American Gas FOUNDATION

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Building a Resilient Energy Future:

How the Gas System Contributes to US Energy System Resilience

An American Gas Foundation Study Prepared by:

Guidehouse

Background and Methodology

This study was conducted to investigate the resilience of the US gas system and the ways in which the gas system contributes to the overall resilience of the US energy system. This work was directed to ask and answer four key questions:

- What are the characteristics of the US gas system that contribute to its resilience?
- How do those resilience characteristics allow the US gas system to contribute to the overall resilience of the US energy system?
- How can the US gas system be leveraged more effectively to strengthen the US energy system?
- What are the policy and regulatory changes that may help ensure that gas infrastructure can be maintained and developed to continue to support energy system resilience?

These questions were explored through a qualitative assessment conducted by Guidehouse, including discussions and interviews with many energy industry subject matter experts. Case studies and examples of resilience were identified as a part of these discussions. Guidehouse used these studies and examples to develop a framework for considering the resilience of the US gas system and to identify barriers and opportunities related to the gas system's role in supporting the resilience of the US energy system. The findings presented in this work identify issues that merit consideration and further exploration when developing future energy policy and regulation to ensure a resilient, reliable, and clean future energy system in all regions and jurisdictions.

Disclaimers

American Gas Foundation

Founded in 1989, the American Gas Foundation (AGF) is a 501(c)(3) organization focused on being an independent source of information research and programs on energy and environmental issues that affect public policy, with a particular emphasis on natural gas. When it comes to issues that impact public policy on energy, the AGF is committed to making sure the right questions are being asked and answered. With oversight from its board of trustees, the foundation funds independent, critical research that can be used by policy experts, government officials, the media and others to help formulate fact-based energy policies that will serve this country well in the future.

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Abbreviations

Abbreviation	Definition
AGF	American Gas Foundation
AWIA	America's Water Infrastructure Act
Bcf	Billion Cubic Feet
Btu	British Thermal Units
C&I	Commercial and Industrial
CAGR	Compound Annual Growth Rate
CAISO	California Independent System Operator
CHP	Combined Heat and Power
CIP	Critical Infrastructure Protection
CNG	Compressed Natural Gas
DSM	Demand Side Management
Dth	Dekatherm
EIA	US Energy Information Administration
ESR	Energy Storage Resources
EV	Electric Vehicle
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, And Air Conditioning
ISO	Independent Service Operator
ISO-NE	Iso New England Inc.
LCOE	Levelized Cost of Electricity
LDC	Local Distribution Company
LNG	Liquified Natural Gas
KWh	Kilowatt-Hour
MMcf	Million Cubic Feet
MMcfd	Million Cubic Feet Per Day
MMBtu	Million British Thermal Units of Natural Gas
MW	Megawatt
MWh	Megawatt-Hour
NASA	National Aeronautics and Space Administration
NERC	North American Electric Reliability Corporation
NGV	Natural Gas Vehicle
NOAA	National Oceanic and Atmospheric Administration
NJNG	New Jersey Natural Gas
NYISO	New York Independent System Operator
OBA	Operational Balancing Agreement
PGE	Portland General Electric
psi	Pounds Per Square Inch
PSPS	Public Safety Power Shutoff
PUC	Public Utility Commission
PV	Photovoltaic
RNG	Renewable Natural Gas
RTO	Regional Transmission Organization
SCADA	Supervisory Control and Data Acquisition
T&D	Transmission and Distribution
US	United States
UTMB	University of Texas Medical Branch

