherent benefit to diversity, regardless of

[13] Source: The National Academy of Sciences, Engineering, and Medicine, Enhancing the Resilience of the Nation's Electricity System (prepublication copy), 2017, p. 1-3.

[14] Source: EIA, Electric Power Monthly, accessed July 27, 2017.

[15] Source: Ibid.

[16] Source: The Council of State Governments, Overview of State Renewable Portfolio Standards, December 2008.

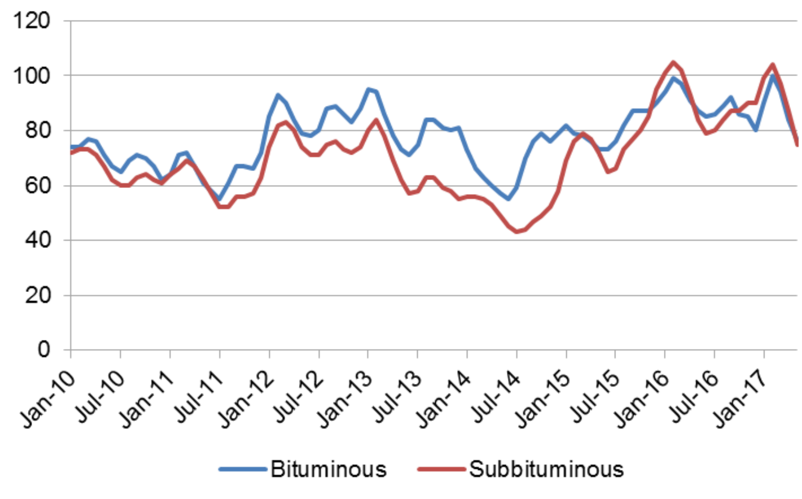
fuel supply. However, many of these renewable energy technologies are not dispatchable, meaning the electric system must have dispatchable generation to balance their intermittency. Dispatchable generation includes coal, natural gas, and, to some extent, nuclear and hydroelectric power. However, if the electric system has an over-reliance on dispatchable natural gas fired generation, it reduces diversification from a critical sub-class of generation that has unique reliability and resilience attributes compared to natural gas.

2.3 Coal-fueled generation contributes to system resilience with an on-site fuel supply

While coal-fueled plants are not free from outage risks, they have unique attributes that contribute to grid resilience, including a secure fuel supply. First, the vast majority of coal consumed in the United States is used for electricity generation (93% in 2016)[17] and does not compete with higher-priority uses. This practically eliminates the risk that coal deliveries to generators would need to be forcibly curtailed in order to serve other uses. In contrast, natural gas is also used for residential space heating, and flows on the same pipelines as natural gas provided to power generators.

Second, coal is an energy-dense solid that is relatively easy for generators to stockpile on site, mitigating exposure to supply disruptions. As of May 2017, a representative sample of coal-fueled plants had approximately 76 days and 75 days of bituminous and subbituminous coal stockpiled at their facilities, respectively. Over the last five years, coal-fueled plants had an average of approximately 82 days and 73 days of readily accessible bituminous and subbituminous coal stockpiled at their facilities.[18] See Figure 2-2. Because lignite coal is generally consumed at mine-mouth power plants (all but two lignite coal-fueled plants source their coal from mines within 30 miles of the plant),[19] it is also relatively insulated from supply shocks.

Figure 2-2. Days of Stockpiled Coal Burn[20]



Furthermore, unlike natural gas, coal can be shipped through a variety of transportation methods, including rail, truck, and barge. In contrast, a disruption to a major natural gas pipeline or prolonged excessive demand

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[17] Source: EIA, Quarterly Coal Report, accessed July 27, 2017.

[18] Source: EIA, Electricity Monthly Update, accessed July 27, 2017.

[19] Source: ABB's Energy Velocity Suite.

[20] Source: EIA, Electricity Monthly Update, accessed July 27, 2017.

that stresses pipeline infrastructure, particularly in regions with limited underground storage, could substantially reduce access to natural gas for an extended period of time. The diversity in transportation methods makes coal supply infrastructure as a whole far less vulnerable to single points of disruption than natural gas.

This is not meant to imply that natural gas is a poor fuel choice for electricity generation. Rather, it is meant to demonstrate that each fuel used to generate electricity has its own unique benefits and drawbacks, and ensuring a diverse mix of fuels creates a more reliable and resilient electricity system.

