RELIABILITY, RESILIENCE AND THE ONCOMING WAVE OF RETIRING BASELOAD UNITS, VOLUME II-B: ELECTRICITY GENERATION SUPPLY CHAIN IN THE NORTHEAST

April 19, 2019

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Disclaimer

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Note (1): This volume is part of a three-part study, for parts II-A and II-C, see (1) and (2).

Note (2): Events have transpired between the writing and publication of this report that impact some of the results presented within. Specifically, on July 23, 2019 the Ohio Legislature passed House Bill 6 establishing the Ohio Clean Air Program and providing subsidy for several in state generating plants that were slated for retirement as of April 19. These retirement notices have since been recalled and the units expected to continue operation. Furthermore, in this same period, additional generation retirements have been announced.

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LIST OF EXHIBITS

ACRONYMS AND ABBREVIATIONS

Bcf	Billion cubic feet
BES	Bulk electric system
Btu/Ft^3	British thermal unit per cubic foot
DOE	Department of Energy
EIA	Energy Information Administration
GW	Giga-watt
GWh	Giga-watt hour
ISO	Independent system operator
ISO-NE	ISO New England
LDC	Local distributing company
LMP	Locational marginal price
LNG	Liquefied natural gas
MESA	Mission Execution and Strategic Analysis
MISO	Midcontinent Independent System Operator
MMBtu	Million British thermal units
MMcf	Million cubic feet
mph	Miles per hour
MW	Mega-watt
MWh	Mega-watt hour
NETL	National Energy Technology Laboratory
NGCC	Natural gas combined cycle
NYISO	New York Independent System Operator
PJM	PJM Interconnection
RMR	Reliability must run
RTO	Regional transmission organization
scf	Standard cubic feet
Tcf	Trillion cubic feet
TGP	Tennessee Gas Pipeline
U.S.	United States

EXECUTIVE SUMMARY

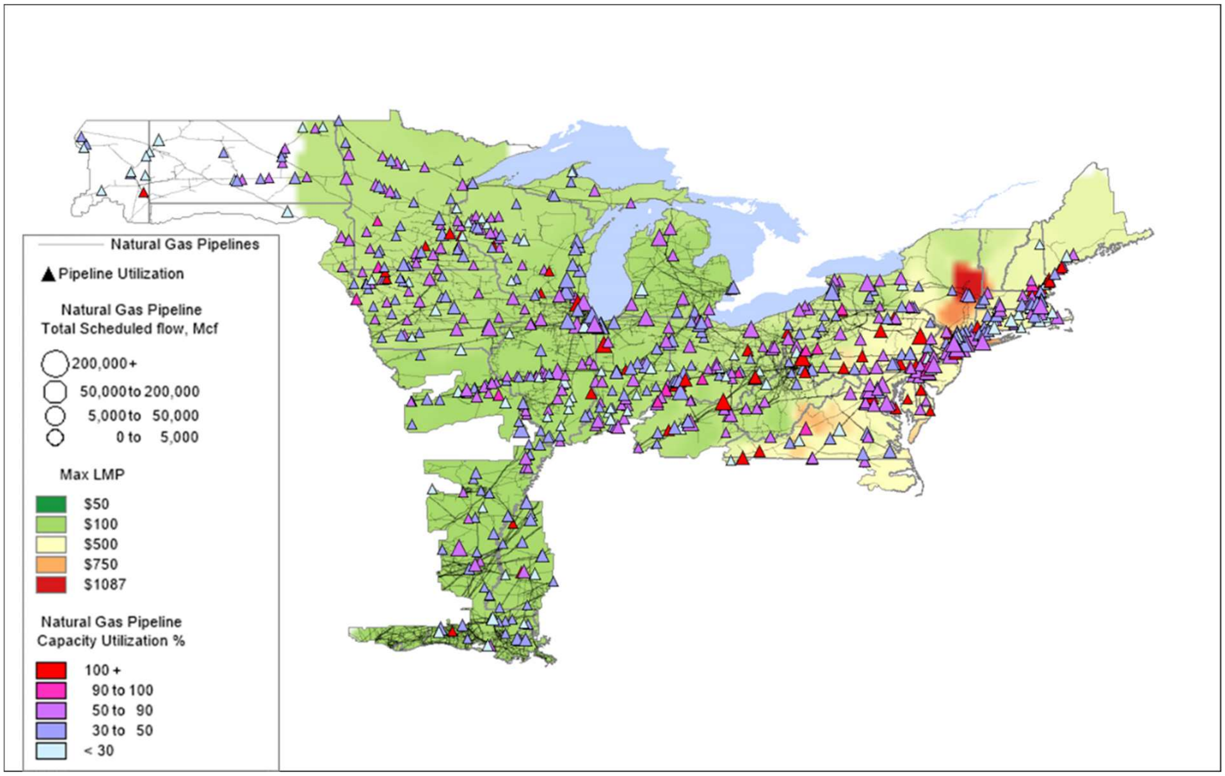
As the electric power system begins to rely more heavily on natural gas-fired capacity, the reliability and resiliency of the bulk electric system (BES) becomes increasingly tied to the performance and capabilities of the natural gas delivery system. Coal-fired power plants maintain a ready supply of on-site fuel to sustain, at a minimum, several days of operation. Nuclear power is insulated from fuel-supply curtailments, as nuclear plants run continuously outside of periodic scheduled refueling shutdowns and very infrequent periods of forced outage. In contrast, natural gas-fired generating units rely on just-in-time delivery of fuel via pipeline.

This has become a particular issue of concern in the Northeast, which has been transitioning away from coal and nuclear power toward more natural gas and renewable power generation, and which was hard hit by recent severe weather events. Two cold weather events, namely the "Polar Vortex" during the winter of 2013–2014 and the "Bomb Cyclone" during the winter of 2017–2018, exerted pressure on the BES in the northeastern and mid-Atlantic regions of the United States (U.S.).

During the Bomb Cyclone, price spikes were reflective of pipeline utilization rates in excess of 100 percent in many areas of the Northeast and scattered throughout the Midwest, as shown in Exhibit ES-1.[a] Higher pipeline utilization corresponds to locations with higher locational marginal prices (LMPs), especially in the pipeline-constrained regions along the eastern coast where there is little coal-fired generation. The relationship between high pipeline utilization and high LMP is concentrated in regions with a natural gas heavy generation resource mix.

[a] Pipeline utilization is calculated by dividing the scheduled capacity at a point by that point's operating capacity. Operating capacity is reflective of lower value than the design or maximum capacity and accounts for adjustments to a nominal set of operating conditions. This leaves the operator with headroom capacity that can be scheduled under certain circumstances, meaning that by following the calculation described above, the utilization can occasionally reflect values exceeding 100%.

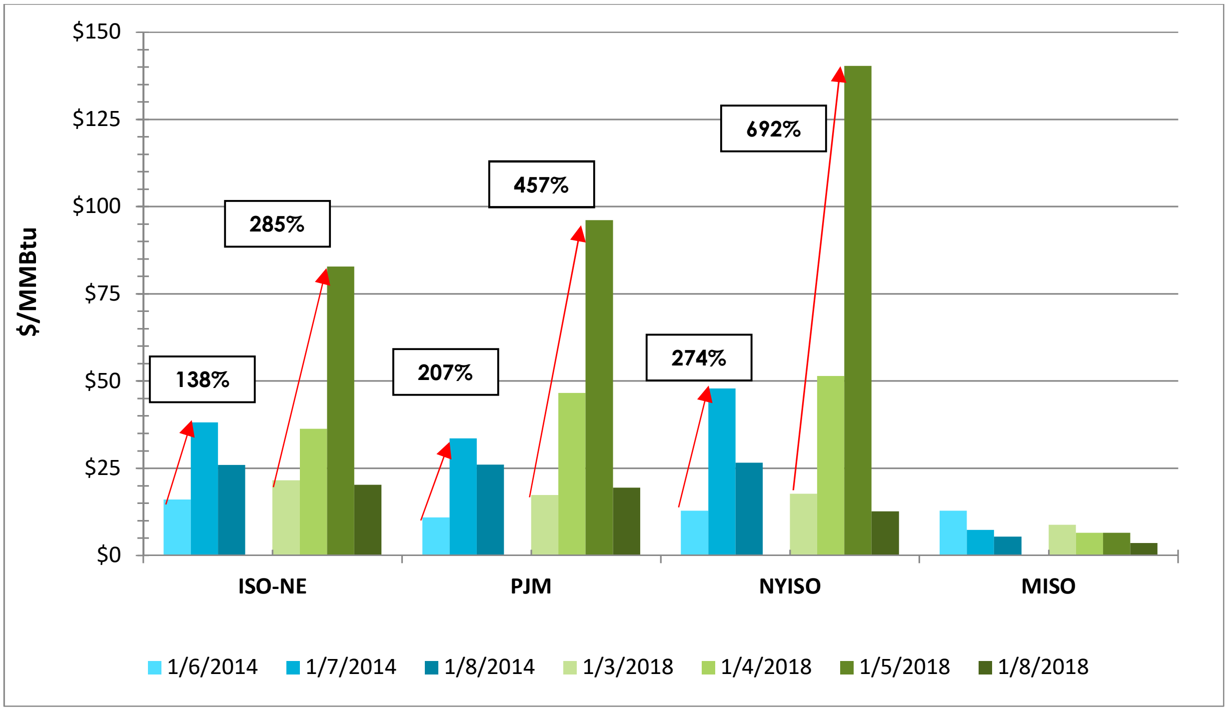
Exhibit ES-1. Pipeline utilization on January 5, 2018



Source: ABB Velocity

A comparison of the impact of these extreme weather events on four regional transmission organizations (RTOs)/independent system operators (ISOs) is shown in Exhibit ES-2, with the first set of three bars of each ISO representing the natural gas prices during the Polar Vortex, and the second set representing the Bomb Cyclone prices. While the Polar Vortex had a significant impact on spot gas prices, the most severe impacts were only felt on one day. During the Bomb Cyclone, the spot gas prices increased significantly more over a two-day period, with New York Independent System Operator (NYISO) seeing an almost 700 percent increase in prices, compared to a still significant 274 percent increase during the Polar Vortex. ISO New England (ISO-NE) and PJM Interconnection (PJM) also saw significantly higher spot gas prices during a two-day stress during the Bomb Cyclone compared to the single-day spike during the Polar Vortex. By comparison, Midcontinent Independent System Operator (MISO) had very little change in spot natural gas prices due to the extensive network of pipelines in the region.

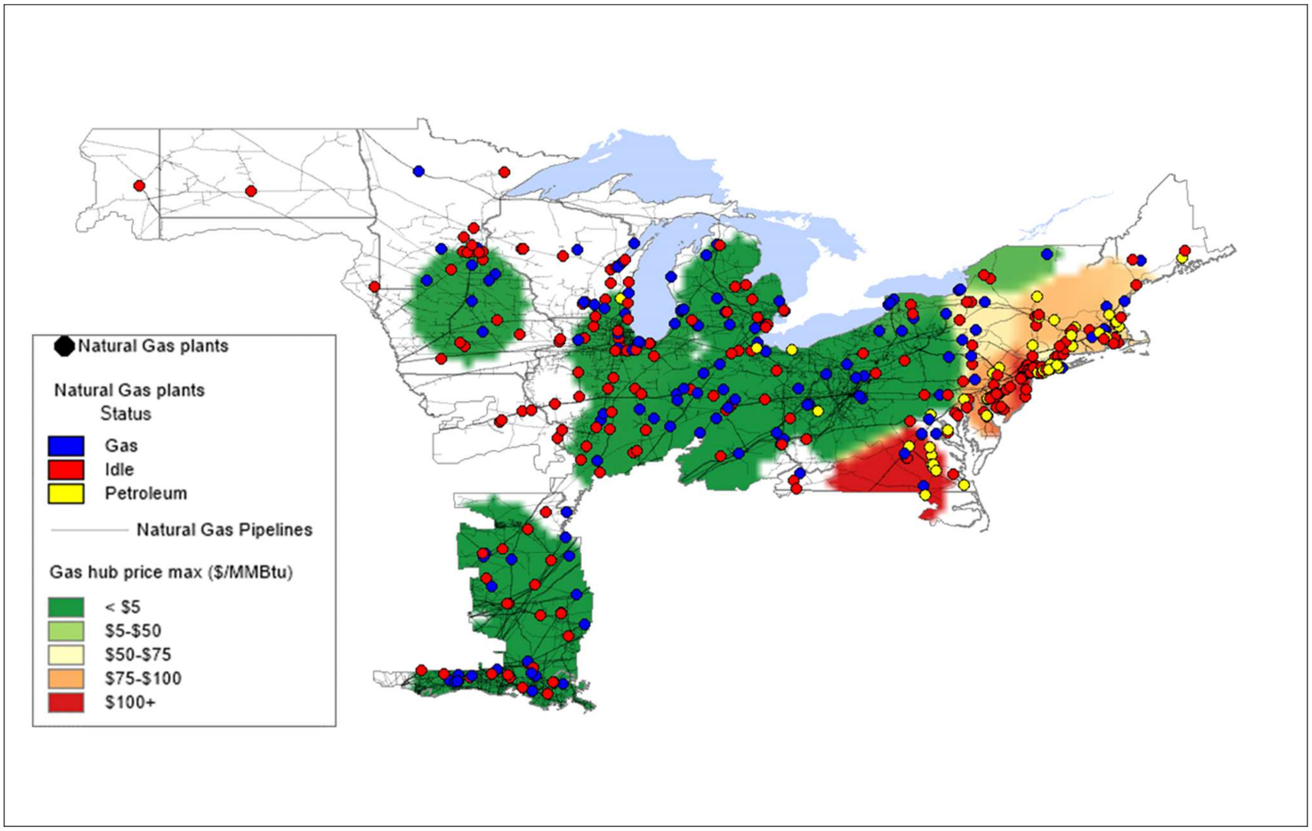
Exhibit ES-2. Regional natural gas spot prices, 2014 Polar Vortex vs. 2018 Bomb Cyclone



Source: ABB Velocity

On January 5, 2018—the peak demand day during the Bomb Cyclone, as shown in Exhibit ES-3—there were a significant number of natural gas generators that were idle in areas (the eastern portion of PJM, up through NYISO, and into ISO-NE) where there was a significant change in the spot gas hub prices due to the significantly higher demand for natural gas for heating. Many of the natural gas generators that were idle on December 24, 2017 (especially in eastern and central PJM) were generating electricity on January 5, 2018. This demand for gas, as the pipeline flow traveled north and east, raised the spot prices at the eastern hubs in PJM and hubs in NYISO and ISO-NE. Due to increased prices and pipeline constraints driven by the increased demand for gas, there was an increase in petroleum-fired generation as dual-fuel generators switched to secondary fuel in these regions, shown as yellow dots along the East Coast in Exhibit ES-3.

Exhibit ES-3. Natural gas generators on January 5, 2018

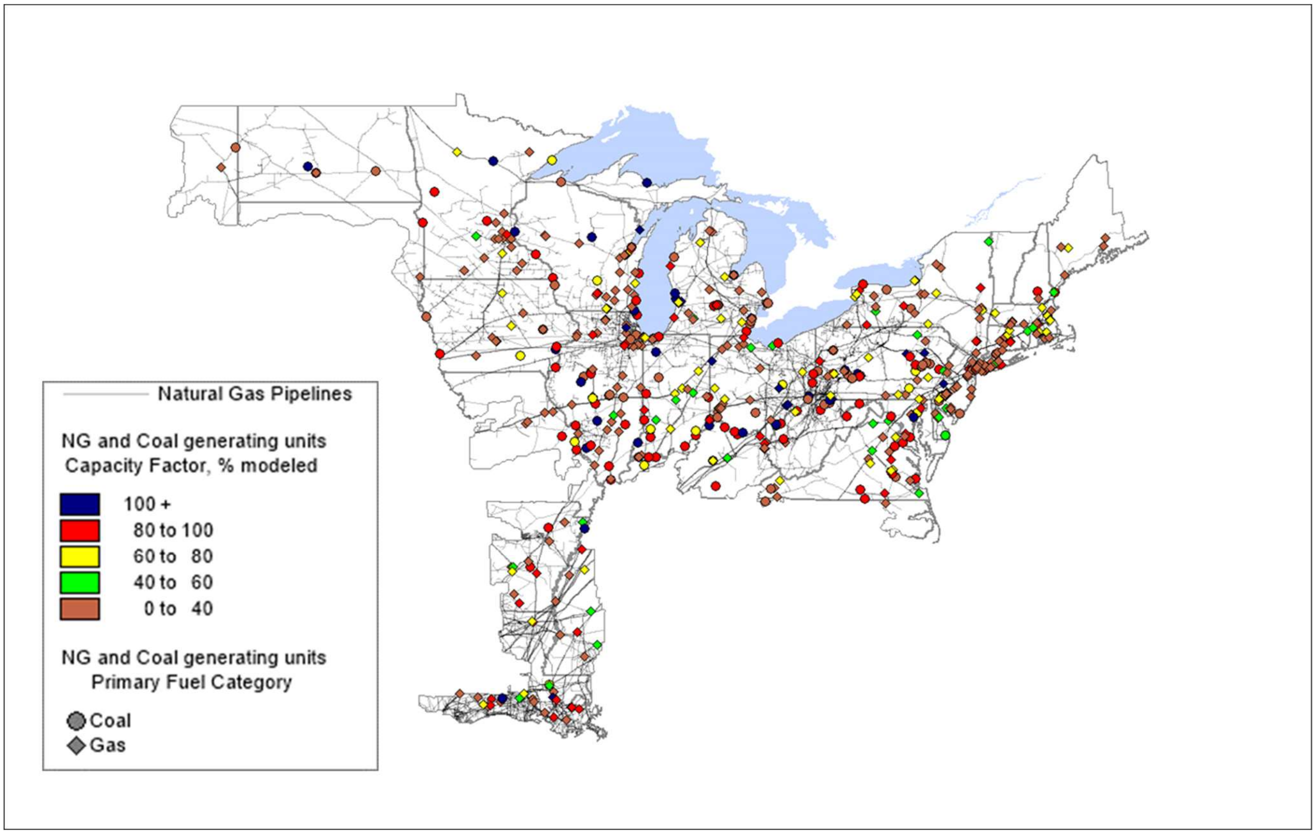


Source: ABB Velocity

Exhibit ES-4 illustrates the coal and natural gas-fired power generation capacity factors for the day of January 5, 2018. As can be seen, most of the coal-fired generation assets were operating at greater than 75 percent with many units running at 100 percent of their nameplate capacities. Additionally, many of the natural gas-fired units were operating at capacity factors greater than 75 percent. This large natural gas electricity generation demand coupled with a larger than normal residential heating demand resulted in pipeline utilization rates in excess of 100 percent in many areas of the Northeast, as well as some in the Midwest.[b]

[b] Pipeline utilization is calculated by dividing the scheduled capacity at a point by that point's operating capacity. Operating capacity is reflective of lower value than the design or maximum capacity and accounts for adjustments to a nominal set of operating conditions. This leaves the operator with headroom capacity that can be scheduled under certain circumstances, meaning that by following the calculation described above, the utilization can occasionally reflect values exceeding 100%.