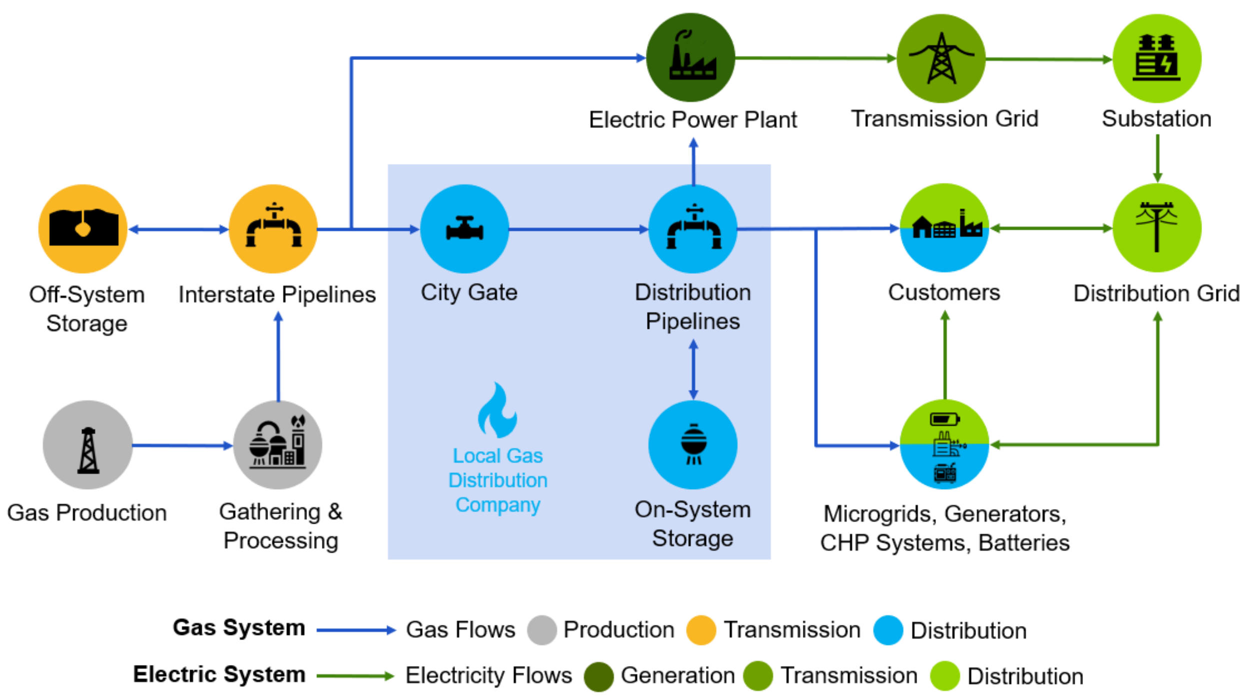
EXECUTIVE SUMMARY

A resilient energy system is essential to the operation of nearly every critical function and sector of the US economy as well as the communities that depend upon its services. Disruptions to the US energy system create widespread economic and social impacts, including losses in productivity, health and safety issues, and—in the most extreme cases—loss of life. As utilities, system operators, regulators, and policymakers deliberate the design and structure of the future energy infrastructure, they must consider the resilience of the entire energy system. As the transformation of the energy system accelerates, it is important for stakeholders to understand the increasing interdependence of gas and electric systems and their role in creating a more resilient future.

A Primer on the Energy System

An energy system is defined as the full range of components related to the production, conversion, delivery, and use of energy. Energy in the US can take many forms; this report focuses on the natural gas system, herein referred to as the gas system, and its interdependencies with the electric system (Figure 1).

Figure 1. Interdependencies Between the Gas and Electric Systems



Source: Guidehouse

What Is Resilience?

Resilience is defined as a system's ability to prevent, withstand, adapt to, and quickly recover from system damage or operational disruption. Resilience is defined in relation to a high-impact, low-likelihood events. The most common examples of these events are extreme weather events (which go beyond standard hot days or snowstorms) of a size and scale to cause significant operational disruption, system damage, and devastating societal impacts. Recent resilience events that affected the US energy system include the 2020 California heat waves, Hurricane Isaias, and the 2019 Polar Vortex.

> *Resilience and reliability are often referenced together, but they reflect critical differences in system design and operation.* ***Resilience*** *is defined as a system's ability to prevent, withstand, adapt to, and quickly recover from a high-impact, low-likelihood event such as a major disruption in a transmission pipeline. In comparison,* ***reliability*** *refers to a systems' ability to maintain energy delivery under standard operating conditions, such as the standard fluctuations in demand and supply.*