This dynamic has been noted frequently by system planners. For instance, NERC has stated that "*overdependence on a single fuel type increases the risk of common-mode or single-point-of-failure disruptions as experienced during recent extreme weather events…*"[21] and that "*maintaining fuel diversity provides inherent resilience to common-mode risk*."[22] Similarly, PJM has highlighted that "*resource diversity can be considered a system-wide hedging tool that helps ensure a steady, reliable supply of electricity*,"[23] and that "*PJM recognizes that the benefits of fuel mix diversity include the ability to withstand equipment design issues or common modes of failure in similar resource types, fuel price volatility, fuel supply disruptions, and other unforeseen system shocks*."[24] Furthermore, ISO-NE identifies specific fuels that are particularly helpful in maintaining reliability and resilience, stating that "*the lights stay on during extremely cold periods with a combination of these fuels: nuclear, coal, oil and LNG*."[25]

2.4 Gas-fired generation has limitations

Despite its status as a dispatchable fuel, natural gas supply is not as physically secure as other thermal generation fuels, particularly coal. Among generation technologies, natural gas is unique in that, similar to electricity, it relies on a complex production, transmission, and distribution network for just-in-time fuel delivery, often over long distances. This interconnected system of production wells and pipelines, while capable of smooth operation under normal circumstances, is exposed to disruptions during low-probability, high-impact events. For example, natural gas systems pose fuel supply risk from disruptions during earthquakes "*given the long supply chain and vulnerability of pipelines*."[26] Additionally, as natural gas and electric transmission and distribution systems are increasingly interdependent, natural gas compressor stations on gathering lines and along major pipelines are often vulnerable to electric system outages.[27]

While storage is possible, natural gas must be stored at high pressure to be volumetrically efficient, which is both physically challenging and costly at the small scale of individual generators. Instead, natural gas is typically stored in large-scale, centralized underground storage facilities, which include depleted oil and natural gas fields, salt caverns, and aquifers. As of November 2016, the total demonstrated maximum working gas capacity of underground storage in the continental United States was 4,373 Bcf. This capacity is an important balancing mechanism for the natural gas market. Demand in the winter often exceeds daily

[21] Source: NERC, Short-Term Special Assessment: Operational Risk Assessment with High Penetration of Natural Gas-Fired Generation, May 2016, p. v.

[22] Source: NERC, 2016 Long-Term Reliability Assessment, December 2016, p. 20.

[23] Source: PJM, PJM's Evolving Resource Mix and System Reliability, March 30, 2017, p. 3.

[24] Source: Ibid p. 6.

[25] Source: Gordon van Welie, ISO-NE, State of the Grid: 2017 (presentation), January 30, 2017, p. 19.

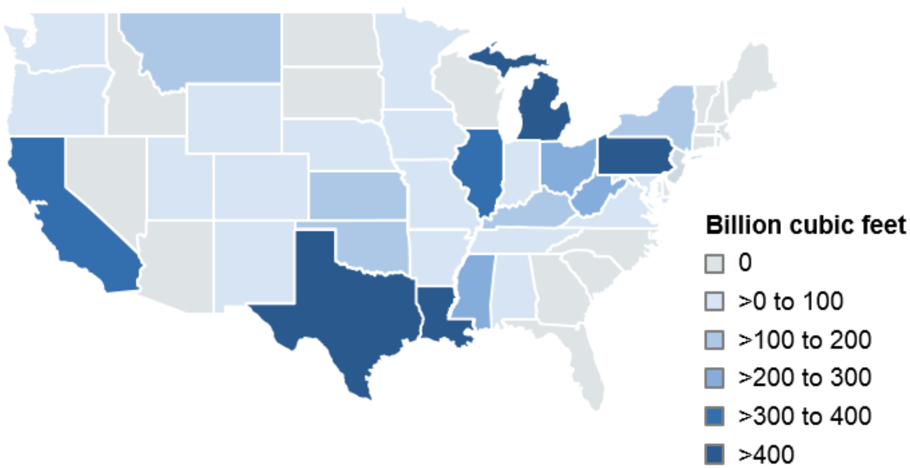
[26] Source: The National Academy of Sciences, Engineering, and Medicine, Enhancing the Resilience of the Nation's Electricity System (prepublication copy), 2017, p. 3-5.