Exhibit ES-4. Plant net generation and utilization factor on January 5, 2018



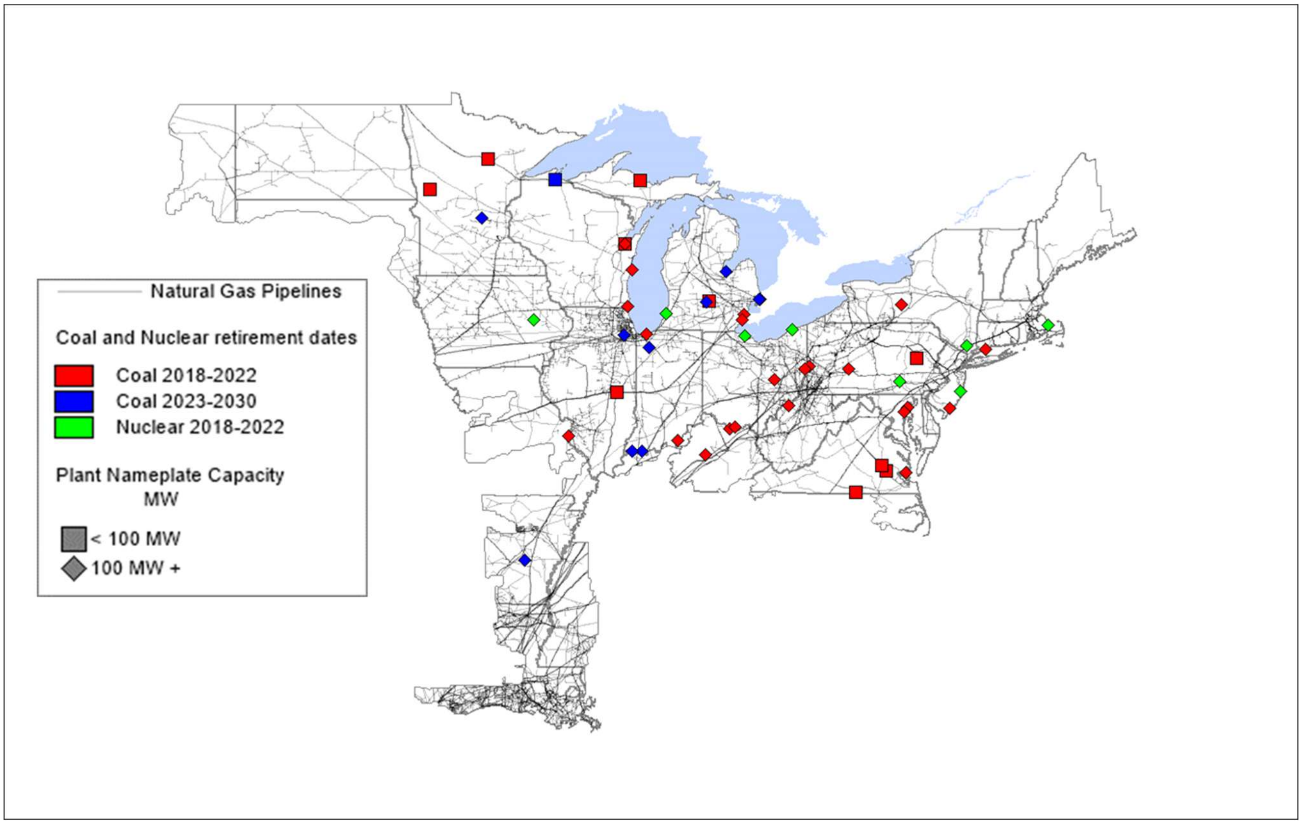
Source: ABB Velocity

The electricity supplied from coal was critical throughout the entire Bomb Cyclone, as Exhibit ES-4 shows by the capacity factors of the coal fleet during the peak demand day during the Bomb Cyclone. However, as Exhibit ES-5 shows, there are large quantities of coal and nuclear generator retirements planned over the next decade that have the potential to significantly increase the demand for natural gas.

Many of the coal retirements are planned to occur before 2022 in the MISO and PJM regions, leaving limited time to expand gas pipeline through-put or develop other gas and energy storage options. Additionally, the announced retirements of multiple nuclear-powered generators in the four regions will add an even more significant strain on natural gas, renewables, and storage to replace lost capacity. In order for the ISO/RTOs to maintain the security of power systems during high demand periods, they will likely need to increase the number of reliability must run (RMR) or dual fuel capable facilities in their regions.

Additional coal plant retirements are scheduled in MISO between 2022 and 2030, putting additional demand on natural gas supplies as the pipelines flow through MISO into PJM and up the Northeast through NYISO and ISO-NE.

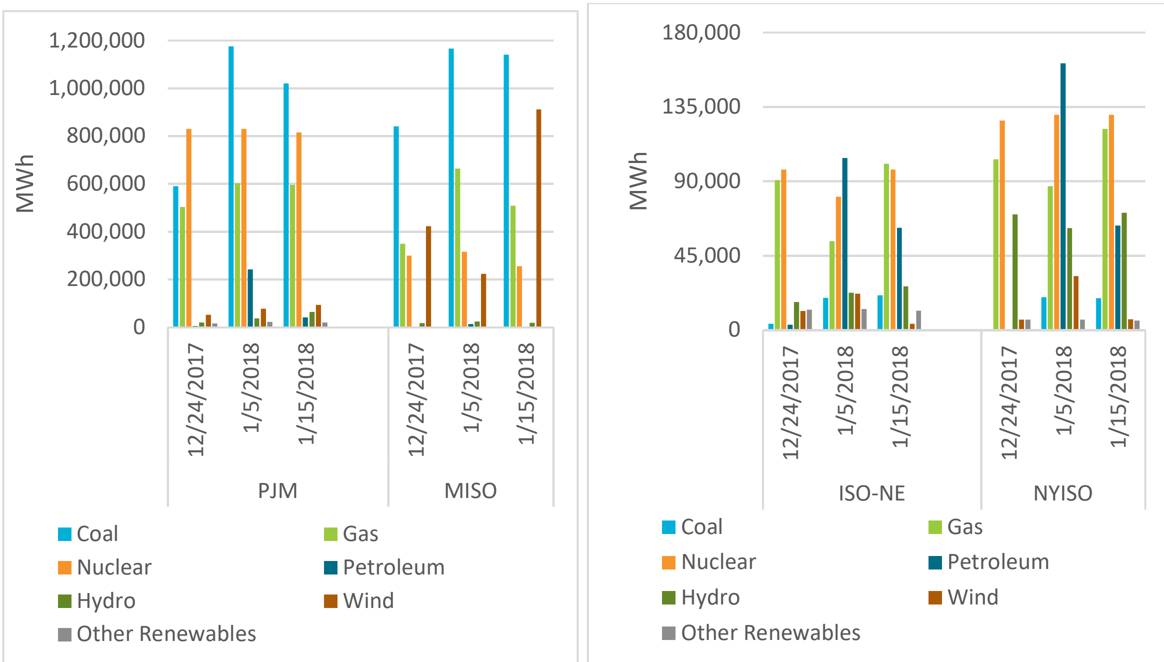
Exhibit ES-5. Announced and planned coal and nuclear retirements



Source: ABB Velocity

Exhibit ES-6 shows the generation during the peak Bomb Cyclone demand day, January 5, 2018, and periods before and after. ISO-NE and NYISO rely heavily on nuclear generation to provide baseload power in their respective regions, as does PJM. The three regions respectively contributed 800,000 mega-watt hour (MWh), 80,000 MWh, and 120,000 MWh of the power on their region's peak demand day of the Bomb Cyclone.

Exhibit ES-6. Source generation (MWh)



The four regions examined in this study have a combined 48 coal-fired units and 11 nuclear plants that plan to retire between before 2022, with a combined nameplate capacity of 24,496 megawatts (MW) that generated nearly 461,171 MWh of electricity on January 5, 2018. To replace that with natural gas-fired generation, an additional 3.1 billion standard cubic feet (scf) (3.1 trillion British thermal units (Btu)) of natural gas would be needed to flow into the four RTO/ISO regions, fueling thirty-one 630 MW natural gas combined cycle (NGCC) units. Another 106,400 MWh generated from coal on January 5, 2018, in MISO came from 12 coal-fired units that are at-risk of retiring between 2023 and 2030. This would require an additional 0.71 billion scf (0.72 trillion Btu) of natural gas, enough for another seven 630 MW NGCCs running at full output.

1 INTRODUCTION

This analysis focuses on the impact of the cold snap of late December 2017 and early January 2018, which was punctuated by a Bomb Cyclone event that impacted four regional transmission organizations (RTOs)/Independent system operators (ISOs)—ISO New England (ISO-NE), New York Independent System Operator (NYISO), PJM Interconnection (PJM), and Midcontinent Independent System Operator (MISO). All four RTOs/ISOs were impacted by the cold weather events and experienced higher than normal natural gas and electricity demand because of the cold weather. However, the differences in the electric generation mix and natural gas infrastructure in each RTO/ISO resulted in different reliability and price impacts. ISO-NE and NYISO, in particular, have limited natural gas transmission pipelines serving their regions, and high electric demand coinciding with peak demand for natural gas as heating fuel causes congestion along those pipelines and fuel substitution during the winter. MISO, in contrast, has a lower reliance on natural gas-fired power plants and a more robust natural gas infrastructure.

The operational difficulties caused by the Bomb Cyclone were anticipated by the RTOs/ISOs based on their past experiences. Before the Bomb Cyclone event, the Polar Vortex event during Winter 2013–2014 caused the highest peak demand on record. Wholesale natural gas and electricity prices increased across the four RTOs/ISOs. The Polar Vortex caused significant spikes in the price of wholesale electricity, as well as strained operations.

ISO-NE, in particular, struggled to maintain reliability during the Polar Vortex, despite the region's preparations for winter demand, which went so far as to institute special out-of-market procedures to ensure reliability, known as ISO-NE's "Winter Reliability Program." The region historically relied heavily on petroleum-fired generation but began to shift away from petroleum as a result of increasing concerns over air quality. Natural gas has largely replaced petroleum as the preferred fuel source for electric generation in ISO-NE. Under the Winter Reliability Program, ISO-NE planned to increase the use of petroleum in order to reduce its reliance on natural gas during winter months, thereby limiting the system's vulnerability to natural gas shortages. ISO-NE has largely credited the Winter Reliability Program with its ability to meet load during the Polar Vortex, although prices still spiked in that region. (3) ISO-NE continued to adjust the Winter Reliability Program from lessons learned during the Polar Vortex, and relied on the program again to maintain reliability during the Bomb Cyclone. However, the reliability came at a cost of increased SO_2 and NO_x emissions compared to the use of natural gas, or coal. For comparison, had the three coal-fired units at Brayton Point power plant[c], which had closed in mid-2017, been in operation at the same level they were during the peak of the 2015 Polar Vortex, approximately 350 tons of SO_2 and 120 tons of NO_x would have been avoided.[d] Respectively, a comparably sized natural gas combined cycle unit would have avoided approximately 485 tons of SO_2 and 263 tons of NO_x emissions.

PJM also responded to the Polar Vortex with efforts to improve generator performance. PJM enhanced performance incentives for generators, winterization measures, and gas-electric

[c] 1,082 MW combined winter capacity.

[d] SO_2 and NO_x are two of the six criteria pollutants as defined under the National Ambient Air Quality Standards and reported in EPA's Air Market Program Data. (26) (26)

coordination, preparations that PJM credits as reducing forced generator outages during the Bomb Cyclone However, PJM also acknowledges that more needs to be done to improve performance during periods on prolonged stress on operations, including giving continued attention to fuel security. (4)

Neither NYISO nor MISO made significant changes to their market rules after the Polar Vortex. MISO has a robust pipeline infrastructure as well as a lower reliance on natural gas-fired generation than NYISO and ISO-NE, and it reported following the Polar Vortex that overall the system performed well under stress.

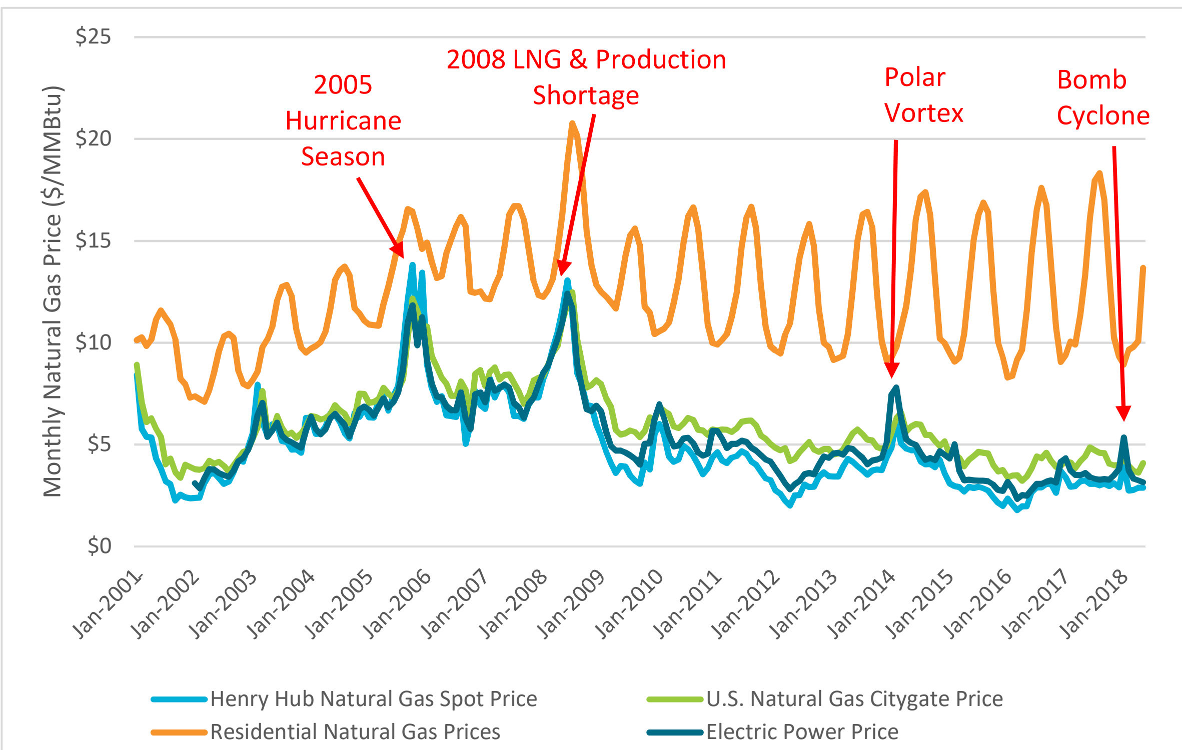
This report explores the performance of these four RTOs/ISOs during the Bomb Cyclone, with some comparison to performance during the Polar Vortex, to provide a picture of how well the RTOs/ISOs are managing their ability to maintain reliability and stable electricity prices under periods of operational stress. Section 2 of this report compares historical natural gas price variability with variability during the Bomb Cyclone in the four RTOs/ISOs. Section 3 analyzes the role of fuel storage and fuel switching during the Bomb Cyclone. Finally, Section 4 reviews electricity demand and analyzes the generation mix and performance of different types of generation during the Bomb Cyclone.

2 Natural Gas Price Variability

2.1 Historical Natural Gas Price Variability

Exhibit 2-1 shows the average monthly natural gas spot market prices at several different points in the gas distribution system from January 2001 to January 2018. This exhibit shows that, typically, citygate and electrical generation natural gas prices mirror the Henry Hub price with those prices being marginally higher because of transportation costs. During the polar vortex and bomb cyclone, residential prices are lower, even though spot and citygate prices increased. In general, when commodity prices are highest (in winter) residential prices are not. Residential prices typically increase over summer months, according to EIA data, because fixed cost components of residential tariffs are recovered from fewer quantities. Further, the fixed cost components are larger than commodity costs that are typically hedged by local distribution companies (LDCs). The price the residential customer pays is then incrementally higher due to the operating and delivery costs of the LDCs. Because of the compounding of costs, pipeline firm service requirements, and the cost inefficiencies of last mile problem[e], the seasonal price variation for residential customers is much more apparent.

Exhibit 2-1. Average monthly natural gas spot price[f] (5)



Source: Energy Information Administration (EIA)

[e] *Last mile problem* concerns the "short geographical segment of … delivery of products to customers located in dense areas. Last mile logistics tend to be complex and costly to providers … who deliver to these areas." (26)

[f] Prices are in nominal dollars. Residential price is the price of gas used in private dwellings, including apartments, for heating, cooking, water heating, and other household uses. Henry Hub price is the average monthly price at the Henry Hub calculated at 1030 Btu/Ft[3]. Citygate price is

Exhibit 2-1 shows the price spikes during 1) the 2005 hurricane season, 2) a period in 2008 where liquefied natural gas (LNG) imports were down 64 percent and natural gas production was insufficient to meet demands, 3) the Polar Vortex and 4) the Bomb Cyclone. (6) The largest spike in Henry Hub, citygate, and electricity power prices occurred during the 2005 hurricane season when production and delivery was essentially halted. The 2008 LNG production shortage had the greatest combined effect on prices, including residential natural gas. The Polar Vortex and Bomb Cyclone, while only producing modest spikes in Henry Hub, citygate, and electricity power prices, had a much larger impact on residential natural gas prices (20- and 10-percent respectively) as the demand for gas was exceedingly high. This is because, unlike the hurricane and LNG shortage, these events took place in the winter when demand for heating was highest.

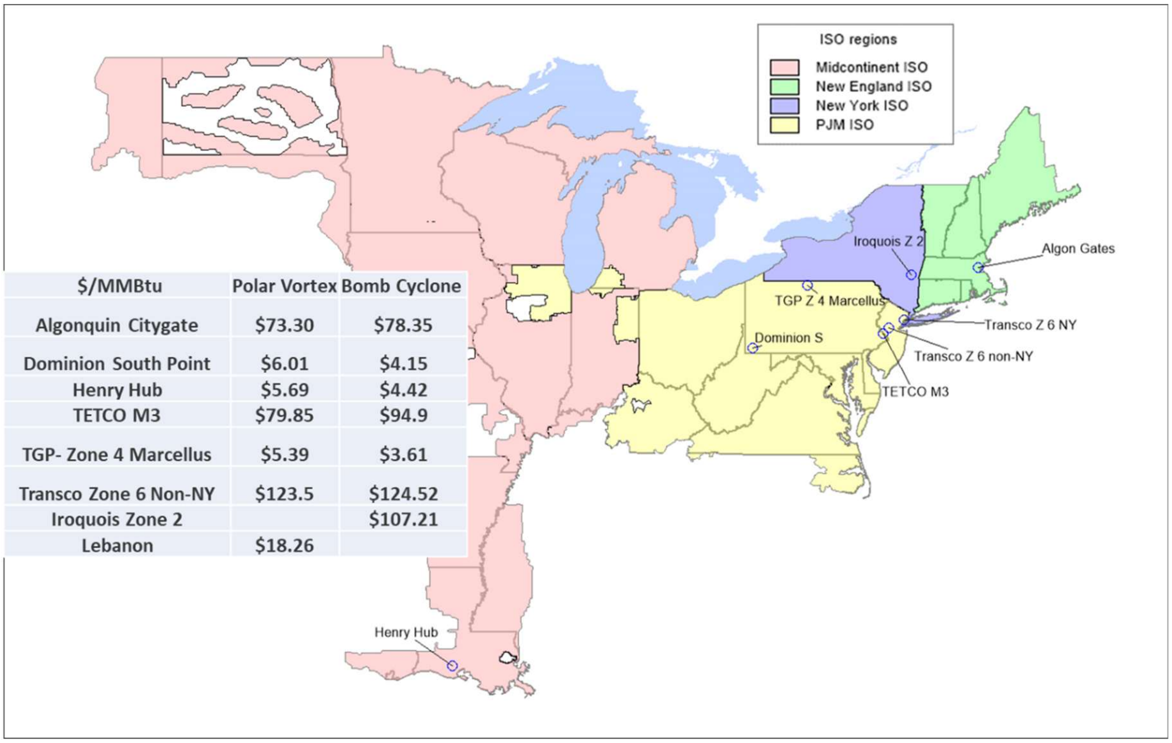
2.2 Regional and Weather-Related Natural Gas Price Variability

The price of natural gas also varies by regional natural gas distribution hub and changes in demand caused by major regional weather events. Although the national impacts of both the Polar Vortex and Bomb Cyclone can clearly be seen in Exhibit 2-1, the major price increases are more apparent when looking at regional prices.