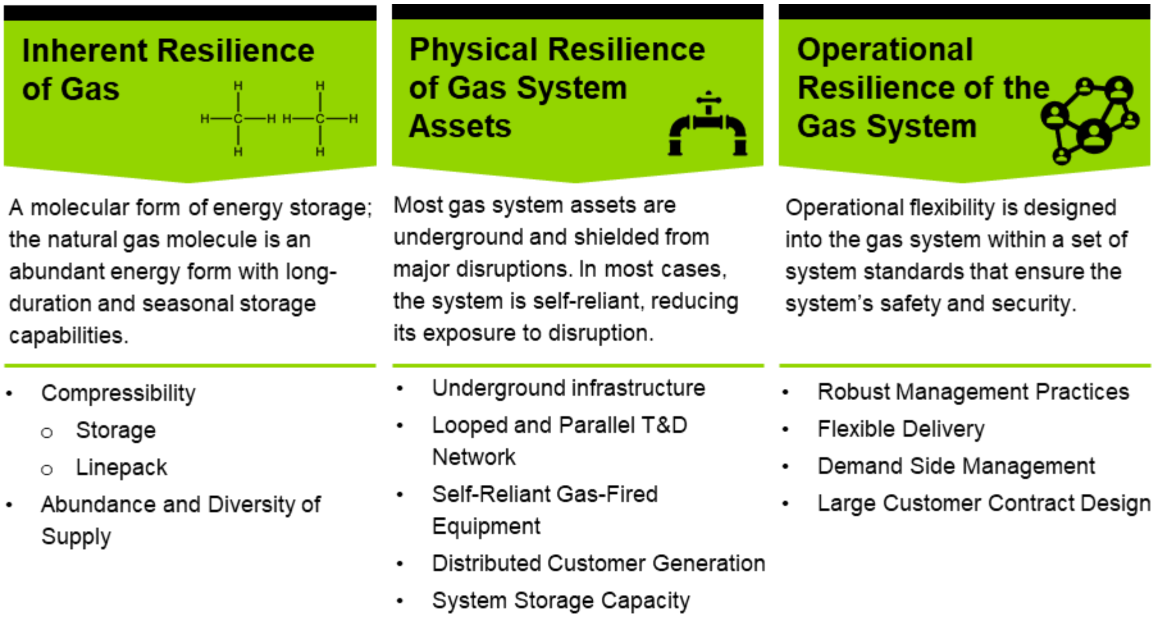
The increasing frequency and severity of climatic events amplifies the need to maintain the resilience of the US energy system. System resilience is gained through diversity and redundancy. The resilience of the US energy system is increased through evolving and holistic management of the gas and electric systems, valuing each of their unique characteristics. To ensure resilience, the energy system needs pipeline delivery infrastructure and storage capabilities meeting both short- and long-duration needs.

The nation's gas system is a critical resource for addressing resilience threats to the overall energy system. This report examines how the characteristics of the US natural gas system enable energy reliance today and opportunities to effectively use the gas system to achieve future energy resilience.

Resilience Characteristics of the Gas System

The gas system supports the overall resilience of the energy system through its inherent, physical, and operational capabilities (Figure 2) that enable it to meet the volatile demand profiles resulting from resilience events.

Figure 2. Resilience Characteristics of the Gas System



Source: Guidehouse

Resilience in Action

Large, catastrophic failures of the energy system have been few and far between—the energy system has performed well, overcoming periods of high stress that have threatened its resilience. These high stress events are becoming more frequent due to the increase in the frequency and severity of extreme weather events associated with climate change. To successfully build for the future and invest in the right set of resilience solutions, it is important for stakeholders to understand how the energy system has performed under recent resilience events.

Recent climate events have revealed the US energy system's potential vulnerabilities. However, the multitude and diversity of resilience assets that already exist as part of the energy system have made the difference—facilitating energy flows to critical services and customers. As the following case studies illustrate, the resilience assets that are part of the gas system have supported the overall integrity of the energy system during these high stress periods.

2019 Polar Vortex

In 2019, the Midwest experienced record-breaking cold temperatures, which led to increased demand on the energy system to meet heating needs.

- CenterPoint Energy curtailed gas service to interruptible customers and pulled gas from every possible storage resource to maintain service to homes and businesses. In one day, CenterPoint delivered almost 50% more than a standard January day.
- On January 30, 2019, Peoples Gas, North Shore Gas, and Nicor Gas together delivered gas in an amount equivalent to more than 3.5 times

	the amount of energy that ComEd, the electric utility serving an overlapping territory has ever delivered in a single day. • The Consumers Energy's Ray Compressor Station fire on January 30 took a primary storage supply resource offline. Consumers leveraged several gas resilience characteristics (linepack, backup storage, and a highly networked gas system) to ensure that no critical, priority, or residential customer lost service.
2014 Polar Vortex	During early February 2014, a polar vortex brought extreme cold temperatures, snowfall, and high winds to Oregon. On February 6, during the system peak, NW Natural set a company record for natural gas sendouts, which still stands today. Nearly 50% of this peak demand was met by natural gas storage capacity. In combination with diligent planning and dedicated employees, this case study highlights the critical role that natural gas storage plays in meeting demand during extreme weather events.
2020 Hurricane Isaias	On August 4, 2020, Hurricane Isaias made landfall in North Carolina. It caused significant destruction as it moved north, triggering electric outages that affected more than 1 million New Jersey homes and businesses. Many customers experiencing electric outages turned on their natural gas backup generators, resulting in a massive increase in demand for New Jersey Natural Gas (NJNG). In 24 hours, NJNG experienced a 60% increase in daily demand on its gas system—the daily demand for this one day was higher than any other August day for the previous 10 years. Because of the built-in storage capacity (compressibility and on-system storage) and flexibility of the gas system, NJNG was able to ramp up service to customers with disrupted electricity supply.
2020 Heat, Drought, and Wildfires	In August 2020, California was in the middle of its hottest August on record,[1] a severe drought, and its worst wildfire season in modern history. Concurrent to increased demand on the electric system driven by increased cooling loads, California also experienced a decrease in renewable output (due to smoke from the fires)[2] and lower imports than had been anticipated by electric supply planners. To meet increased electric demand, system operators turned to gas-fired generation facilities. During the week of August 11, all of SoCalGas' system storage assets were employed to fill the gap between abnormally high electric demand and low renewable energy generation experienced in Southern California.