[27] Source: Department of Energy, QER Report: Energy Transmission, Storage, and Distribution Infrastructure (Chapter 2), April 2015.

production, while the opposite is true in the summer, so storage is typically built up in the summer in anticipation of winter use. In order to keep storage levels within an acceptable band that will provide security in the winter, seasonal prices move to encourage or discourage consumption from price-sensitive demand sources. However, this capacity is not designed to provide long-term natural gas reserves. In 2016, nearly 27,500 Bcf of natural gas was consumed in the United States, meaning that there is only about 60 days of natural gas supply in storage reserves, not accounting for geographic concentration and pipeline constraints that limit actual deliverability.

Additionally, because effective underground natural gas storage is dependent on favorable geology, it is highly concentrated in certain geographies. Notably, over 50% of the working gas storage capacity is located in just five states – Michigan, Texas, Louisiana, Pennsylvania, and California. Furthermore, 18 states in the continental United States have no material storage capability, including all of New England and four Atlantic coast states in the Southeast[28] (see Figure 2-3). This means that access to natural gas continues to rely on long-distance pipeline infrastructure, even to access stored gas.

Figure 2-3. Working Natural Gas Storage Design Capacity by State (November 2016)[29]



Furthermore, the demand for natural gas storage will likely increase in the future as the penetration of intermittent renewable generation increases. Natural gas firming generation which is used to respond to fluctuations in renewable energy supply, relies at least in part on stored gas, since it is difficult to ramp natural gas delivery quickly enough to fuel natural gas firming generators when additional output is called for. This places additional stress on physically limited stored natural gas supply, and increases the potential impact of risks such as rapid demand increases and large storage leak events. Furthermore, natural gas storage capacity is difficult to expand, due to factors like limited geology and challenging economics with recently low summer and winter gas price spreads.

In addition to physical limitations, natural gas-fired generators face unique contractual and regulatory fuel supply restrictions. First, many generators directly interconnected with interstate and intrastate pipelines do not have firm gas supply arrangements, which are typically more costly than non-firm arrangements. Unlike firm arrangements, suppliers are not obligated to deliver natural gas under all circumstances under non-firm arrangements, including emergency events. This is particularly true in less regulated regions with

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[28] Source: EIA, Underground Natural Gas Working Storage Capacity, accessed July 27, 2017.

[29] Source: Ibid.

competitive centralized wholesale markets, where electricity prices do not incorporate the benefits that are associated with more expensive firm transportation.

Second, some generators are not served directly by large pipelines, and instead receive gas service through a local distribution company ("LDC"). Because LDCs also serve other, higher-priority end uses such as residential heating, they hold the right to interrupt gas supply to electric generators if needed.

Although direct information on the amount of natural gas-fired generation capacity that has firm versus interruptible gas supply arrangements is not publicly available, nor the amount that is supplied through LDCs, it is clear that the amount of natural gas delivered on an interruptible basis is significant in several less-regulated markets. For example, in ISO-NE, MISO, NYISO, and PJM, PA estimates that at least 30% of the natural gas delivered to power plants in 2016 from pipelines was delivered on an interruptible basis.[30] PA further estimates that, nationwide, 10-20% of gas-fired generators receive service through an LDC.[31]

Third, the Natural Gas Policy Act of 1978[32] authorizes the Department of Energy to direct the allocation of natural gas supplies by interstate pipelines and LDCs to "*high-priority users*" if the President declares a natural gas emergency. High-priority users under the Act specifically include residential customers, smaller commercial establishments, and buildings with critical operations, like schools and hospitals. Therefore, due to the lack of firm supply agreements and the potential curtailment of natural gas deliveries to generators ahead of high-priority users during emergency events, natural gas-fired generators face certain supply risks that may prevent them from operating during certain low-probability, high-impact events.

While low-probability, high-impact events on the electric system are bound to occur, fuel diversity can improve the reliability and resilience of the grid, and coal-fueled generation has several unique attributes that contribute to reliability and resiliency. Coal-fueled generation does not compete for fuel supply with other demand, unlike natural gas generation which often faces fuel supply curtailment risk due to competition with higher-priority demand and the lack of firm supply arrangements. Coal is also easy to stockpile on-site in quantities large enough to ensure that coal-fueled plants can continue operating for several months even in the event of a supply disruption.

On the other hand, natural gas is difficult to store except in large, geologically appropriate underground storage facilities that remain vulnerable to critical failures. Additionally, gas from storage facilities still must be transported to natural gas generators, often over long distances, and is vulnerable to the same contractual and physical disruptions that are discussed above. Coal can also be transported through several means, while natural gas relies on just-in-time delivery through a complex web of production wells, transmission, and distribution lines. These unique characteristics make coal-fueled generation critical to the continued reliability and resilience of the electric system.