Natural gas spot prices are determined at various transmission hubs and vary by supply and demand in the regions where they are located. Selected hubs in the four RTOs/ISOs are shown in Exhibit 2-2 along with the maximum gas prices on January 28–29, 2014, during the peak of the Polar Vortex, and January 5, 2018, for the Bomb Cyclone. Exhibit 2-2 shows that NYISO, ISO-NE, and some regions of PJM saw spot prices increase by a factor of 10 to 20 times compared to spot prices in MISO and other regions of PJM in both events. The peak prices at the hubs were similar between events, with only TETCO M3 seeing a 20 percent increase.

the average price at a point or measuring station at which a distributing gas utility receives gas from a natural gas pipeline company or transmission system.

Exhibit 2-2. Natural gas hub prices on during Polar Vortex (2014) and Bomb Cyclone (2018)



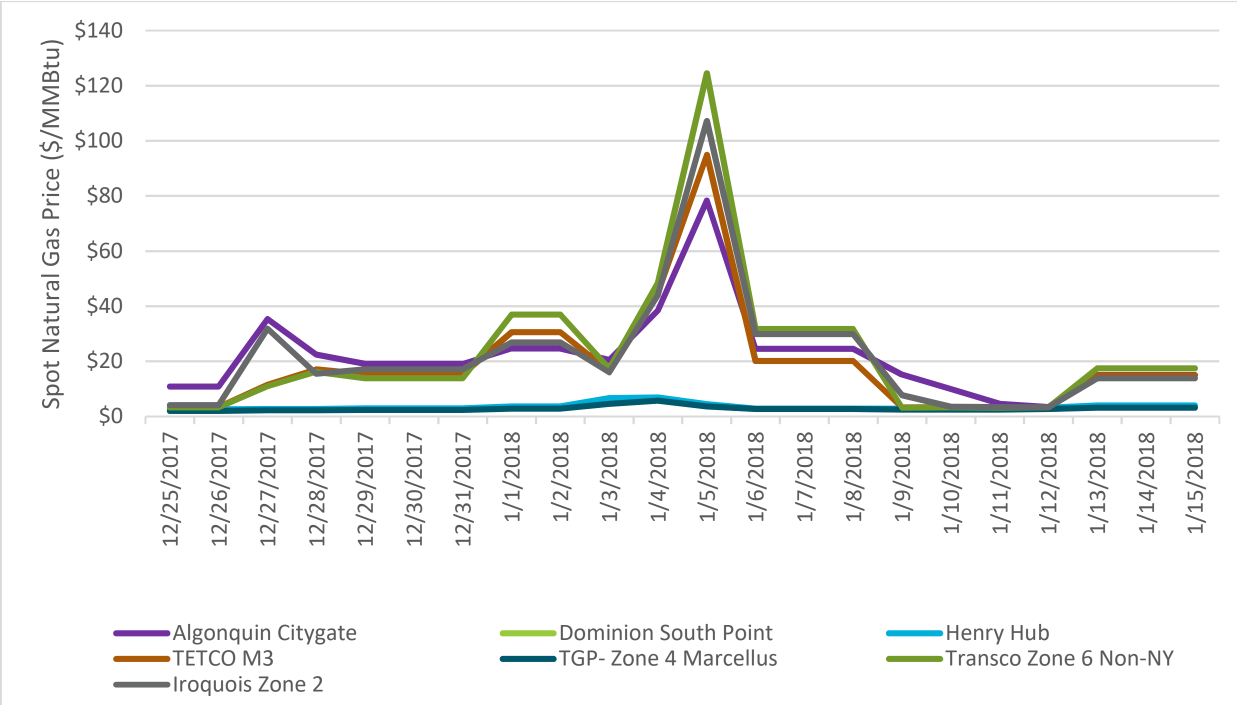
$/MMBtu	Polar Vortex	Bomb Cyclone
Algonquin Citygate	$73.30	$78.35
Dominion South Point	$6.01	$4.15
Henry Hub	$5.69	$4.42
TETCO M3	$79.85	$94.9
TGP- Zone 4 Marcellus	$5.39	$3.61
Transco Zone 6 Non-NY	$123.5	$124.52
Iroquois Zone 2		$107.21
Lebanon	$18.26	

Source: ABB Velocity

Algonquin Citygate in ISO-NE (near Boston) peaked near the same spot price during both the Bomb Cyclone ($78.35) and the Polar Vortex ($78.64). However, Algonquin Citygate's spot price was far below those in PJM in the New Jersey/New York corridor (Transco Zone 6 NY, Transco Zone 6 Non-NY, and TETCO M3) and NYISO (Iroquois Zone 2) during the Bomb Cyclone. This increased demand resulted in a large jump in the spot price of natural gas at some regional hubs.

Exhibit 2-3 and Exhibit 2-4 show the dramatic spot price increase during the height of the Bomb Cyclone and Polar Vortex, when localized areas were beginning to experience natural gas availability issues. During the Bomb Cyclone, the price spikes around January 5, 2018, are clearly localized. As Exhibit 2-3 shows, there were large spot price increases along the East Coast. Transco Zone 6, Non-NY (which peaked at $124.52/MMBtu), Iroquois Zone 2, and TETCO M3 all peaked at over $90/MMBtu.

Exhibit 2-3. Enerfax daily spot natural gas price surrounding the Bomb Cyclone

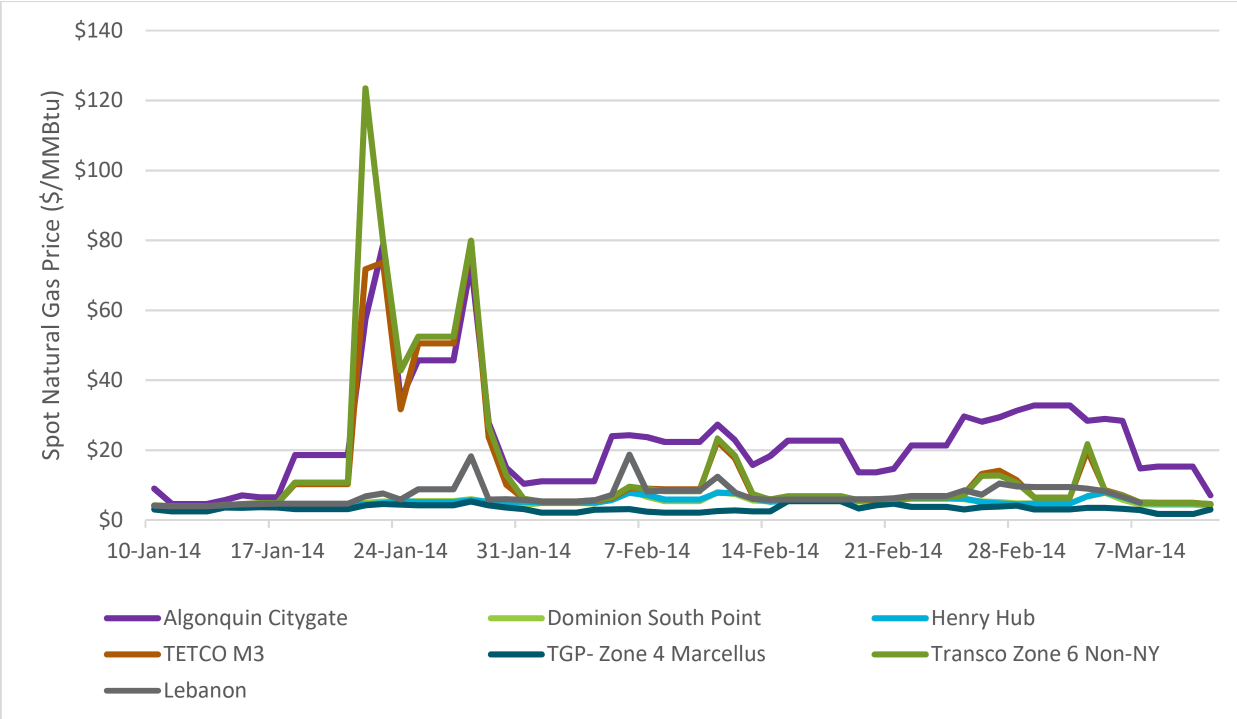


Source: ABB Velocity, S&P Global

The spot prices at Dominion South Point remained very close to Henry Hub prices throughout both events, showing that there was ample gas available through that hub. Tennessee Gas Pipeline (TGPG)-Zone 4 Marcellus located in northeast Pennsylvania continued to have low spot prices during the Bomb Cyclone, signifying that they had sufficient supply. The same can be seen for Lebanon in Exhibit 2-4 during the Polar Vortex, although Lebanon is in southwest Ohio.

As Exhibit 2-4 shows the Algonquin Citygate, TETCO M3 and Transco Zone 6 Non-NY prices remained elevated for nearly one month after the Polar Vortex.

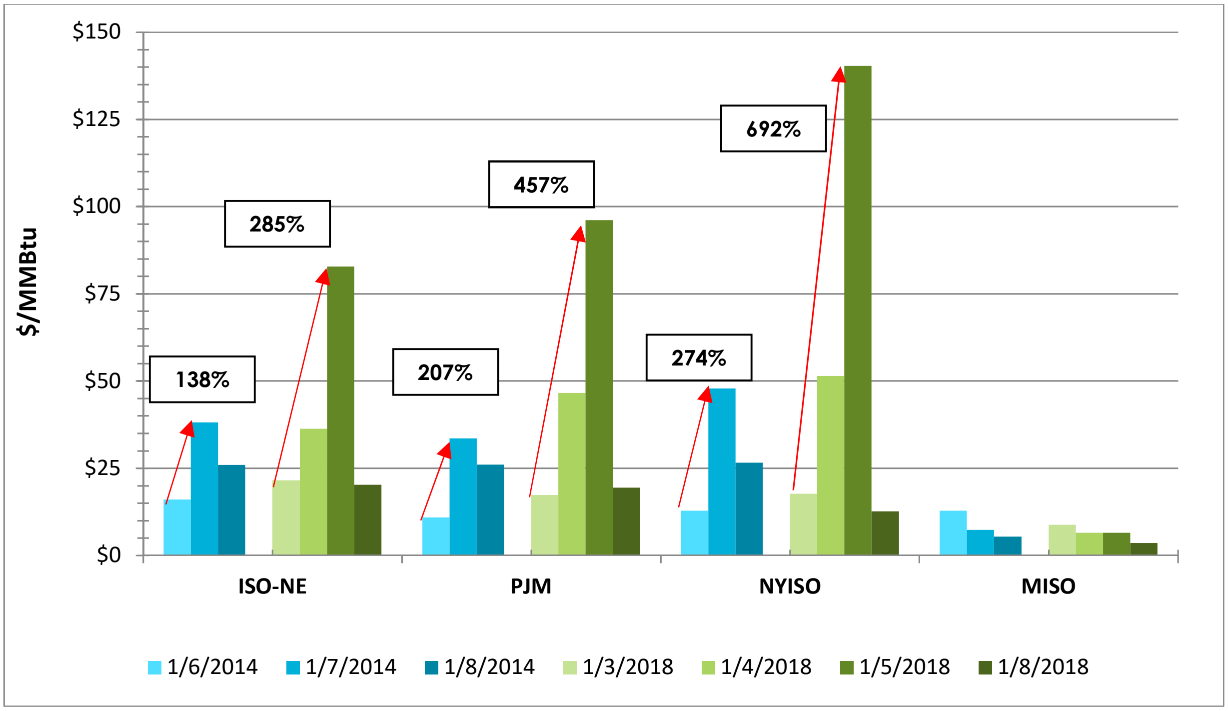
Exhibit 2-4. Enerfax daily spot natural gas price surrounding the Polar Vortex



Source: ABB Velocity, S&P Global

A comparison of the impact of these extreme weather events on the four RTOs/ISOs is also shown in Exhibit 2-5, with the first set of three bars of each ISO representing the prices during the Polar Vortex, and the second set representing the Bomb Cyclone prices. While the Polar Vortex had a significant impact on spot gas prices, the most severe impacts were only felt on one day, even as some spot prices remained elevated for a month due to a lack of infrastructure to replenish supply. However, during the Bomb Cyclone, the spot gas prices increased significantly more over a two-day period, with NYISO seeing an almost 700 percent increase during the Bomb Cyclone, compared to a still significant 274 percent increase during the Polar Vortex. ISO-NE and PJM also saw significantly higher spot gas prices during a two-day stretch during the Bomb Cyclone compared to the single-day spike during the Polar Vortex. By comparison, MISO had very little change in spot natural gas prices due to the extensive network of pipelines in the region.

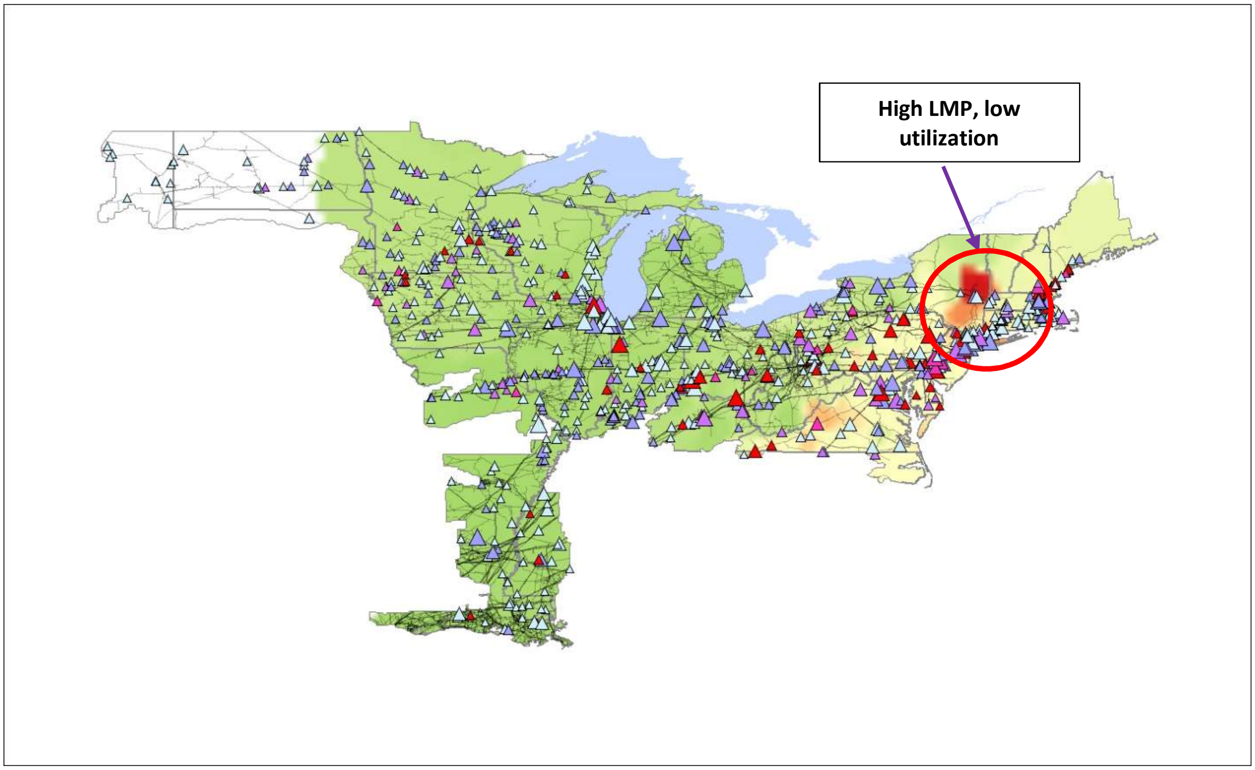
Exhibit 2-5. Regional natural gas spot prices, 2014 Polar Vortex vs. 2018 Bomb Cyclone



Source: ABB Velocity

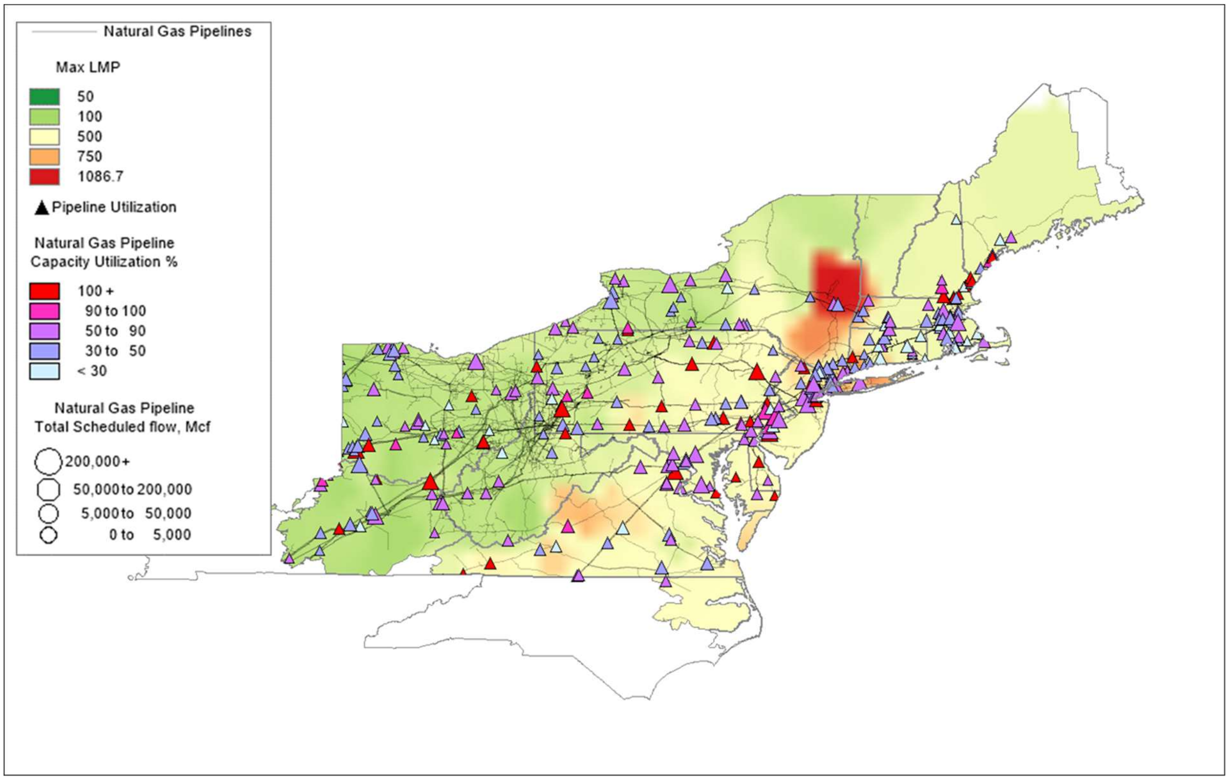
These price spikes were reflective of pipeline utilization rates in excess of 100 percent in many areas of the Northeast, as well as scattered throughout the Midwest, as shown in Exhibit 2-6, a heat map of the locational marginal price (LMP) overlaid with natural gas pipeline utilization. Higher pipeline utilization corresponds to locations with higher LMPs, especially in the pipeline-constrained regions along the eastern coast where there is modest nuclear generation and little coal-fired generation. In MISO, even though some pipelines experienced 100 percent utilization, LMPs remained low. Rather than relying on limited pipelines to deliver natural gas to produce electricity, MISO had access to other pipelines with lower utilization as well as a greater number of coal-firing resources and significant nuclear power resources. The correlation between high pipeline utilization and high LMP is concentrated in regions with a natural gas heavy generation resource mix, and constrained pipeline throughput, specifically in the Northeast. Exhibit 2-7 expands Exhibit 2-6, highlighting the Northeast. Of note is an area in the New York/New England region with a very high LMP and a very low pipeline utilization. The low utilization is possibly due to exceedingly high upstream demand and pipeline constraints due to over-utilization. This area in New York is also known to have high electricity congestion. (7)

Exhibit 2-6. Pipeline utilization on January 5, 2018



Source: ABB Velocity

Exhibit 2-7. Pipeline utilization on January 5, 2018 – expanded Northeast view



3 Role of Fuel Storage and Fuel Switching During Bomb Cyclone

Fuel storage and fuel switching are important components of reliability and resiliency for both the natural gas delivery system and the bulk electric system (BES). Storing natural gas underground and in LNG facilities improves the natural gas delivery system's ability to provide during periods of high demand. Coal is stored locally on the generator's plant site or the generator may be located adjacent to a coal mine to ensure its availability to fuel the plant at all times. Petroleum and dual fuel unit operators often store liquid fuels on-site to cover short duration periods of operation. Nuclear energy does not have the fuel supply issues that conventional energy producers have, as the reactor is charged to run for long periods. Energy can also be stored through pumped hydro and batteries, and rapidly released to the electric grid to meet peak demand.

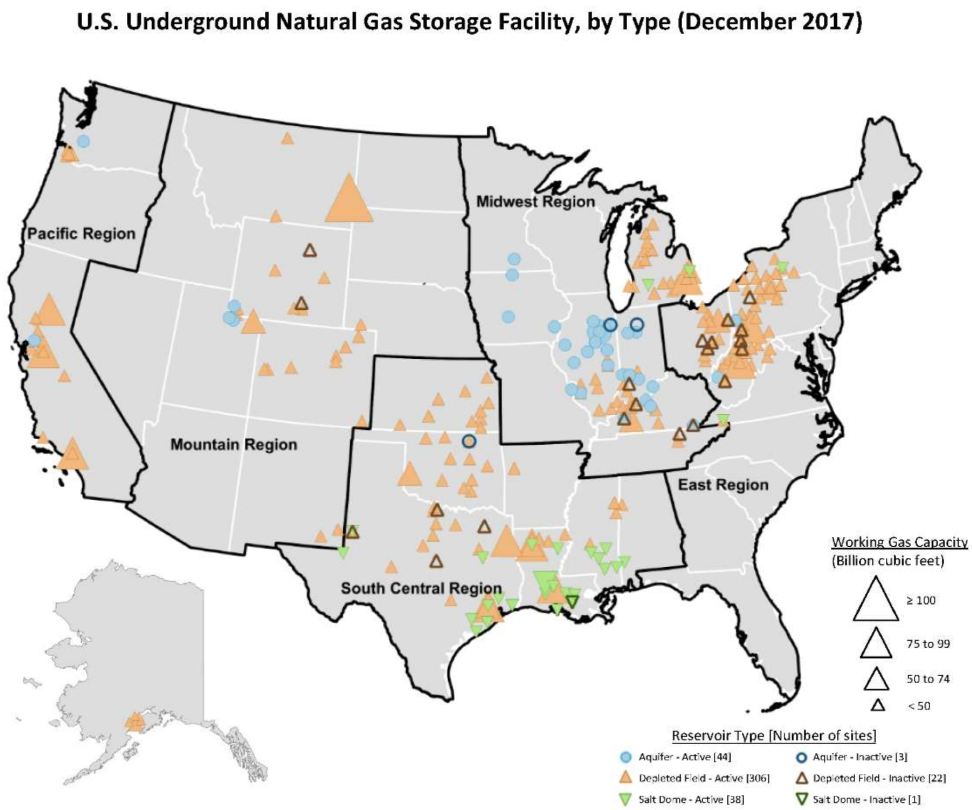
Fuel switching is critical to maintain reliability and dampen price spikes when the primary fuel is unavailable or too costly for the generator to produce electricity and still recover their costs.

3.1 Underground and LNG Storage

The total working natural gas storage capacity in the United States is 4.9 trillion cubic feet (Tcf) with 3.9 Tcf of this total in depleted natural gas fields, 0.4 Tcf in underground saline aquifers, and 0.5 Tcf in salt domes. (8) Natural gas is injected and withdrawn from these facilities on a cyclic basis based on seasonal demands with working gas storage levels reaching lows of between 0.9–2.5 Tcf by the end of the winter heating seasons to highs typically around 4.0 Tcf by the end of the fall injection season. (8) These numbers have been trending downward over the past several years as demonstrated peak storage capacity has fallen (9) and injection season volumes have decreased (10). The rate at which natural gas can be injected into, and withdrawn from, any type of storage varies by individual reservoir.

A map of the natural gas storage facilities located in ISO-NE, NYISO, PJM, and MISO (Exhibit 3-1) shows that there are significant storage facilities, mostly comprises depleted reservoirs located in the Appalachian region. There are also dense patches of storage facilities in the upper Peninsula in Michigan, through Illinois and Iowa, and along the Gulf of Mexico. Fortunately, the Appalachia and Gulf regions are also where a great deal of natural gas is being produced. There are very few underground storage facilities located in NYISO and none in ISO-NE, which also make up the greatest pipeline-constrained regions.

Exhibit 3-1. Map of natural gas storage facilities in the U.S.



Source: EIA

The United States also has peak shaving storage in the form of above-ground LNG storage tanks at import facilities and strategic locations across the pipeline system. Of the two, LNG import facilities are larger—capable of storing between 10 and 20 billion cubic feet (Bcf) at each facility—while strategically located facilities are smaller and capable of storing up to around 5 Bcf. (11) (12) These storage facilities normally operate on a demand cycle basis, filling when demand is low and releasing when demand is high. Both LNG storage mechanisms are designed to contain about 10 days' worth of gas at their maximum delivery rate. LNG storage enables an uninterrupted supply of natural gas in areas where pipeline capacity limitations and weather conditions may cause supply and demand separation. Exhibit 3-2 shows the location of pipeline-connected LNG storage facilities. As is expected, the highest concentration of these facilities is in pipeline capacity-constrained New England, with the largest number of in-service LNG facilities located in Massachusetts (Exhibit 3-3), where they can provide the most impact by primarily providing fuel for peak shaving facilities. This ride-through capacity is a critical asset to New England since gas travels about 25 miles per hour (mph) in pipelines, meaning that it may take a matter of hours, to days, for gas from extra-regional storage to reach demand centers along the northeastern coast, depending on regional demand. (13)

Exhibit 3-2. Liquefied natural gas plants connected to natural gas pipeline systems (14)

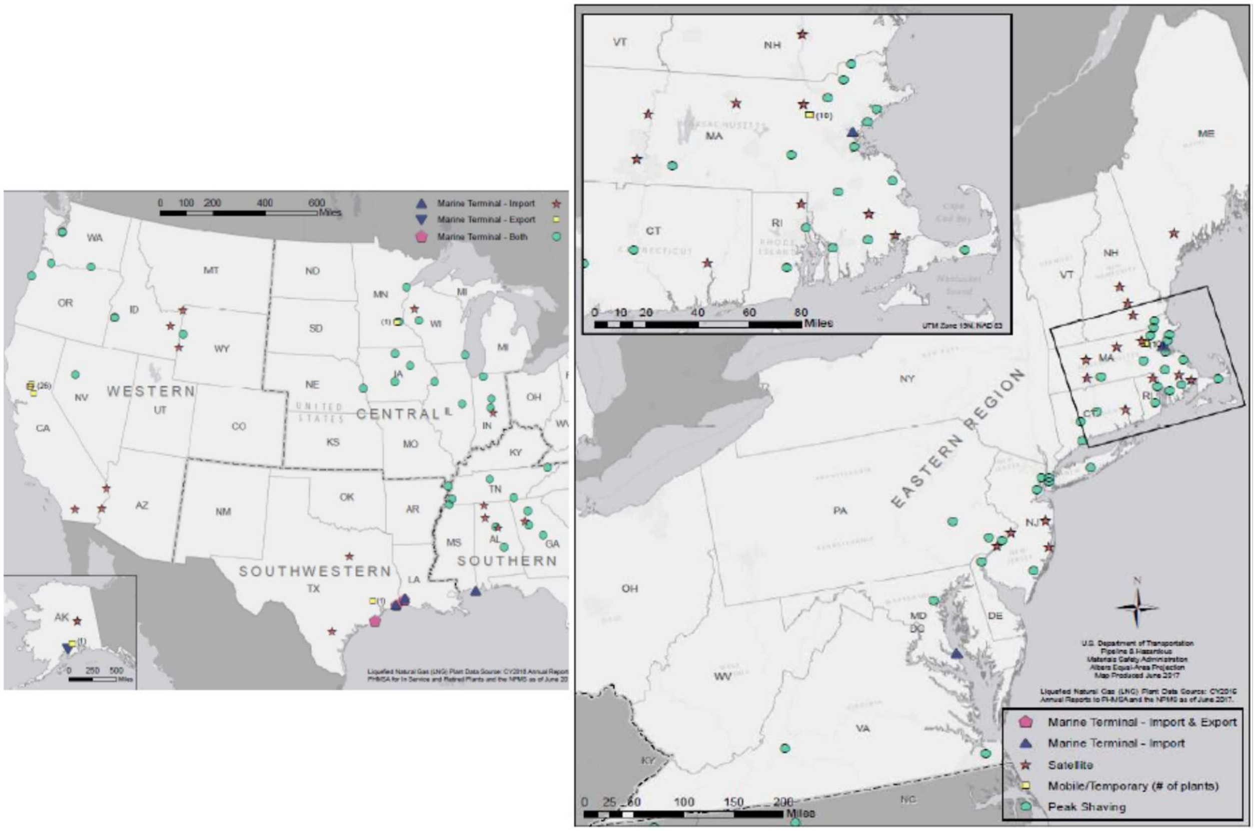
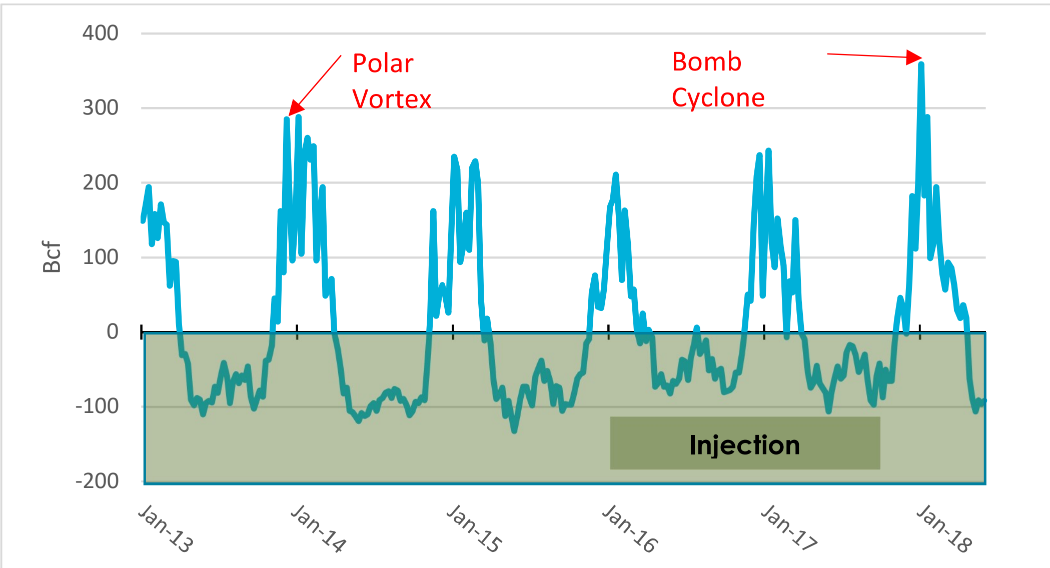


Exhibit 3-3. In-service LNG facilities (15)

State	No. of LNG Facilities	Total Capacity (MMcf)	LNG Source Truck/Ship/Liquefaction	Type of Facility Base Load/Peak Shaving
CT	3	325	0/0/3	0/3
DE	1	50	0/0/1	0/1
IL	1	300	0/0/1	0/1
IN	2	430	0/0/2	0/2
MA	14	1,612	12/1/1	1/13
MD	2	2,112	1	1/1
NJ	3	540	1/0/2	0/3
NY	3	640	0/0/3	0/3
PA	4	244	0/0/4	1/3
RI	2	174	2/0/0	0/2
VA	2	150	0/0/2	0/2

Gas withdrawn from storage during the Bomb Cyclone reached an all-time high of 359 Bcf, shown in Exhibit 3-4, 25 percent higher than the previous record set for the week ending January 10, 2014, just prior to the Polar Vortex. Consequently, electricity prices during this period also escalated, to be eventually borne by consumers. While withdrawal from underground storage was high, there was still ample working gas remaining in underground storage[g]; however, these volumes were stranded from providing relief to gas constraints in the Northeast by the physical deliverability limitations of the storage facilities. [h]

Exhibit 3-4. Natural gas withdrawn from storage by week (8)



3.2 Energy Storage

Exhibit 3-5 shows the energy storage facilities located within the four RTOs/ISOs. Energy storage facilities, such as pumped hydro and batteries can rapidly release electric power onto the grid, providing a valuable peaking resource. Both batteries and pumped hydro can rapidly release large amounts of power, but batteries can only provide power for short periods of time. Larger pumped hydro facilities can provide power for 20 hours.

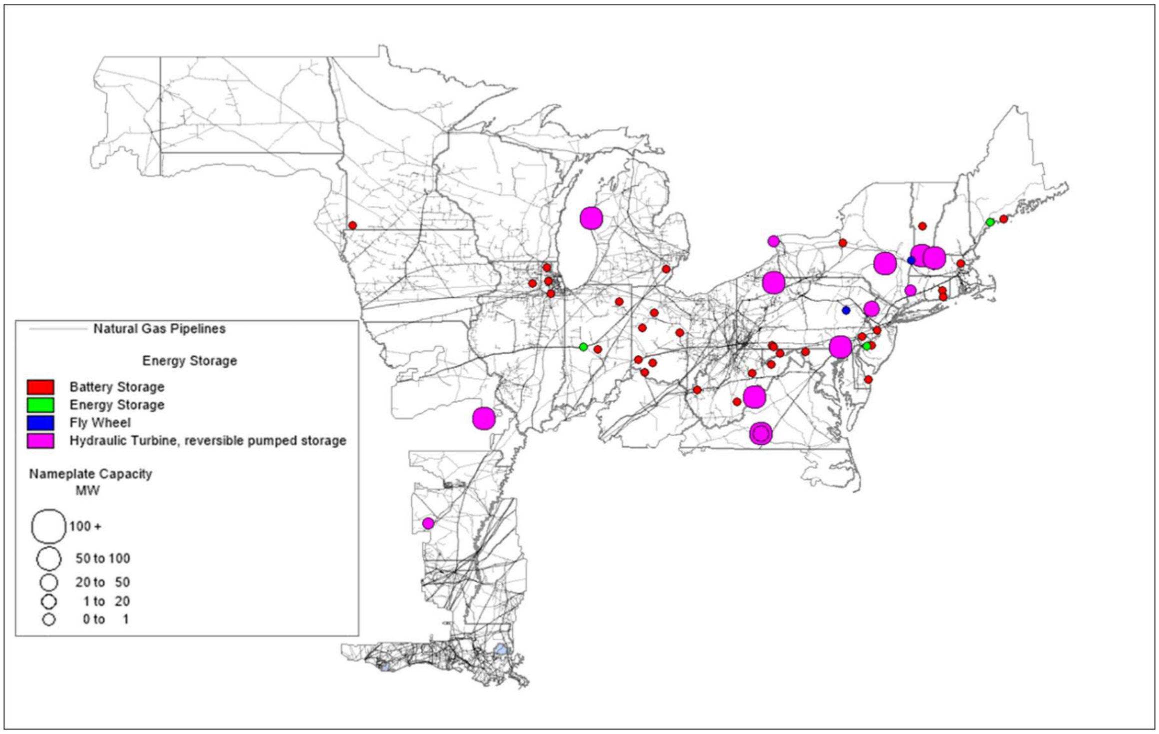
Large pumped hydro facilities are spread across all four RTOs/ISOs, and can provide the most backup capacity, as almost all the pumped hydro storage facilities are capable of providing 50–100 mega-watt (MW) of power or more. There are a number of fuel cell facilities along the East Coast in PJM, NYISO, and ISO-NE that can provide 1–5 MW on demand, assuming they have

[g] During the Bomb Cyclone, reported underground storage levels were 3.0 Tcf at the end of December 2017 and 2.1 Tcf at the end of January 2018.

[h] Analysis of EIA weekly underground storage data indicates that, on average, from 2005 to 2016, salt dome storage has the highest maximum daily delivery rate at just over 8 percent of the working gas volume, while aquifers and depleted fields have the ability to supply significantly less at just over 3 percent. At a maximum withdrawal rate of 8 percent per day, the U.S. underground salt dome storage facilities contain about 12 days of producible gas volume, while aquifers and depleted fields contain about 30 days of volume. Since storage facilities are operated on an economic basis, they, for the most part, do not operate at their maximum withdrawal rates. (8)

access to natural gas, but for the sake of this report, fuel cells are not being considered as storage.