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[30] More specifically, PA estimates that the percentage of gas delivered to power plants on firm transportation arrangements in 2016 was approximately 35-45% for ISO-NE, 45-55% for MISO, 35-45% for NYISO, and 60-70% for PJM. PA's analysis of firm versus interruptible gas supply is based on a review of EIA Form 923 data for natural gas-fired generators, and the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database ("eGRID").

[31] PA's analysis of LDC gas delivery is based on a review of EIA Form 860 data for natural gas-fired generators.

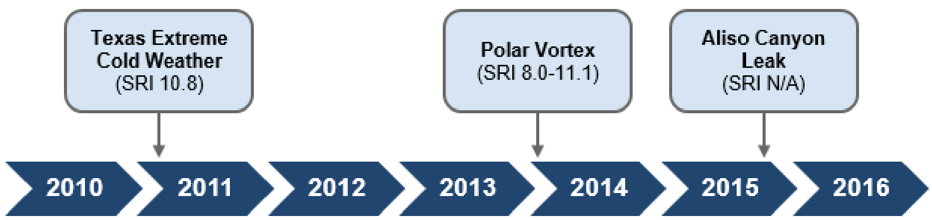
[32] Public Law 95-621, 95th Congress, Natural Gas Policy Act of 1978, November 9, 1978.

2.5 The recent instances of low-probability, high-impact events

Low-probability, high-impact events on the electric system have occurred recently with notable frequency, despite their unpredictability. The North American Electric Reliability Corporation ("NERC"), the primary authority responsible for monitoring and enforcing electricity reliability on the U.S. system, calculates a daily Severity Risk Index ("SRI") to measure the reliability performance of the bulk power system. The SRI includes generation, transmission, and load loss components, and accounts for unplanned generation outages, high-voltage transmission system outages, and load lost on the distribution system as a result of upstream events. In its most recent *State of Reliability* report, NERC notes that days with a SRI rating that exceeds 5.0 "*are often memorable and may provide lessons learned opportunities*."[33]

From 2010 to 2016, there were two outage events driven at least partially by generator fuel supply issues in which the SRI rating equaled or exceeded 5.0, indicating widespread and sustained generator outages and/or loss of load. There was one additional event that did not lead to immediate outages, but was noted by NERC as creating substantial future reliability risks due to fuel supply constraints[34] (see Figure 2-4).

Figure 2-4. Timeline of Memorable Fuel Supply Constraint Events[35]



Texas extreme cold weather event

The first memorable event since 2010 was an extreme cold front that hit the Southwest United States during the first week of February 2011. Temperatures remained below freezing for several days across the region, causing a large number of generators to trip offline, suffer significant output declines, or fail to start. The ERCOT region in Texas was most heavily affected, where 193 generating plants either failed or had significant declines in output. Combined with scheduled outages, this led to the unavailability of approximately one-third of the total ERCOT fleet.

In their report on this cold weather event, FERC and NERC noted that electric and natural gas interdependency contributed to the outages. Freezing temperatures, along with rolling blackouts caused by the initial wave of generator outages (which were driven largely by weather-related issues like equipment failures), drove substantial production declines at natural gas wells throughout the region. FERC and NERC determined that natural gas supply shortfalls contributed to approximately 1.3 GW of generator outages and derates in ERCOT.[36] For comparison, this was approximately half of ERCOT's spinning reserve requirement.

[33] Source: NERC, State of Reliability 2017, June 2017, p. 13.

[34] Note that there were 10 total days in which SRI met or exceeded 5.0 from 2010 to 2016, but two of these days were associated with the same event as another memorable SRI day (the Polar Vortex and Superstorm Sandy).

[35] Source: NERC, State of Reliability 2017, June 2017; NERC, State of Reliability 2015, May 2015.

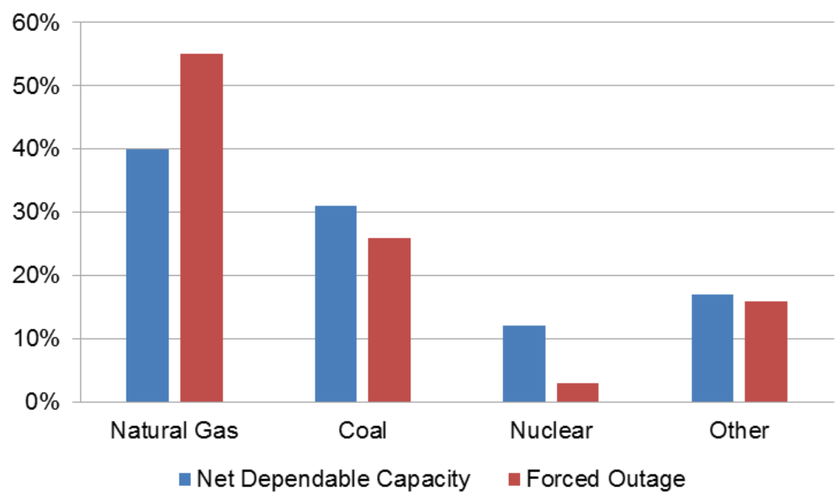
[36] Source: FERC and NERC, Report on Outages and Curtailments during the Southwest Cold Weather Event of February 1-5, 2011, August 2011.