Exhibit 3-5. Map of energy storage facilities in ISO-NE, NYISO, PJM, and MISO



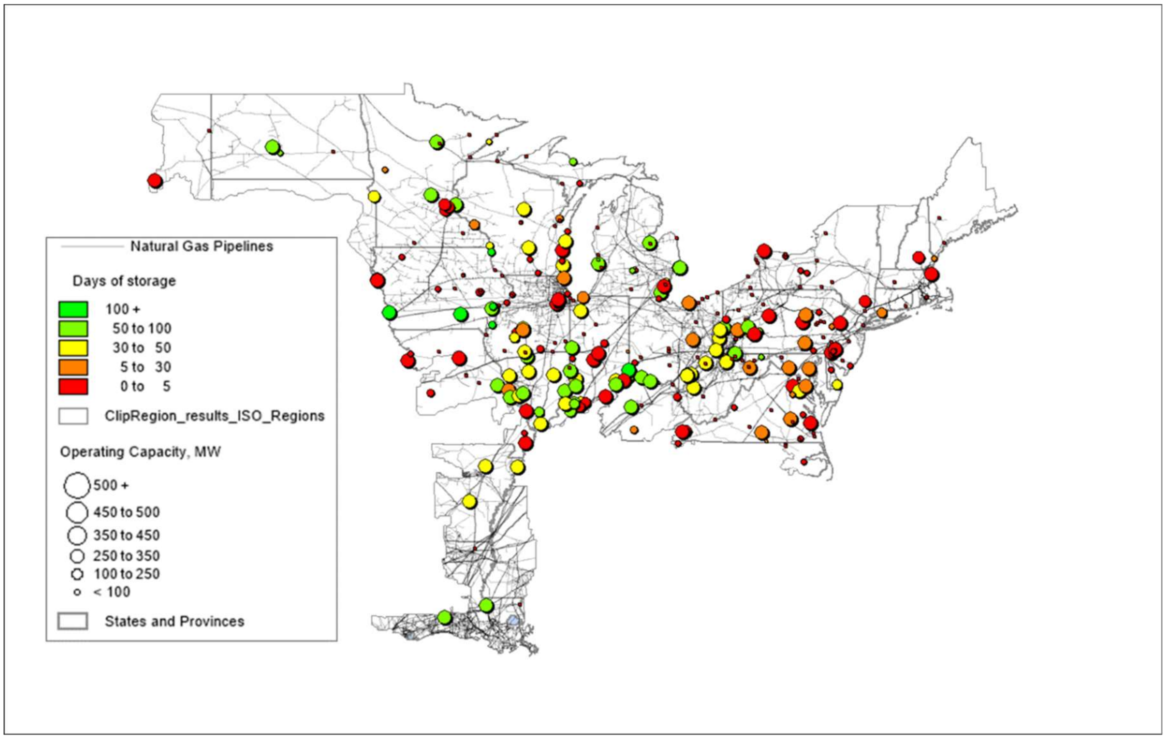
Source: ABB Velocity

Pumped hydro and LNG storage components assisted in maintaining reliability during the Bomb Cyclone in NYISO and ISO-NE, where there is a significantly higher volume of natural gas being used for electricity production compared to PJM and MISO, and where the ability to receive gas via pipelines is constrained during these high demand periods. As more coal and nuclear power generators retire, these energy storage facilities will be stressed more during cold weather events and more energy storage options may become a necessity if pipeline capacity is not built to meet the seasonal demands in the Northeast.

3.3 Coal Storage

Exhibit 3-6 shows the coal storage available at each coal-fired power plant in the region during December 2017. The storage is based on the electricity production rate during the Bomb Cyclone, where most coal plants operated at higher output levels than during their normal seasonal operation. Most of the plants with 50+ days of coal storage are located within MISO. Coal-fired power plants in the other three RTOs/ISOs were more likely to have 30 days or less of coal stockpiled. Unlike other storage options mentioned above, each coal storage pile is dedicated to a specific plant, whereas large underground natural gas storage facilities, and many LNG facilities can supply multiple plants along the pipeline network but are most commonly contractually committed to serving an LDC and firm-contracted customers first.

Exhibit 3-6. Coal storage



Source: ABB Velocity

3.4 Dual-Fuel Capabilities

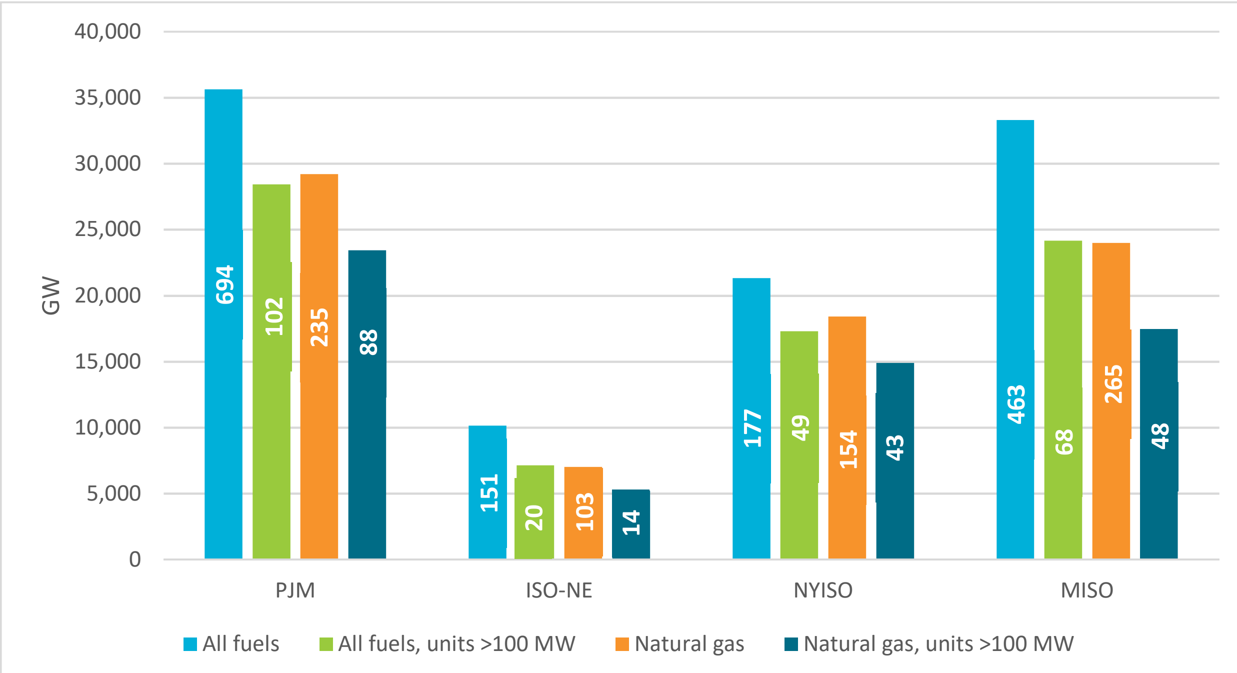
Some power plants that use natural gas as their primary fuel have the capability to operate on a secondary fuel, such as petroleum or LNG. The advantages of this dual-fuel capability are that during periods of high gas demand when natural gas may be either unavailable or expensive, plants can switch to a lower priced secondary fuel that they have stored on site.

In the United States, nearly 180 giga-watts (GW) (approximately 25 percent) of all fossil fuel generation is reported as having dual-fuel capability, while over 140 GW of that amount is reported as using natural gas as the primary fuel. (16) Regionally, most of the dual-fuel units (63 percent) are located in PJM, MISO, and SERC Reliability Corporation regions with most units in PJM and MISO being built prior to restructuring and the implementation of the electric markets.[i] Dual-fuel units (not co-firing with coal) spent less than 5 percent of their operating time on their secondary fuel in 2013, while since 2013, utilization of dual fuel capabilities operating on secondary fuel at natural gas-distillate petroleum units has increased to nearly 20 percent across the United States. (17) Exhibit 3-7 shows the number of units in PJM, MISO, NYISO, and ISO-NE that are dual-fuel capable, and their generating capacities. Units over 100 MW offer the bulk of dual-fuel capacity, both overall and for units where the primary fuel is natural gas. NYISO and ISO-NE, where natural gas pipelines are constrained, have the least amount of potential generation from dual fuels. As described later in Section 4, many

[i] In 1999 the Federal Energy Regulatory Commission issued Order 2000, which fostered participation in ISOs and RTOs.

generators switched to petroleum from gas during the Bomb Cyclone in NYISO, ISO-NE, and PJM.

Exhibit 3-7. U.S. fossil fuel-fired generating plants reporting as secondary fuel capable and capacity (16)



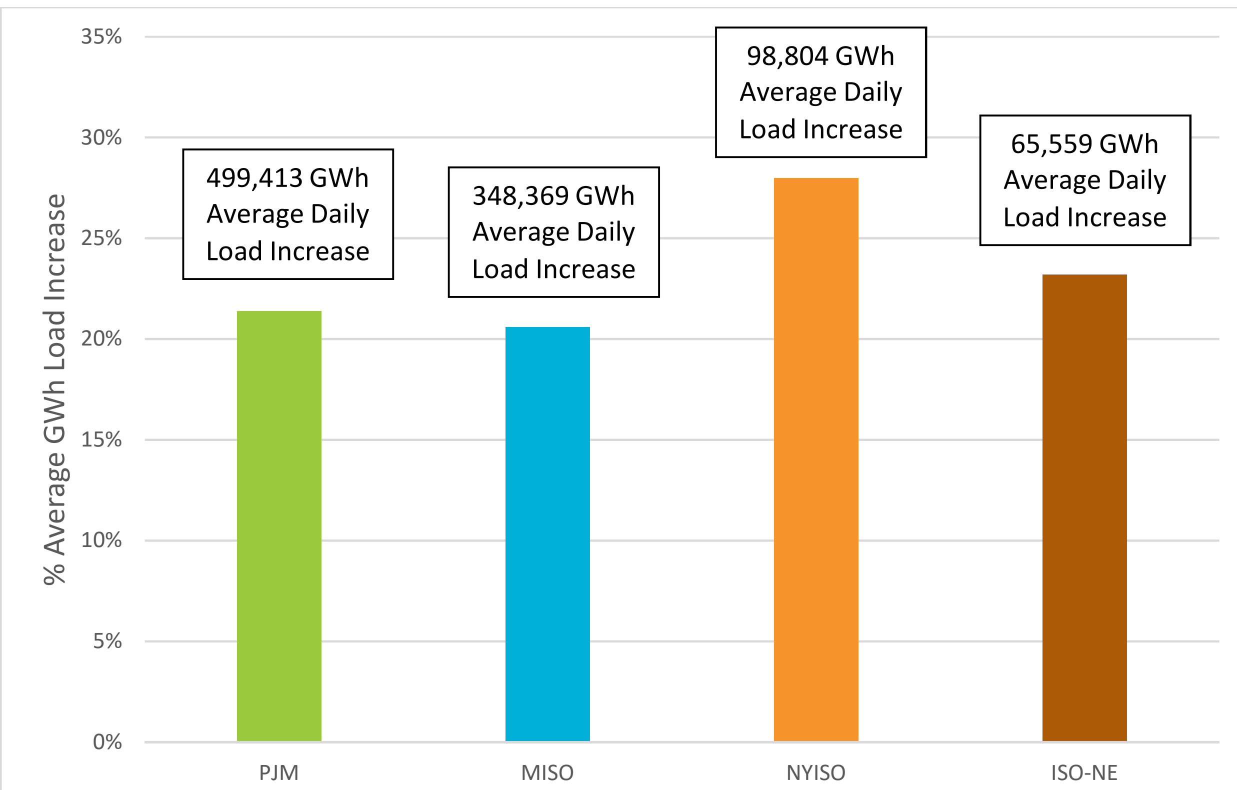
Source: ABB Velocity

4 Electricity Demand, Resource Mix, and Performance

The regional natural gas price spikes detailed in Section 2 (Exhibit 2-2) were not only directly attributed to increased gas utilization for heating during cold weather periods but were also influenced by the increased use of natural gas for electric power generation and the limitations of the existing natural gas transmission infrastructure. In MISO, which has robust natural gas infrastructure, prices were only slightly elevated, even during the highest natural gas demand during the Bomb Cyclone. In ISO-NE, eastern PJM, and NYISO, the effect on spot natural gas prices were particularly pronounced during the Bomb Cyclone.

The increased electric generation during the Bomb Cyclone is illustrated in Exhibit 4-2, with the total daily load in the preceding weeks (December 1–26, 2017) compared with the average daily load during the Bomb Cyclone. Loads increased an average of 23 percent across all ISOs examined for this study, but as much as 28 percent in NYISO.

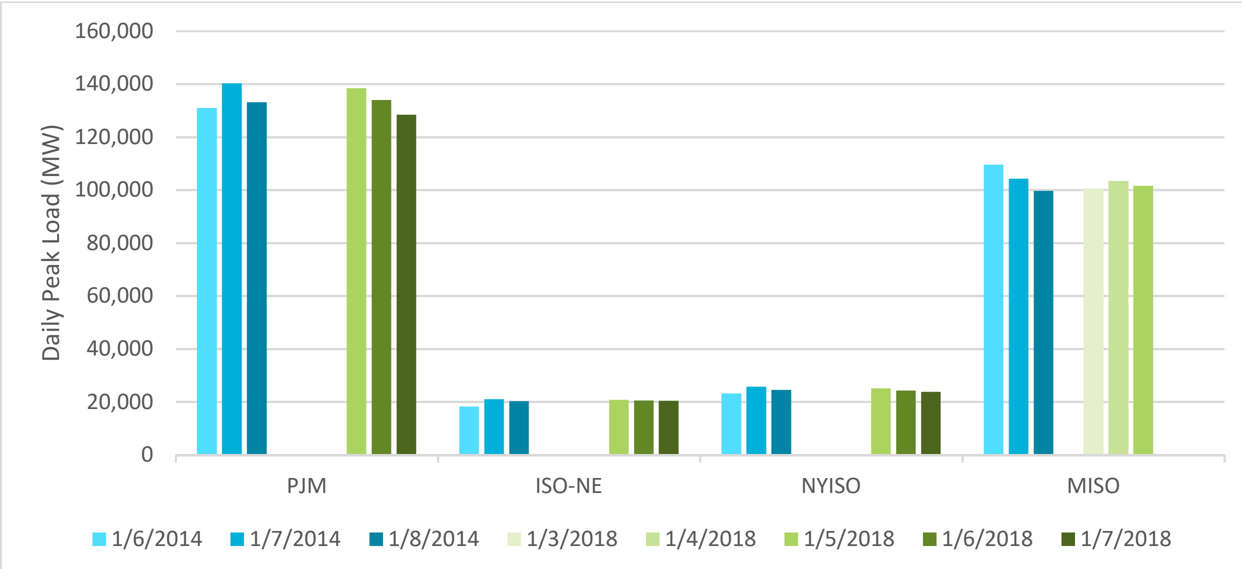
Exhibit 4-1. Increased electricity load during Bomb Cyclone



Source: ABB Velocity

To gain focus on comparisons of the Polar Vortex with the recent Bomb Cyclone, NETL compared similar three-day peak electric demand periods, January 6–8, 2014 (Polar Vortex), with January 5–7[j], 2018 (Bomb Cyclone), as shown in Exhibit 4-2, which compiles data from ABB Velocity and the individual RTO/ISO websites. As can be seen, the daily peak loads behaved similarly during both extreme weather events across each RTO/ISO.

Exhibit 4-2. Daily peak load, 2014 vs. 2018 (16) (18) (19) (20) (21)

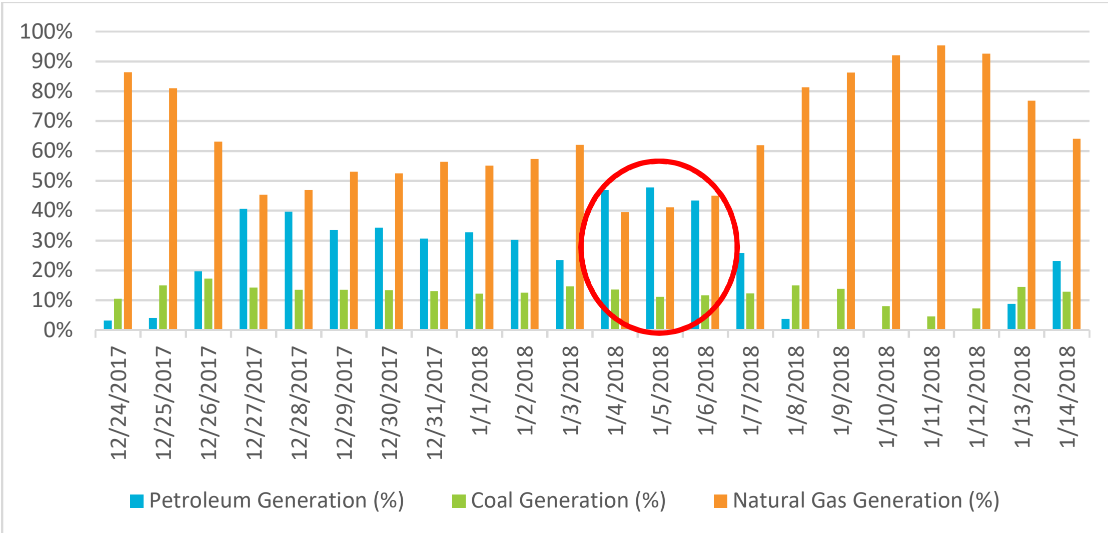


Source: ABB Velocity

To serve this increased electricity demand during periods of high natural gas prices, the generation mix in the RTOs/ISOs changed. This shift was especially pronounced in ISO-NE and NYISO, where petroleum overtook both natural gas and coal to become the primary fossil fuel generation resource dispatched during the Bomb Cyclone's peak in early January 2018. In ISO-NE, electricity generation from petroleum increased rapidly around December 26, 2017, producing around 50,000 giga-watt hours (GWh) of electricity until January 1, 2018. Generation jumped again, after a short retreat, and petroleum was the primary fuel for two of the three days at the climax of the Bomb Cyclone, January 4–6, 2018, producing nearly 47 percent of the electricity demand as shown in Exhibit 4-3. The period of January 4–6, 2018, also saw the lowest electricity production from natural gas generation throughout the Bomb Cyclone period. Natural gas produced electricity accounted for more than 80 percent of ISO-NE's generation prior to and at the end of the Bomb Cyclone. At the peak of the bomb cyclone, natural gas only accounted for 39.5 percent of generation with petroleum making up the difference. Coal resources began to ramp up generation in late December 2017 and remained a steady producer at a higher rate (Exhibit 4-1) through the duration of the Bomb Cyclone (Exhibit 4-4). Nuclear power remained consistent throughout the period, with the exception of Pilgrim 1 in ISO-NE, which was down due to an electricity infrastructure issue.

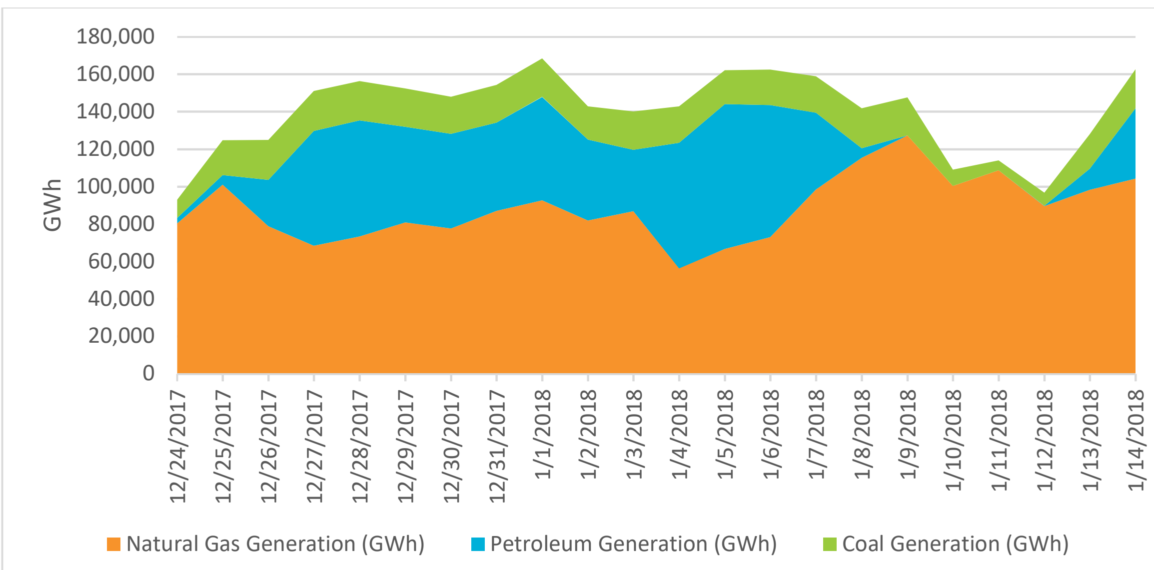
[j] MISO was examined from January 3–5, as the demand was peaking earlier in MISO than PJM, NYISO, and ISO-NE.

Exhibit 4-3. Fossil fuel generation for ISO-NE (%)



Source: ABB Velocity

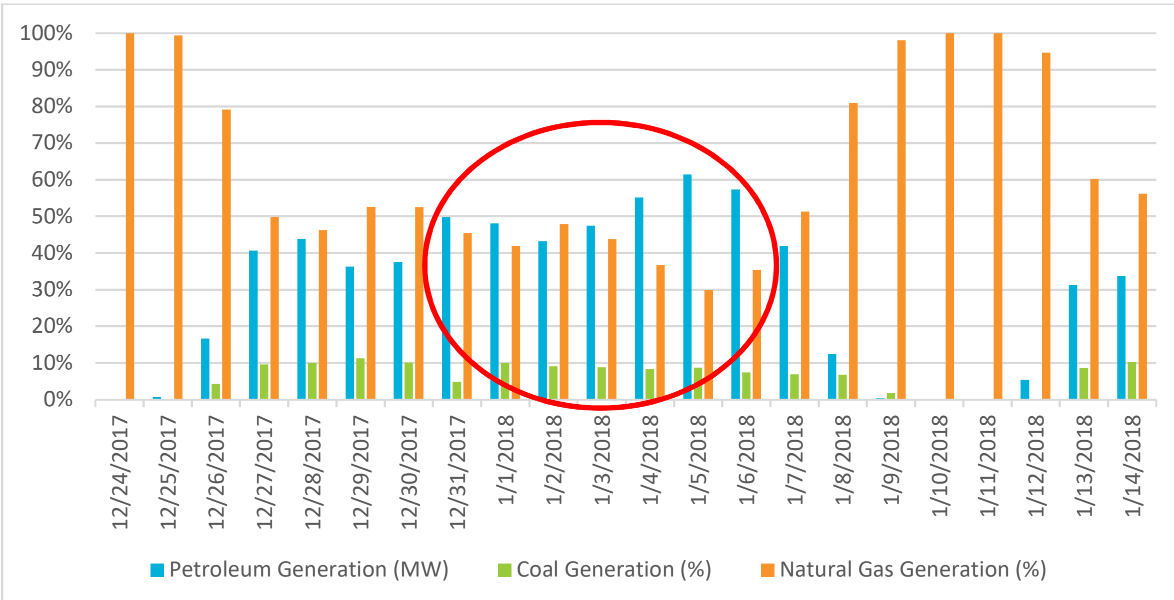
Exhibit 4-4. Fossil fuel generation for ISO-NE (GWh)



Source: ABB Velocity

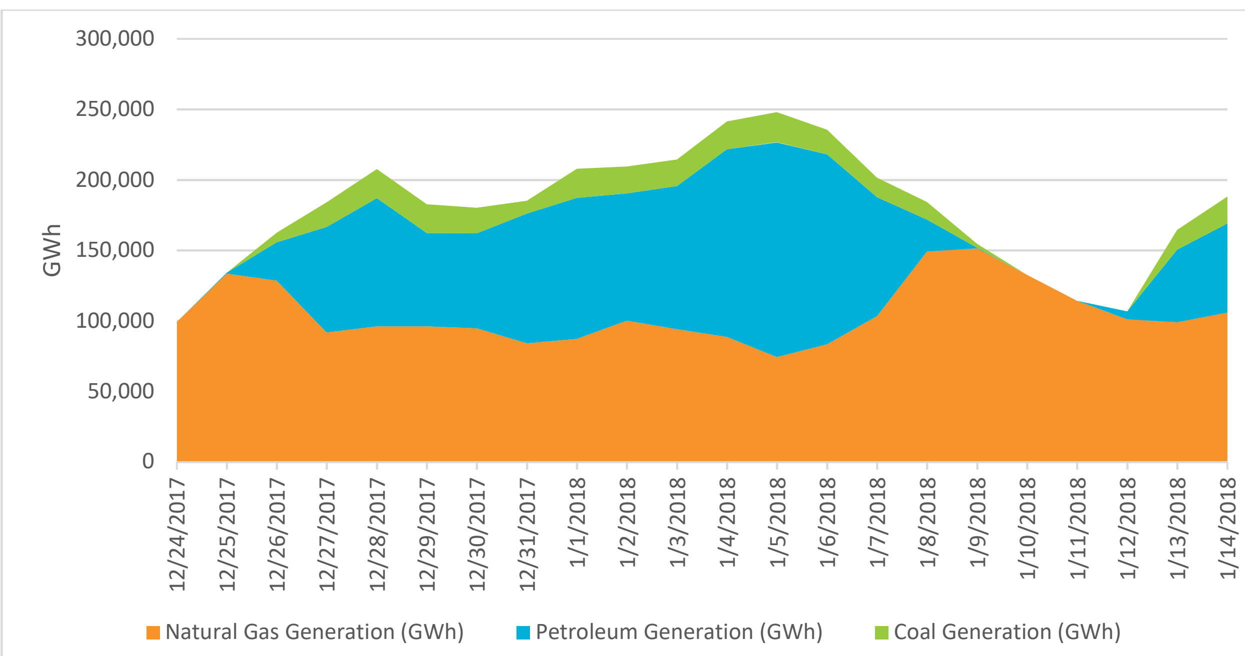
NYISO had a heavier and longer reliance on petroleum as its primary fuel, as seen in Exhibit 4-5, again, beginning around December 26, 2017, with electricity production from petroleum rising to nearly 100,000 GWh, and remaining steady through early January 2018. Petroleum became the dominant fuel source in NYISO for seven out of eight days from December 31, 2017, through January 6, 2018, peaking at nearly 140,000 GWh on January 5, doubling the output from natural gas, contributing 61 percent of the power to the region, with natural gas providing only 30 percent. Natural gas produced electricity before and after the Bomb Cyclone made up between 80 and 90 percent of the region's power. Therefore, NYISO powered the grid with one third the normal amount of gas on a percentage basis. While electricity generation from coal never made up more than 10 percent of the mix, coal, nevertheless, was a steady contributor to NYISO's supply (Exhibit 4-6). The period of high petroleum use corresponds to high LMPs and gas prices as will be seen in Exhibit 4-11.

Exhibit 4-5. Fossil fuel generation for NYISO (%)



Source: ABB Velocity

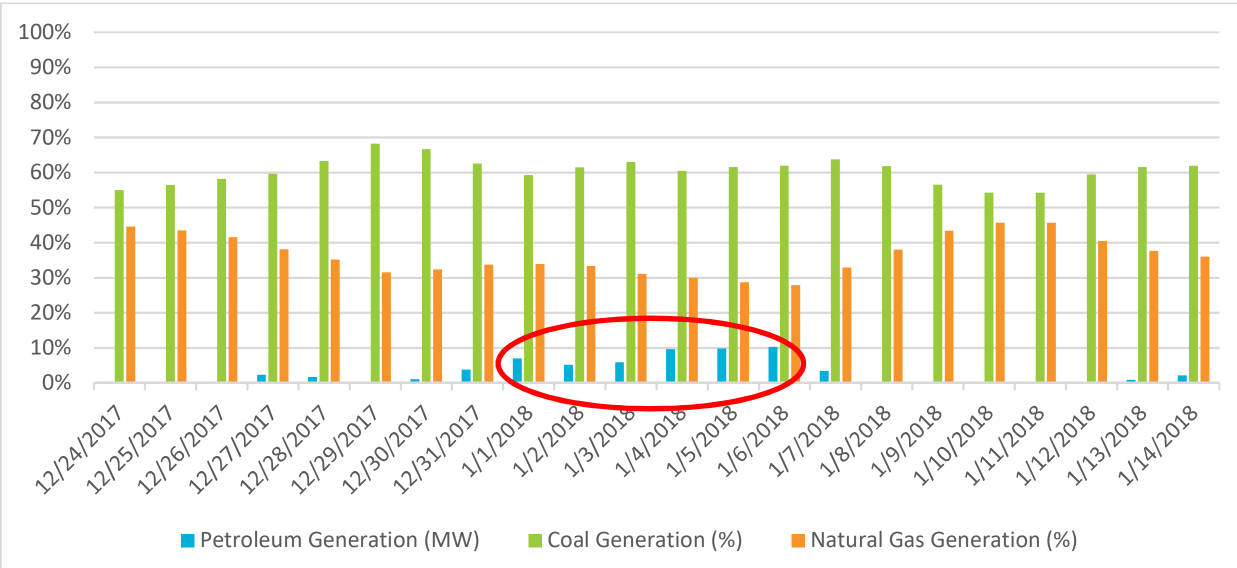
Exhibit 4-6. Fossil fuel generation for NYISO (GWh)



Source: ABB Velocity

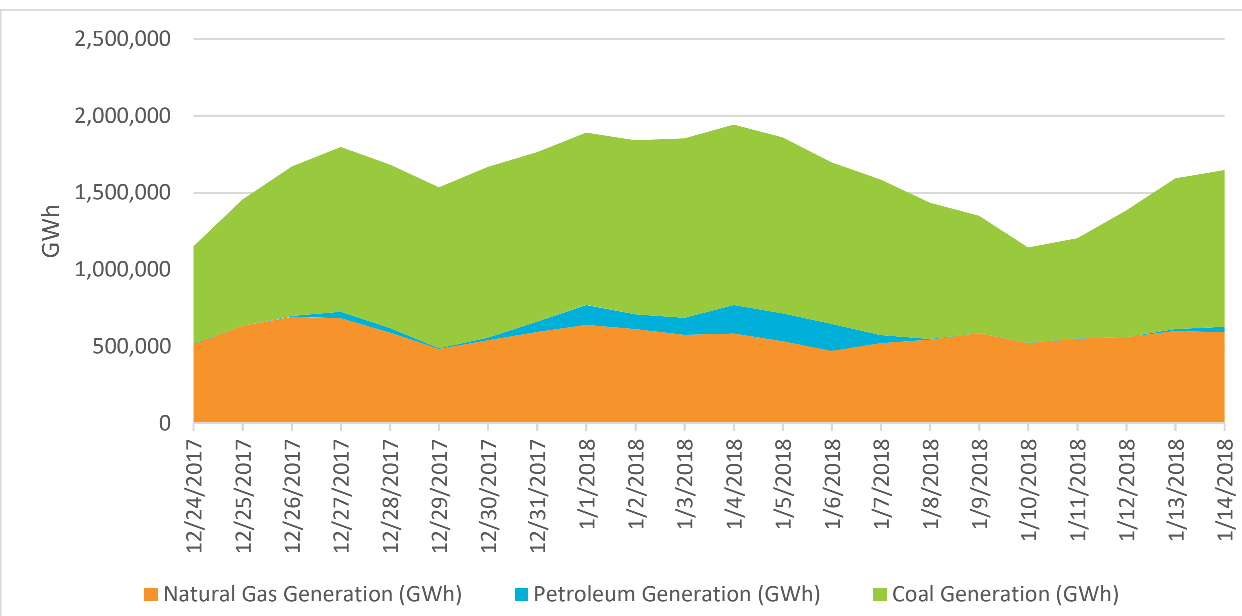
Electricity generation from coal remained steadily above 60 percent in PJM, while natural gas as an electricity generating fuel dipped by over 15 percentage points during the Bomb Cyclone (Exhibit 4-7) and was displaced by petroleum. While PJM saw a much smaller use of petroleum by percentage of generation, it still produced just over 180,000 GWh of electricity from petroleum during the peak of the Bomb Cyclone. Exhibit 4-8 shows coal's considerable contribution and the drop of gas and subsequent increase in petroleum generation.

Exhibit 4-7. Fossil fuel generation for PJM (%)



Source: ABB Velocity

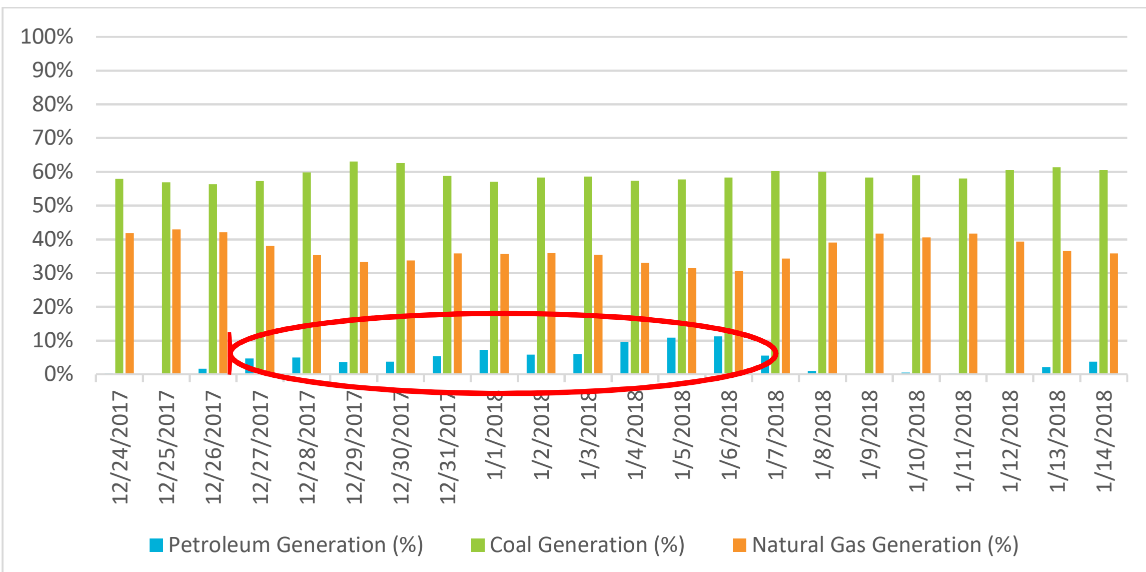
Exhibit 4-8. Fossil fuel generation for PJM (GWh)



Source: ABB Velocity

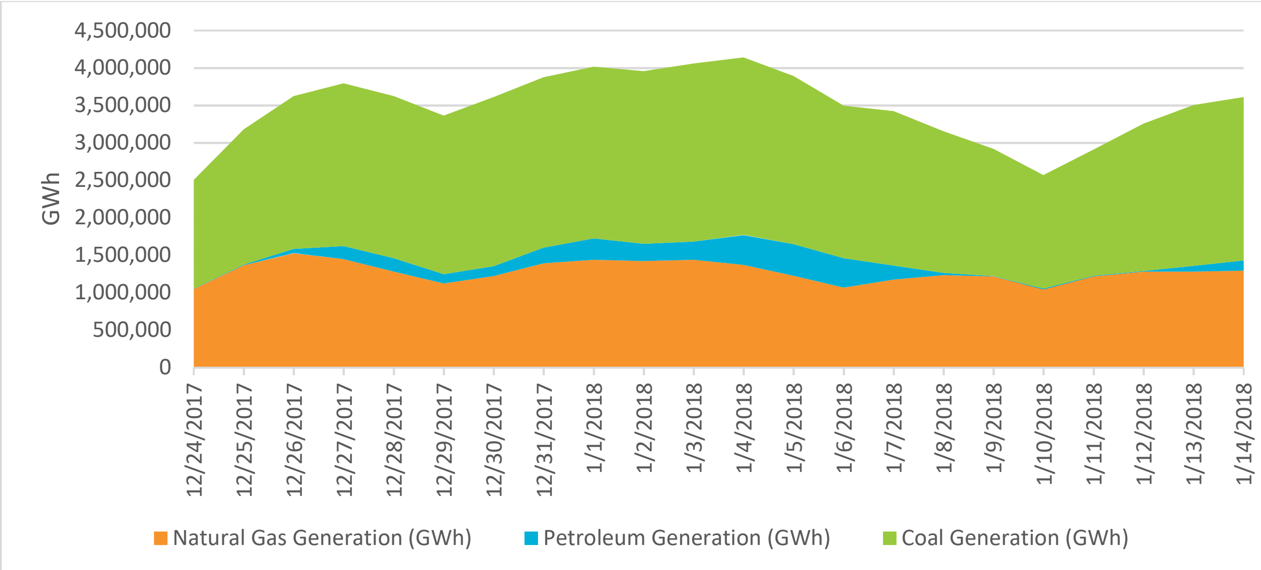
MISO, like PJM saw a much smaller use of petroleum by percentage of generation. MISO utilized petroleum to meet higher demand for two-week period prior to the Bomb Cyclone (similar to NYISO and ISO-NE) as well as a replacement for natural gas during the Bomb Cyclone period (Exhibit 4-9). Generation from natural gas cycled over the Bomb Cyclone with only a minor overall loss of generation. MISO is a large area that covers more geographical regions then the other regions so demand for natural gas follows multiple weather zones, where large demands in some areas are offset by less demand in others, thereby allowing for less shock. Like PJM, electricity generation from coal was strong and steady at over 50 percent of total fossil generation throughout the Bomb Cyclone. While Exhibit 4-10 barely shows any petroleum generation, like PJM, MISO still produced nearly 120,000 GWh of electricity from petroleum during the peak of the Bomb Cyclone, while natural gas-fired electric production dipped significantly during the highest demand days in the other regions.