The Polar Vortex

The second low-probability, high-impact event that caused fuel supply issues for electric generators since 2010 was the Polar Vortex, which caused sustained, extremely cold temperatures across the East Coast, Midwest, and South Central regions of the United States in early January 2014. These extremely cold temperatures increased demand for natural gas for both space heating and electricity. This strained gas transmission and distribution infrastructure in regions that relied heavily on gas for power generation. Due to the lack of firm gas supply agreements at many generators, and LDC and pipeline responsibility to serve heating demand before power generation, natural gas supply for a substantial share of generators was curtailed or interrupted.

Across affected regions, generator forced outages caused by interruptions to fuel supply totaled over 19 GW, largely comprised of natural gas supply disruptions.[37] Across the Eastern and ERCOT interconnections, natural gas-fired generation comprised 55% of forced outages. Coal and nuclear, on the other hand, represented only 26% and 3% of forced outages, respectively.[38] See Figure 2-5. On this dynamic, NERC noted that, "One of the largest issues impacting gas-fired generation was the curtailment or interruption of fuel supply."[39]

Figure 2-5. Polar Vortex Net Dependable Capacity vs. Forced Outage Percentage[40]



Aliso Canyon leak

Although not reflected in NERC's SRI metric, as it did not lead to an immediate generation outage, another low-probability, high-impact event with implications for the electric power system was the failure of the Aliso Canyon natural gas storage facility in Southern California in October 2015. Aliso Canyon is one of the largest gas storage facilities in the country, and was an essential supplier to nearly 10 GW of natural gas-fired generating capacity in the Los Angeles basin. However, a leak that occurred from October 2015 through

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[37] While not simultaneous across regions, fuel supply interruptions during the Polar Vortex impacted 820 MW in MRO, 3,296 MW in NPCC, 10,700 MW in RF, 2,050 MW in SERC, 150 MW in SPP, and 2,309 MW in TRE.

[38] Source: NERC, Polar Vortex Review, September 2014.

[39] Source: Ibid, p. 2.

[40] Source: Ibid.

February 2016 led to the loss of over 70 Bcf (more than 80%) of its gas storage capacity.[41] California energy regulators placed an extended moratorium on new injections into the facility, a moratorium which was only recently lifted in July 2017, and only partially. In a risk assessment of high penetrations of natural-gas fired generation across several electricity regions, NERC noted that this shortage of gas storage capacity presented a significant electricity system reliability risk in the summer of 2016.[42]

It is also important to note that the leak at Aliso Canyon is not the only memorable natural gas storage leak in recent memory, and that significant natural gas storage infrastructure remains at risk of failure. In January 2001, a leak at the Yaggy underground natural gas storage field in Kansas caused multiple explosions resulting in two deaths and caused the loss of approximately 143 MMcf of gas. In August 2004, a wellhead fire and explosion at the Moss Bluff storage facility in Texas caused the release of approximately 6 Bcf of gas. Furthermore, additional natural gas storage facilities potentially remain at risk of leaks or other single points of failure. In its report on *Ensuring Safe and Reliable Underground Natural Gas Storage,* the U.S. Department of Energy noted that *"about 80% of natural gas storage wells with known completion years were drilled before 1980, and many predate modern materials and technology standards. These wells have been subject to environmental processes and mechanical stresses from injection and withdrawal of natural gas across multiple decades."*[43]

[41] Source: NERC, State of Reliability 2017, June 2017.

[42] Source: NERC, Short-Term Special Assessment: Operational Risk Assessment with High Penetration of Natural Gas-Fired Generation, May 2016.

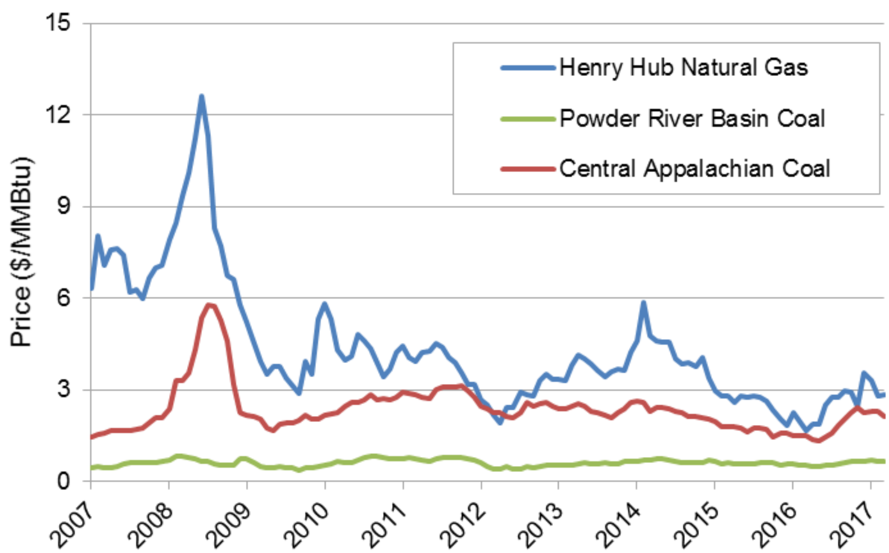
[43] Source: U.S. Department of Energy, Ensuring Safe and Reliable Underground Natural Gas Storage: Final Report of the Interagency Task Force on Natural Gas Storage Safety, October 2016, p. 54.

3 EXISTING COAL-FUELED GENERATION PROVIDES A HEDGE AGAINST POTENTIAL NATURAL GAS PRICE INCREASES

Seventy-seven gigawatts of natural gas-fired power plants have been built since 2009. While the decision to build these new plants is partially driven by load growth, it is predominantly driven by capacity retirements. Expanding supplies of low-cost shale natural gas mean natural gas-fired plants are currently the favored replacement form of capacity. While this boom provides near-term benefits, retaining coal resources provides an insurance policy against unforeseen volatility and increases in natural gas prices.

The current investment boom in natural gas-fired plants is driven in part by an expectation of continued low natural gas prices of approximately $3-4/MMBtu. Historically, however, natural gas prices have been volatile and subject to system shocks due to both market forces and extreme weather. Over the last decade, monthly average prices have repeatedly seesawed between approximately $3/MMBtu to above $12 (see Figure 3-1). During the Polar Vortex, prices at times reached $100/MMBtu in some markets. Preserving operating coal-fueled plants creates an insurance policy against the impacts of volatile natural gas prices.

Figure 3-1: Natural Gas and Coal Commodity Prices, 2007-2017 ($/MMBtu)[44]



[44] Source: ABB's Energy Velocity Suite.

3.1 An over-focus on short-term price signals

In electricity markets, the energy price typically reflects the marginal cost of producing power, which for thermal plants mostly reflects fuel costs. Natural gas-fired plants are cycled to meet intermediate and peaking load needs, such as in response to moment-by-moment changes in demand or supply (for example, to respond to forced outages or balance intermittent renewable generation). These fuel costs often make natural gas-fired plants the “marginal unit” in a market, providing the last incremental megawatt of power and setting the price paid for electricity in the wholesale market. Therefore, throughout the United States, the power price is closely linked to the price of natural gas.

Long-term investment decisions, however, reflect the total cost, rather than the marginal cost, of operating a power plant. The total costs include recovering fixed operating costs that are incurred regardless of whether a plant runs (for example, keeping a plant staffed) and a return on invested capital. When energy prices rise above the marginal cost of a power plant, these additional revenues provide them with a means to recover their fixed costs. However, price signals from the energy markets alone are generally not sufficient for full cost recovery because of market distortions.

For example, when wind units are marginal, production subsidies result in negative pricing for all generators, including baseload generators that are unwilling or unable to turn off for short periods of time. In many regions, regulators require planning reserve margins that mandate levels of supply beyond what an energy-only market would provide, while energy prices are often capped at $1,000/MWh or so, well below the perceived cost to a supply interruption known as the “Value of Lost Load”.[45] Since power prices reflect the marginal cost, rather than the total cost of generation, baseload power plants are unable to recover their fixed costs during most hours, and rely on price spikes for this cost recovery. When power prices can’t reach their natural highs during these spikes, baseload resources cannot recover their full costs from markets.