Exhibit 4-9. Fossil fuel generation for MISO (%)



Source: ABB Velocity

Exhibit 4-10. Fossil fuel generation for MISO (GWh)



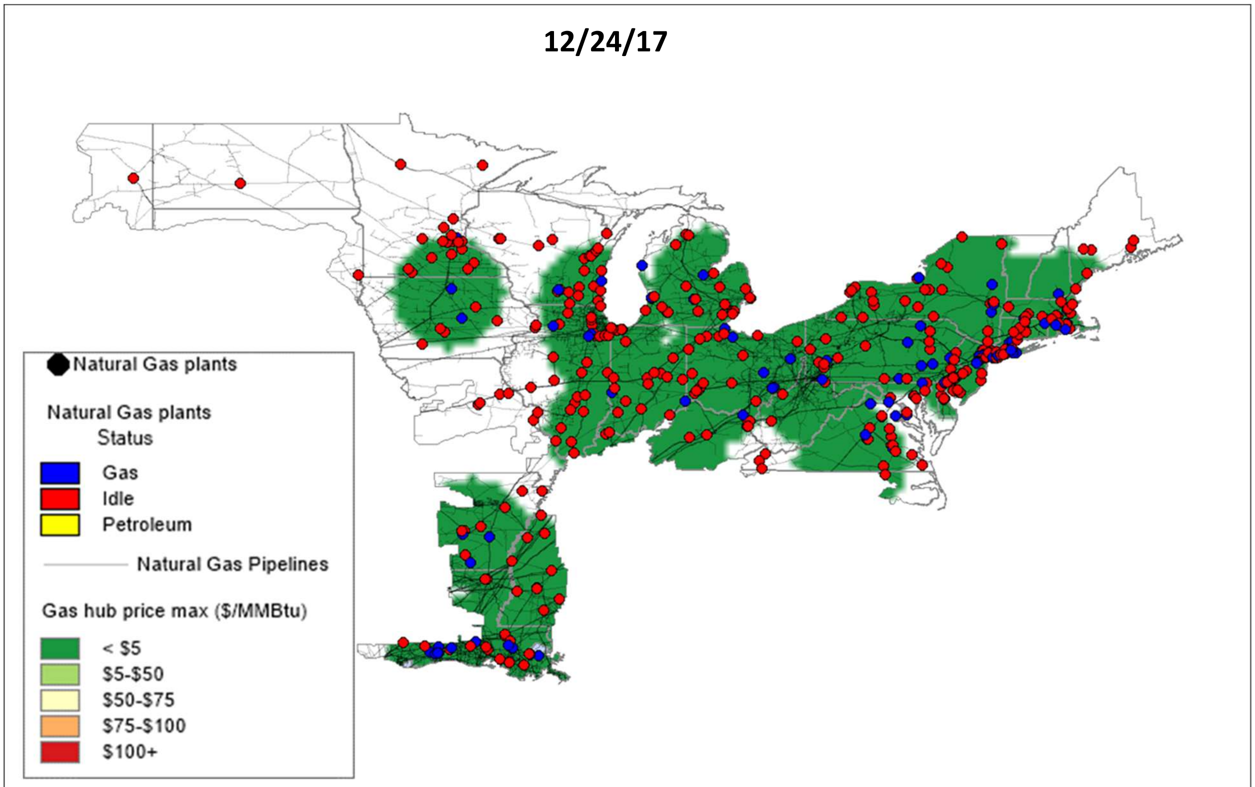
Source: ABB Velocity

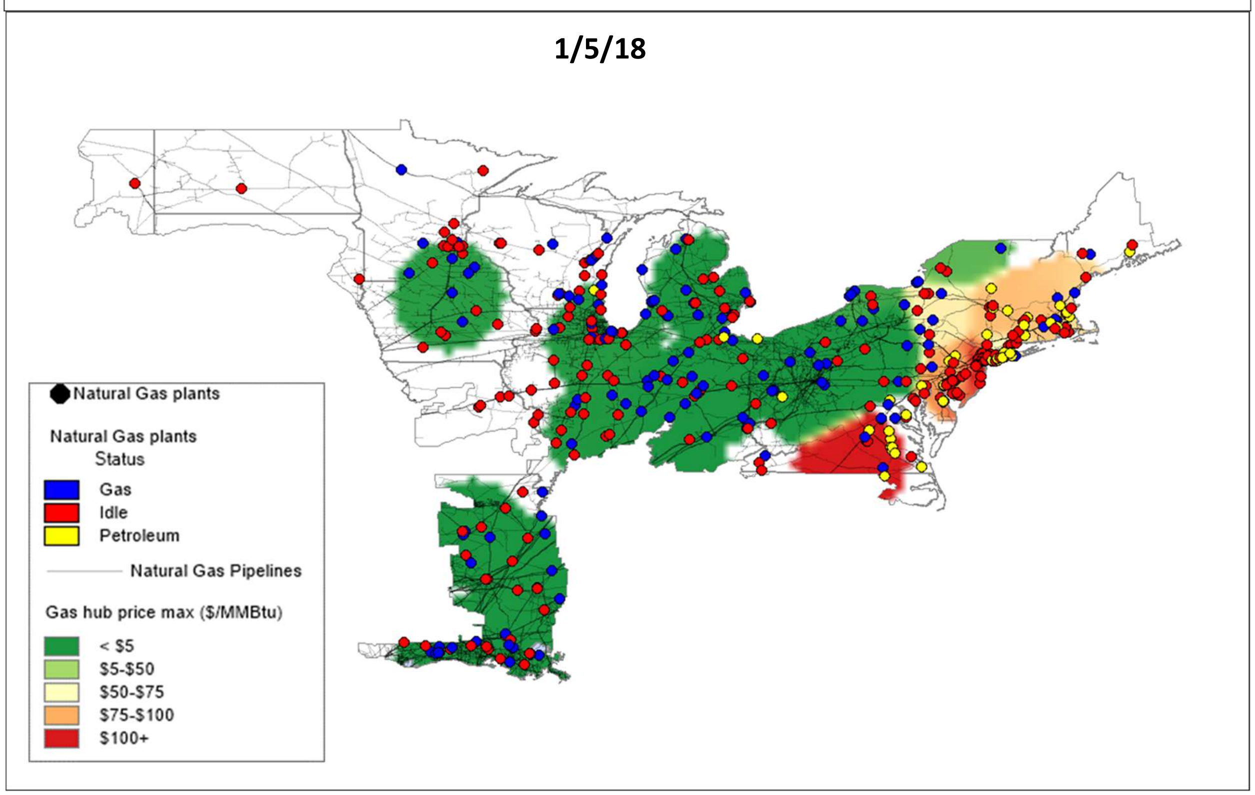
Comparing the natural gas electricity generators in MISO, PJM, NYISO, and ISO-NE at different dates surrounding the Bomb Cyclone (Exhibit 4-11), a significant change can be seen in the spot gas hub prices in the eastern portion of PJM, up through NYISO and into ISO-NE due to greater demand dictated the operating status of many natural gas generators and increasing LDC demand. Many of the natural gas generators that were idle on December 24, 2017, especially in eastern and central PJM, were generating electricity on January 5, 2018. This demand for gas, as the pipeline flow travels north and east, raised the spot prices at the eastern hubs in PJM and the large hubs in NYISO and ISO-NE. Due to the demand for gas, there was an increase in petroleum generation as dual-fuel generators in these regions switched to their secondary fuel, shown as yellow dots along the East Coast in Exhibit 4-11. Additionally, there is a group of plants on the coast of Lake Erie that burned petroleum as opposed to natural gas, and several plants in southern and eastern Virginia, where LMP prices were elevated.

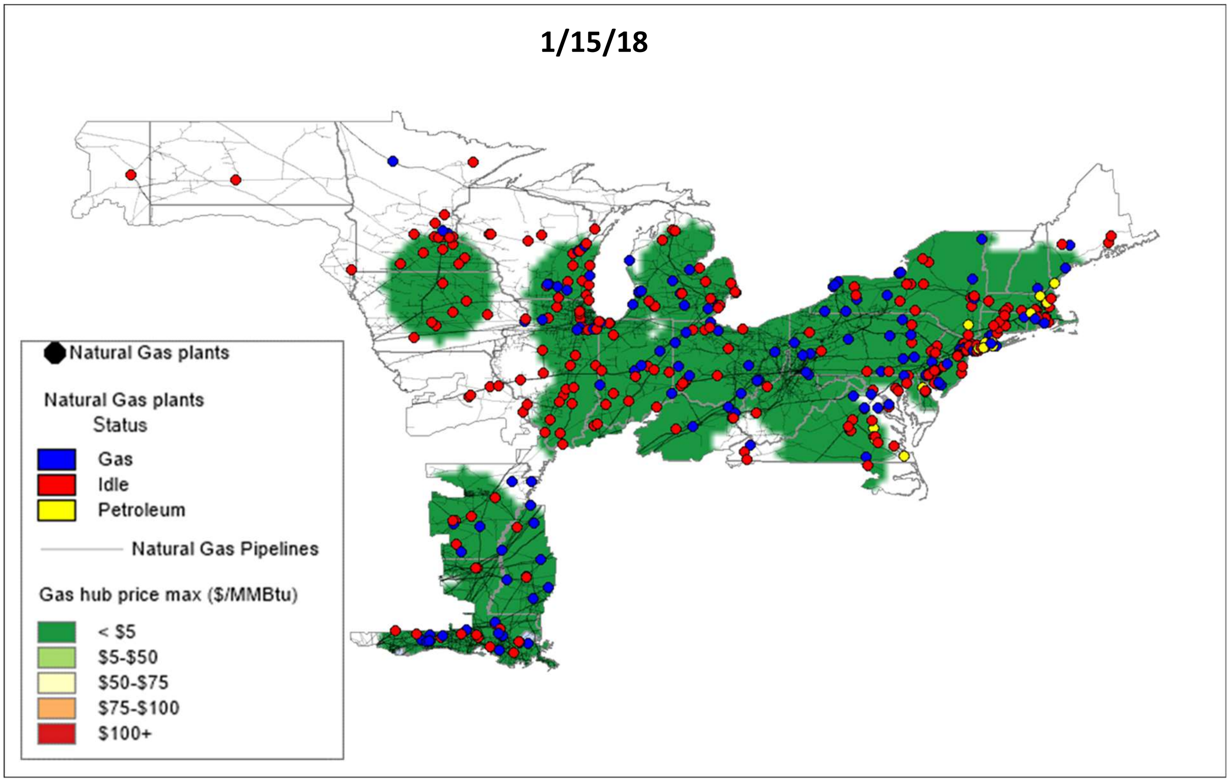
As the Bomb Cyclone ended and gas hub prices returned to seasonal norms, there were still several dual-fuel gas generators on the East Coast burning petroleum, and many of the natural gas generators that were idle on December 24, 2017, and running on January 5, 2018, were still generating electricity.

Exhibit 4-11 illustrates that the demand for natural gas during the peak of the Bomb Cyclone was greater than the ability to deliver it to the high demand regions as many natural gas generators chose to switch to petroleum.

Exhibit 4-11. Natural gas generators on 12/24/2017, 1/5/2018, and 1/15/2018



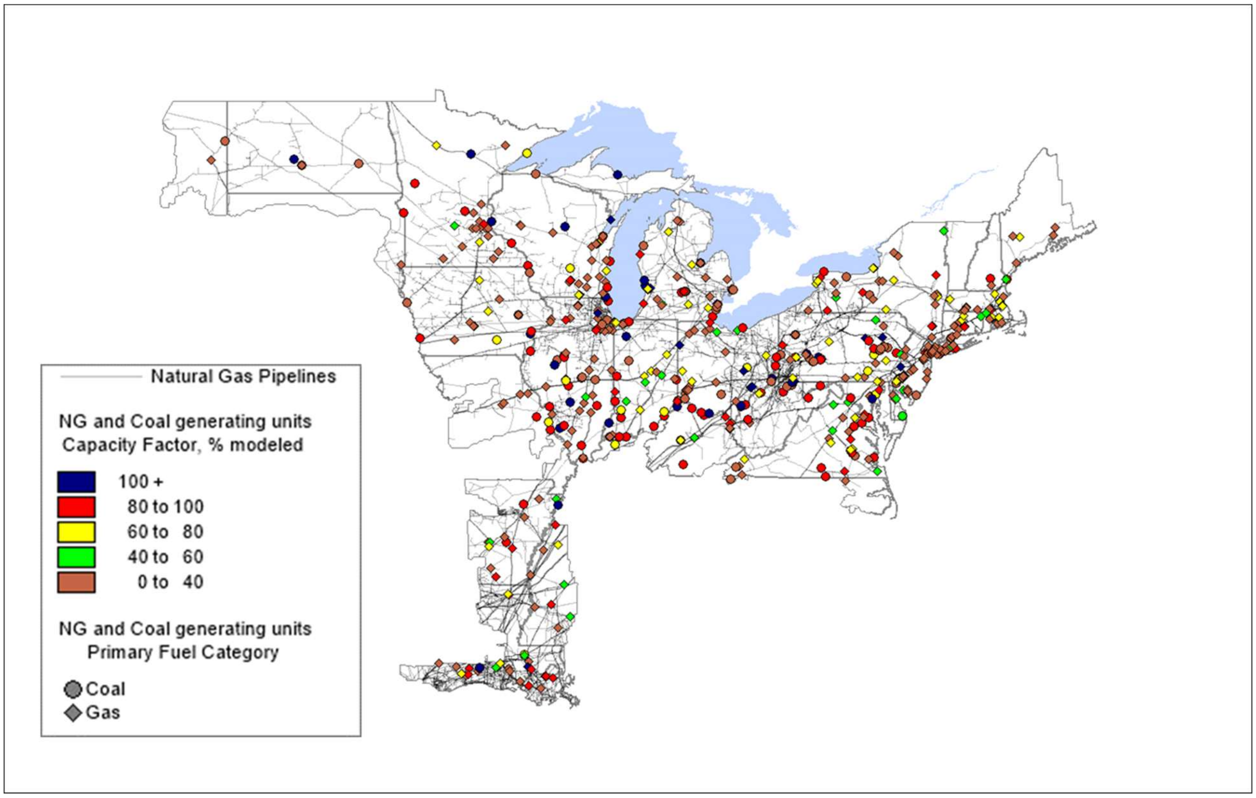




Source: ABB Velocity

While Exhibit 4-11 shows the operating status of natural gas plants during the Bomb Cyclone, Exhibit 4-12 illustrates the coal and natural gas-fired power generation capacity factors on January 5, 2018. As can be seen, most of the coal-fired generation assets were operating at greater than 75 percent of nameplate capacity with many units running at 100 percent. Additionally, many of the natural gas-fired units were operating at capacity factors greater than 75 percent. This large demand for natural gas electricity generation coupled with a larger than normal residential heating demand resulted in pipeline utilization rates in excess of 100 percent in many areas of the Northeast, as well as some in the Midwest.

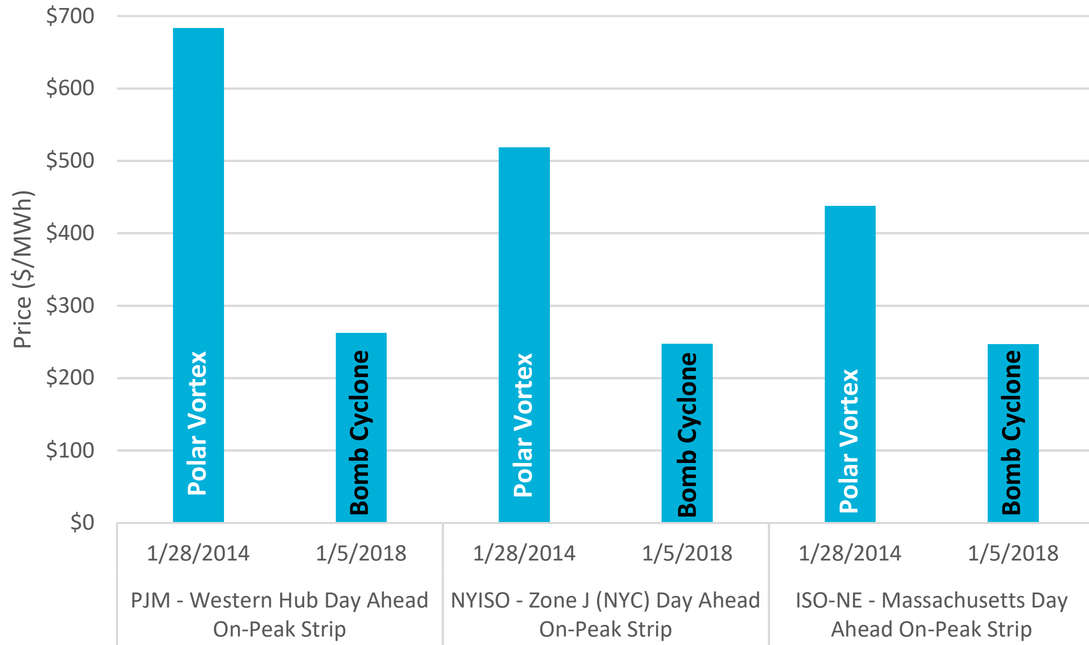
Exhibit 4-12. Plant-level percent of nameplate capacity on January 5, 2018



Source: ABB Velocity

With more natural gas demand, less coal in the mix, and renewables penetration increasing, the RTOs/ISOs are constantly planning for future energy scenarios. In the case of the Polar Vortex, spot electricity prices increased by a factor of ten in PJM, NYISO, and ISO-NE. There were losses of power to customers and the regions realized the need to focus more on severe weather events. As much of this report discusses, during the Bomb Cyclone, there was a significant amount of stress put on the natural gas infrastructure, resulting in higher gas prices, and petroleum being used to deliver electricity when demand was highest. However, the spot peak electricity prices for the Bomb Cyclone, although high compared to normal day ahead spot prices, were significantly lower than peak electricity prices for the Polar Vortex (Exhibit 4-13).

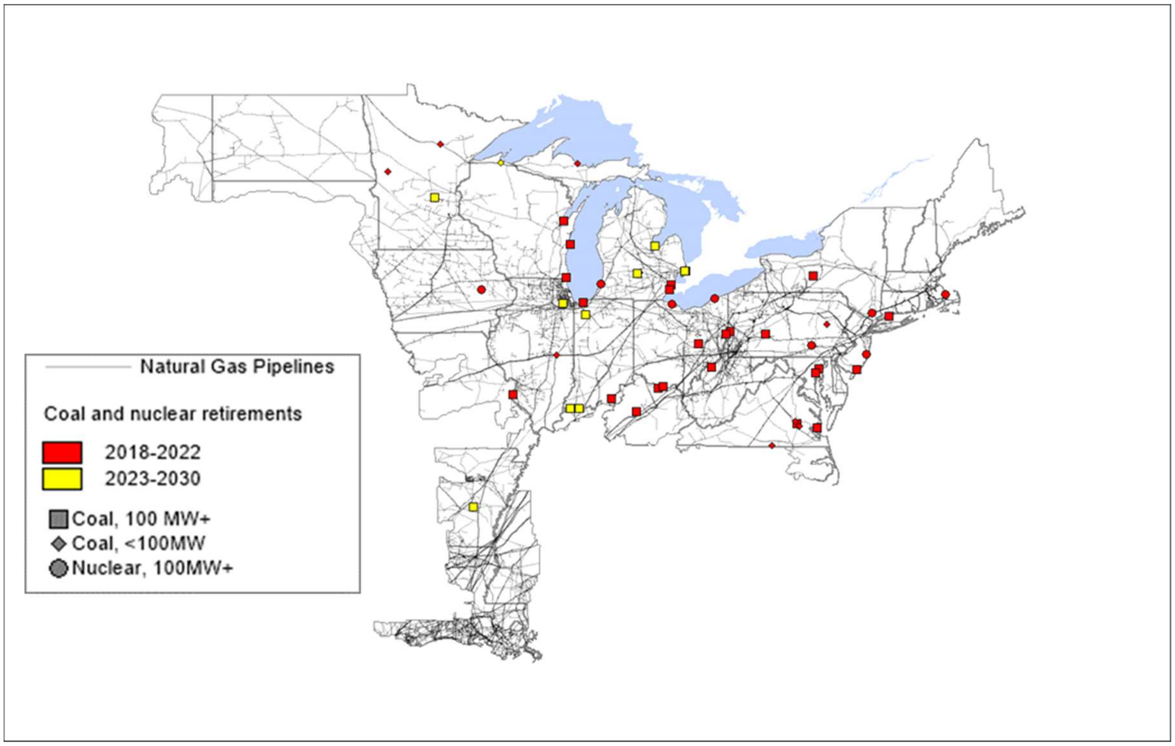
Exhibit 4-13. Day ahead spot electricity prices during the Polar Vortex and Bomb Cyclone



Source: ABB Velocity

However, as Exhibit 4-14 shows, there are retirements planned over the next decade that have the potential to significantly increase the demand for natural gas. Many of these retirements are planned before 2022 leaving little time to expand gas pipeline through-put or other gas and energy storage options.