In competitive electricity markets, some ISOs operate capacity markets designed to provide this “missing money.” These markets generally have time horizons of one year or less, with only two (PJM and ISO-NE) providing a three year outlook. As a result, there is limited price visibility for competitive power generators, which puts limits on the amount and tenor (i.e., time to maturity) that debt markets are willing to finance. Typically, debt markets finance thermal power plants built in competitive power markets over a seven to ten year timeframe, which is far less than the life-cycle of a thermal power plant. This mismatch in turn creates an implicit bias towards technologies with lower upfront capital costs that can recover costs in the short-run compared with technologies that may rely on a longer time frame for cost recovery.

In vertically-integrated markets, regulators are tasked with taking a long-term perspective, and overseeing a process by which regulated utilities also adopt a long-term perspective on investments in generation. This perspective not only includes ensuring reliability and keeping costs down, but also providing predictable electricity pricing to ratepayers. As natural gas prices rise, regulated utilities can turn to their baseload coal and nuclear fleet for power, while reducing reliance on more expensive natural gas-fired generation.

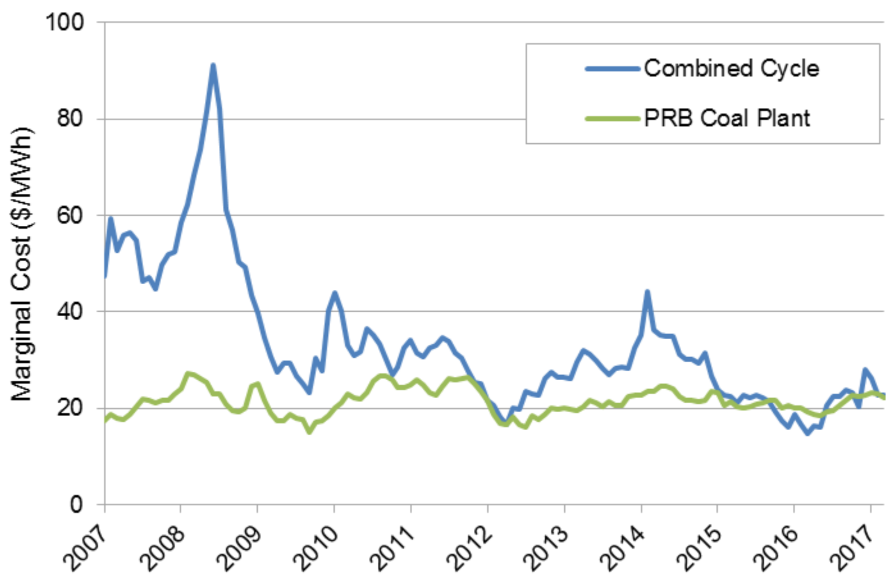
[45] This amount varies significantly by market and by customer class, but is generally accepted to be multiple thousands of dollars per MWh.

3.2 Natural gas prices are projected to rise

Over the last decade, monthly natural gas commodity prices have fluctuated on average between $2 and $12/MMBtu. Near-term movement often reflects drivers such as cold weather increasing demand, storage levels, and pipeline constraints. Long-term drivers include the expansion of fracking technologies that have opened up previously unrecoverable shale plays in the Marcellus region of Pennsylvania and elsewhere. However, while the expansion of fracking has driven gas prices to historic lows, natural gas prices have been volatile.

Over the last decade, coal pricing has been much more stable, reflecting far fewer supply and demand shocks. Over 80% of coal is purchased through multi-year contracts[46] for both the commodity and transportation, whereas natural gas is typically purchased on-demand and as-available. This is because contracting for long-term firm natural gas supply is expensive, and hedging against price volatility can be complicated, requiring a trading desk or going through a marketer. Additionally, gas purchased on an interruptible basis is subject to further daily volatility. For these reasons, the marginal cost of a power plant burning Powder River Basin ("PRB") coal is historically very stable (approximately $20-$30/MWh) compared to a representative combined cycle burning natural gas ($15-$90/MWh), as shown in Figure 3-2.