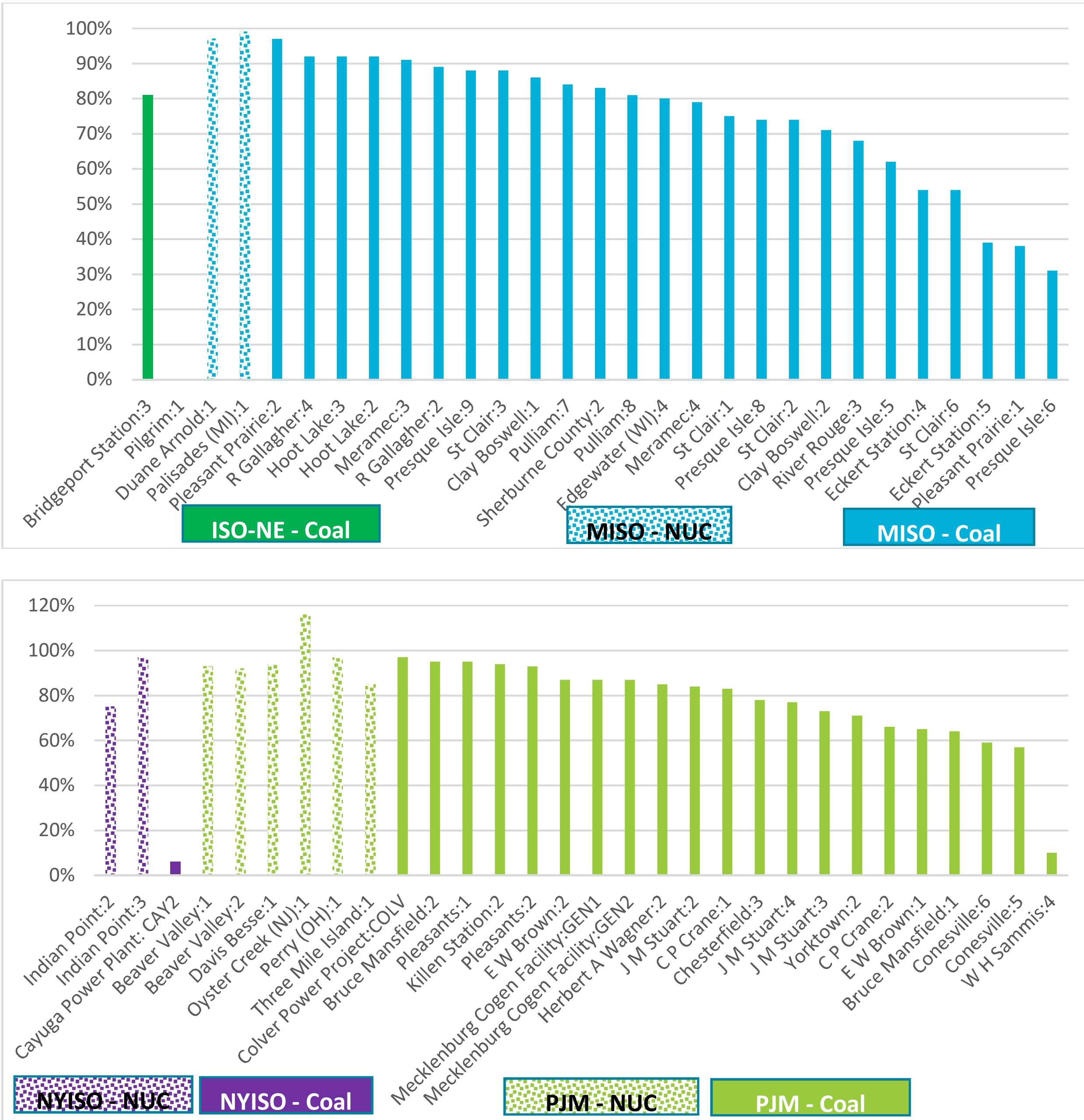
Exhibit 4-14. Announced and planned coal and nuclear retirements



Source: ABB Velocity

Exhibit 4-15 shows coal and nuclear units that have announced or are planning to retire and their contribution to the electricity demand on January 5, 2018. While ISO-NE and NYISO each had only one coal unit that plans to retire before 2023, that unit, the 400 MW Bridgeport Station in Connecticut, was heavily utilized. ISO-NE also had a nuclear unit with a 665 MW capacity, that was manually shutdown on January 4, 2018 due to loss of one of its two 345 kV offsite power feeds. It did not return to service until seven days later. NYISO had two nuclear plants running that provided 49,534 MWh to the grid. MISO and PJM have many plants slated for retirement that provided a significant amount of power to the grid on January 5. Exhibit 4-16 shows that MISO and PJM generated approximately 236,293 megawatt hours (MWh) from 46 different units with a combined capacity of 13,504 MW at an average utilization of 75 percent from coal, and 167,347 MWh from 8 nuclear plants with a combined capacity of 10,425 MW, running at 98 percent and 95 percent average utilization during the peak of the Bomb Cyclone.

Exhibit 4-15. Announced and planned coal and nuclear retirements[k]



Source: ABB Velocity

[k] The three orange striped plants in Exhibit 4-14 were recently announced for retirement by First Energy. (24)

Exhibit 4-16. Coal and nuclear units with retirement schedules before 2023 [l]

Coal units with retirement schedules before 2023				
RTO/ISO	# Units	Generation on January 5, 2018 (MWh)	Combined Nameplate Capacity (MW)	Average Utilization at Event Peak (%)
ISO-NE	1	7,759	400	81%
MISO	25	98,738	5,520	75%
NYISO	1	238	167	6%
PJM	21	137,555	7,984	75%
Total	48	244,290	14,071	72%
Nuclear units with retirement schedules before 2023				
RTO/ISO	# Units	Generation on January 5, 2018 (MWh)	Combined Nameplate Capacity (MW)	Average Utilization at Event Peak (%)
ISO-NE[m]	1	0	665	0%
MISO	2	35,011	1,484	98%
NYISO	2	49,534	2,446	84%
PJM	6	132,336	5,831	95%
Total	11	216,881	10,425	87%

According to the 2015 NETL Cost and Performance Baseline for Fossil Energy Plants (22), a natural gas combined cycle (NGCC) with a nameplate capacity of 630 MW consumes 4.2 million standard cubic feet (scf) of natural gas for every hour of operation at full output.[n] To compensate for the potential loss of coal and nuclear generation, another 3.1 billion scf (3.1 trillion British thermal units (Btu)) of natural gas will need to flow into the four RTO/ISO regions to meet the demand on January 5, 2018. This is the equivalent of adding nearly thirty-one 630 MW NGCCs running at full output.

Another 106,400 MWh generated from coal on January 5, 2018, in MISO came from 12 coal-fired units that are at risk of retiring between 2023 and 2030. This would require an additional 0.71 billion scf (0.72 trillion btu) of natural gas, enough to add another seven 630 MW NGCCs running at full output. Exhibit 4-17 shows the units that have made some announcement of intention to retire between 2023 and 2030.

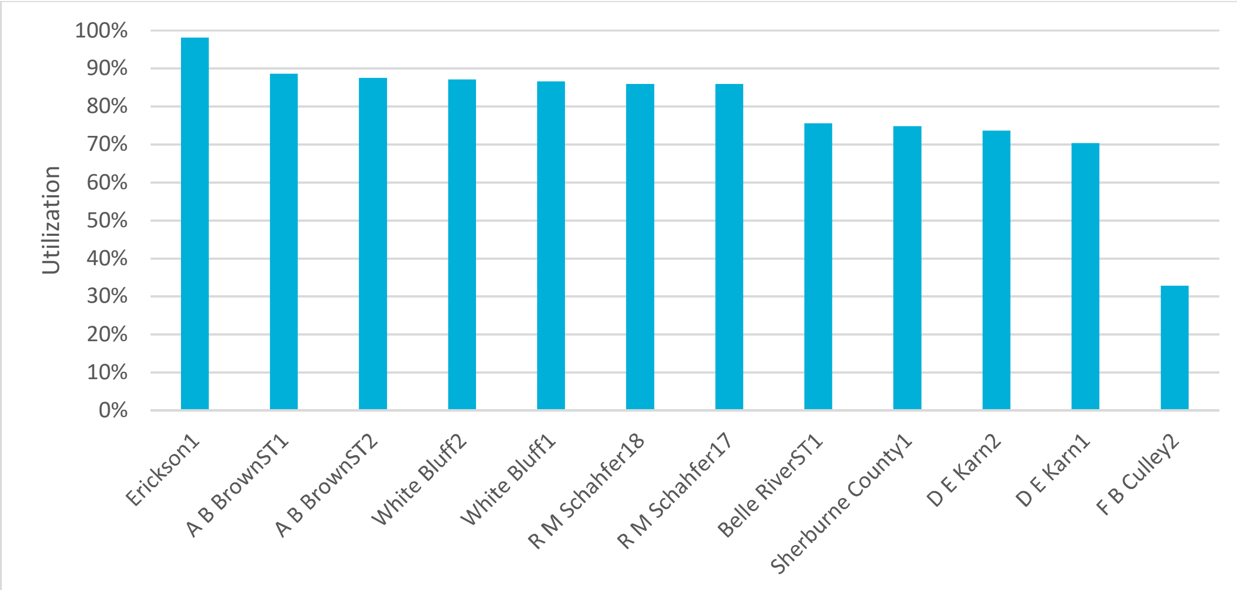
[l] In PJM, there were 14 coal units with a combined capacity of 1,569 MW that did not generate electricity on January 5, 2018. In MISO, there were seven coal units with a combined capacity of 1,860 MW that did not generate electricity on January 5, 2018.

[m] Pilgrim nuclear station was manually shutdown on January 4, 2018 due to loss of one of its two 345 kV offsite power feeds. It did not return to service until seven days later.

(29)

[n] Case B31A (13) of the Baseline cites a gas flow rate of 185,484 pounds per hour. At standard temperature and pressure, the density of natural gas is 0.044 pounds per cubic foot. By multiplying the flow rate by the density, one arrives at 4.2 MMscf per hour.

Exhibit 4-17. Coal units with retirement schedules between 2023 and 2030[o]

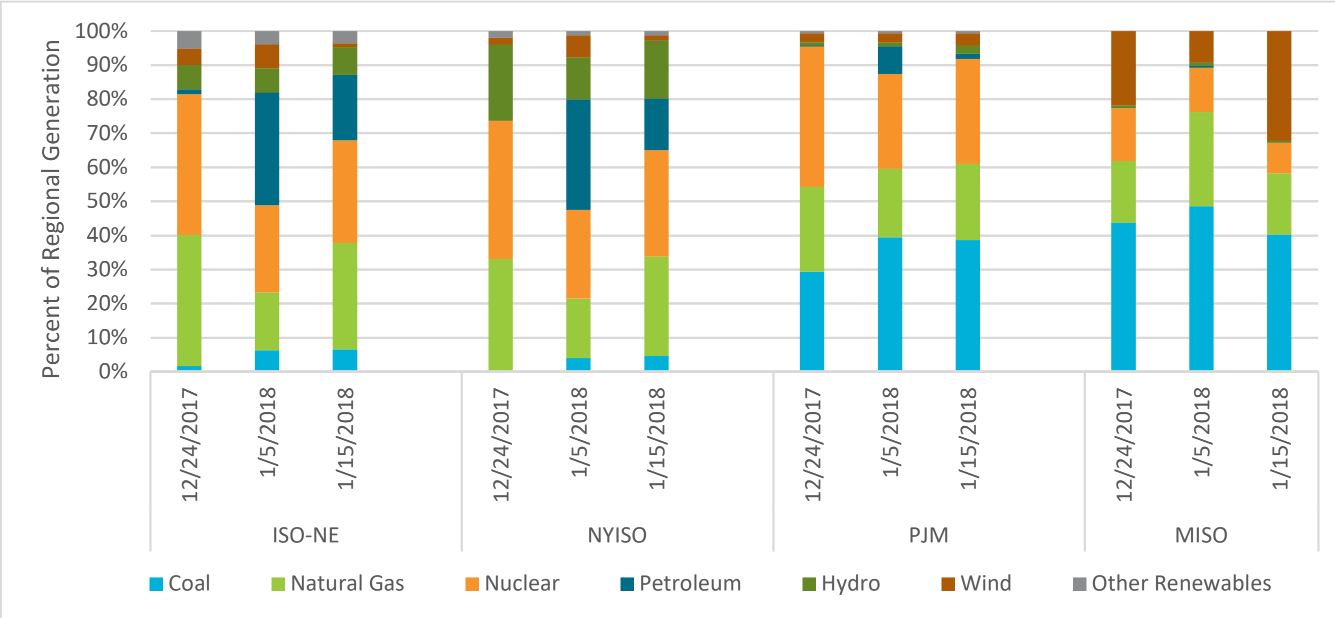


Source: ABB Velocity

Additionally, the announced retirements of multiple nuclear-powered generators in the four regions will add an even more significant strain on natural gas, renewables, and storage to replace lost capacity. Exhibit 4-18 shows the percent generation during the peak Bomb Cyclone demand day, January 5, 2018, and periods before and after. ISO-NE and NYISO rely heavily on nuclear generation to provide baseload power in their respective regions, as does PJM. The three regions respectively contributed 31, 33, and 29 percent of the power on the peak demand day of the Bomb Cyclone (800,000 MWh, 80,000 MWh and 120,000 MWh) (shown in Exhibit 4-19).

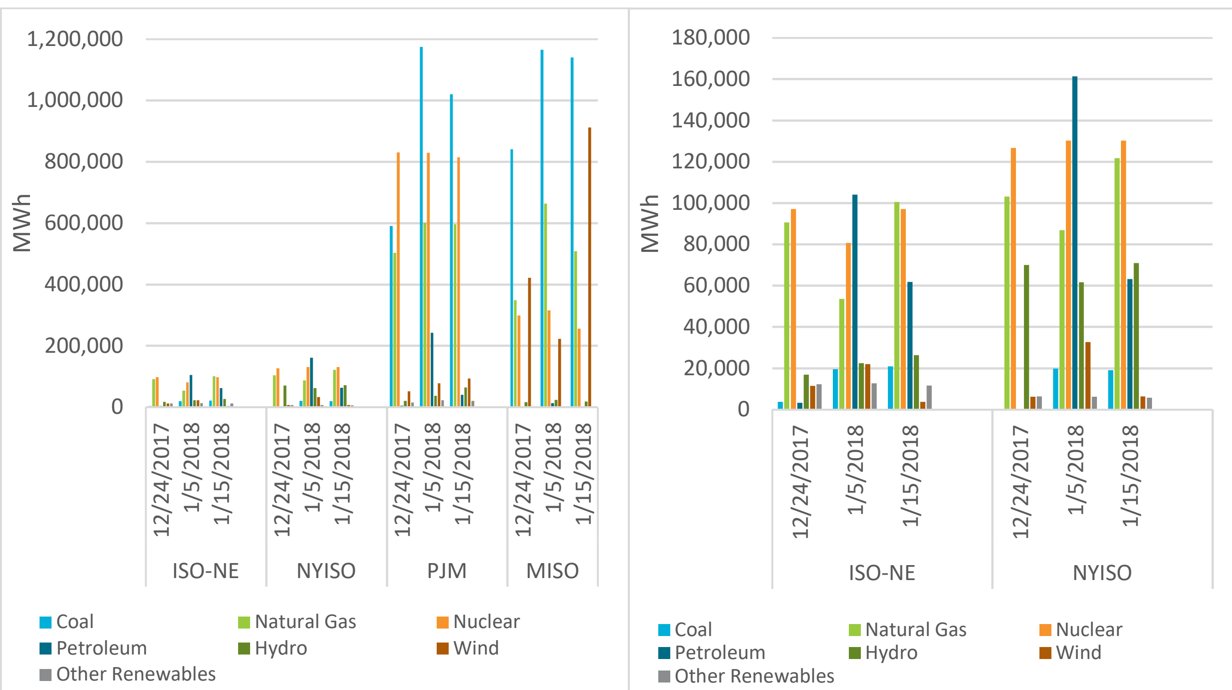
[o] In PJM, there was 1 coal unit with a capacity of 598 MW that did not generate electricity on January 5, 2018. In MISO, there were 2 coal units with a combined capacity of 725 MW that did not generate electricity on January 5, 2018.

Exhibit 4-18. Source generation (%)



Source: ABB Velocity

Exhibit 4-19. Generation source (MWh)



Source: ABB Velocity

5 CONCLUSIONS

During the Bomb Cyclone, natural gas demand coupled with limited natural gas infrastructure in the Northeast and Mid-Atlantic led to spikes in the spot price of natural gas. As the previous sections demonstrated, natural gas infrastructure in the regions examined were constrained, and some pipelines even exceeded 100 percent of their capacity.

Underground natural gas storage in the Northeast and Mid-Atlantic is limited, and because of this, natural gas stored underground was unable to relieve pipeline constraints or to aid in meeting demand. Coal-fired and nuclear power plants were able to rely on coal stored on site. Additionally, dual fuels generation was able to provide a significant source of relief, allowing plants that normally burn natural gas to switch fuels and continue operations.

The lack of natural gas to meet demand, and the subsequent spike in natural gas prices during the Bomb Cyclone does raise concerns for the future reliability of the BES in three of the RTOs/ISOs examined—ISO-NE, NYISO, and PJM. Also, MISO has 6,766 MW of coal slated for retirement by 2030. To meet demand for electricity during times of peak demand for natural gas in pipeline-constrained regions, significant levels of natural gas infrastructure would need to be built. This analysis shows that while dual-fueled plants can partially relieve peak demand for natural gas, more generally maintaining adequate fuel availability to meet that demand, after losing coal and nuclear resources, will be a serious challenge.

6 REFERENCES

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