Figure 3-2: Illustrative Marginal Cost of a Natural Gas-Fired Combined Cycle Plant vs PRB-Burning Coal Plant ($/MWh)[47]



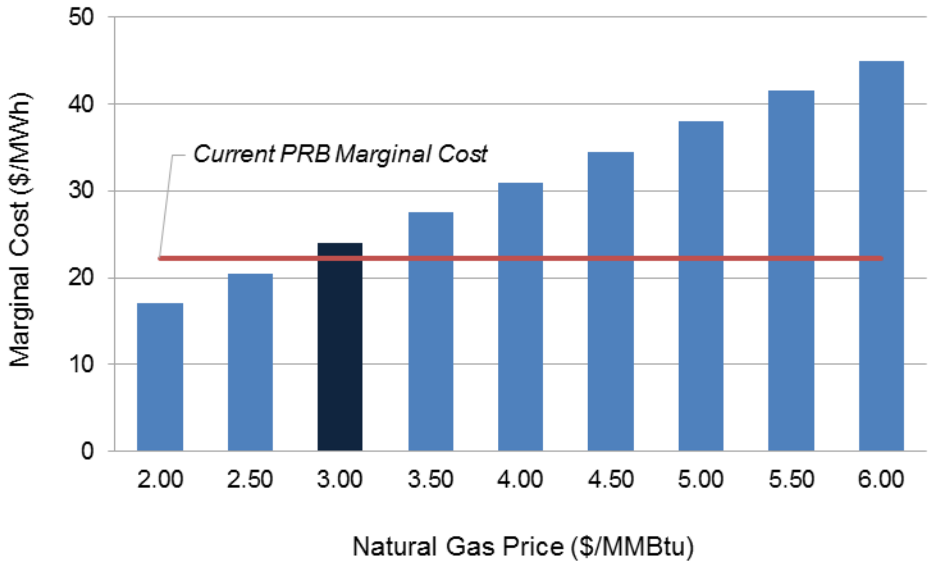
Natural gas-fired generation has been competitive with coal since late 2014. This is unusual, since coal plants have historically dispatched ahead of natural gas-fired plants. However, it would not take a significant rise in natural gas prices for coal-fueled generators to once again be advantaged relative to most natural gas combined cycle generators. Consensus forecasts for natural gas price recovery to these levels (i.e. above $4/MMBtu) is generally three to five years away, driven by higher power sector demand and increasing natural gas exports, including to Mexico via pipelines and globally in the form of Liquefied Natural

[46] The length of an average coal purchase contract is over two years.

[47] Combined cycle reflects Henry Hub natural gas, a 7,000 Btu/kWh heat rate and $3/MWh variable operations & maintenance ("VOM") cost. PRB coal plant reflects a 10,000 Btu/kWh heat rate and $6/MWh VOM. Source: ABB's Energy Velocity Suite.

Gas ("LNG").[48] This timeline is beyond the near-term horizon of wholesale markets, but well within the useful life of the average existing coal-fueled plant.

Figure 3-3: Marginal Cost of Illustrative Combined Cycle Plant at Different Natural Gas Prices[49]



When natural gas prices rise above $4/MMBtu, coal is poised to return to its traditional role as an infra-marginal baseload resource (see Figure 3-3), providing stable and low-cost power for ratepayers. Prudently retaining this coal-fueled capacity would provide significant hedge value against rising natural gas prices.

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[48] In its most recent 2017 Annual Energy Outlook, EIA forecasts $4.90/MMBtu Henry Hub in 2020.

[49] Source: PA Consulting Group analysis.

4 CONCLUSION

This report has highlighted the benefits that existing coal-fueled generation provides to our current and future electricity system, and how these resources can be effectively leveraged to ensure the system remains reliable and resilient and prices remain stable. As the electricity system evolves, many of these requirements will take on greater importance. These requirements include reliability attributes such as inertia and frequency response, resiliency attributes advanced by diversity in technology and fuel supply, and stable pricing via reduced exposure to volatile natural gas prices.

Coal is well-positioned to provide many of these system attributes:

- Coal-fueled plants contribute to reliability through the rotational inertia of spinning generators that provide essential ancillary services, including frequency response, spinning reserves, and reactive power.
- Coal-fueled plants utilize a low-cost, domestically available fuel which can be stockpiled, is available for purchase on long-term contracts, and is used almost exclusively for electricity generation. These factors combine to make coal one of the most reliable generating resources, and its inclusion in the diverse mix of generating resources results in a more resilient grid.
- Coal-fueled generation contributes to long-term stable and low-cost power prices.

While often overlooked, these benefits should be part of the conversation when objectively weighing the contributions that various technologies make toward a reliable, resilient, and affordable electricity system. This conversation should furthermore acknowledge the varied regional market structures and generation mixes that shape policy. We encourage regulators and policymakers to recognize the value of a diverse mix of resources to ensure grid reliability and resilience.

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