In all of these case studies, the gas system provided significant support to the energy system in maintaining resilience and ensuring that energy service was maintained to customers. To understand the gas system's contribution to resilience, it is important to differentiate between the pipeline infrastructure system and the natural gas molecules that flow through it. The gas pipeline system is defined as a series of physical assets that transport energy molecules from the source of production to end users, including residential, commercial, and industrial customers who use gas in their buildings and processes, and electric generators who use gas to

[1] NOAA. *National Climate Report*. August 2020.
[2] EIA. *Smoke from California Wildfires Decreases Solar Generation in CAISO*. September 30, 2020.

make electricity. Today, the gas system is used to transport mostly geologic natural gas, but it can be leveraged to transport low-carbon gases such as renewable natural gas (RNG) and potentially hydrogen in the future as utilities move to decarbonize the energy system.

The Growing Resilience Challenge

Driven by changes in the cost and availability of new technologies and increasing political and social pressure to decarbonize, our energy system is undergoing a transformation. This transformation exposes an issue of energy system resilience related to the interaction of the gas and electric systems.

> *As the percentage of electricity generation from intermittent renewable sources increases, the volume of natural gas used for electric power generation may decline; however, in responding to resilience events the necessity of the services provided by gas-fired electric generators may increase. As current compensation models for the gas system serving the power generation sector are tied to the volume of gas delivered to the facility, there becomes an increasing disconnect between the value of the services provided and associated remuneration for said services.*

To further highlight the need for energy system resilience as part of the current transformation, it is worth considering a recent review of the root cause of the California Independent System Operator (CAISO) electric outages during the August 2020 heatwave. One of the three factors identified was: "In transitioning to a reliable, clean and affordable resource mix, resource planning targets have not kept pace to lead to sufficient resources that can be relied upon to meet [electric] demand in the early evening hours. This makes balancing demand and supply more challenging. These challenges were amplified by the extreme heat storm."[3]

The current model for maintaining the resilience of our energy system was built to support a legacy view of how the energy system operates. As an example, natural gas infrastructure replacement and modernization programs were designed to enhance reliability and safety. As noted in this report they have also contributed to resilience. As the transition to the future energy system accelerates, it is important to understand how these programs complement future energy state resilience needs. The manner in which this energy system is regulated and managed is becoming outdated, and an update is necessary to maintain resilience of the evolving future energy system.

Ensuring a Resilient Future Energy System

The increasing frequency and intensity of climatic events combined with the transformation of the energy system to one increasingly powered by intermittent renewable sources establish the need for a new consideration of the resilience of the energy system. Utilities, system operators, regulators, and policymakers need to recognize that resilience will be achieved through a diverse set of integrated assets—for the foreseeable future, policies need to focus on optimizing the characteristics of both the gas and electric systems.

[3] CAISO. *Preliminary Root Cause Analysis: Mid-August 2020 Heat Storm*. 2020.

Achieving this is easier said than done. It will require a realignment of the valuation and cost recovery mechanisms that currently define the development of the US energy system:

- Energy system resilience must be defined as a measurable and observable set of metrics, similar to how reliability is considered.
- Resilience solutions must be developed considering all possible energy options and across utility jurisdictions, requiring electric, gas, and dual-fuel utilities to work together to determine optimal solutions.
- Methodologies need to be built to value resilience, such that it can be integrated into a standard cost-benefit analysis. Value should consider the avoided direct and indirect costs to the service provider, customers, and society.

The resilience of the current energy system is largely dependent on the gas system’s ability to quickly respond to events and use its extensive long-duration storage resources to meet peak and seasonal demand. Ensuring future energy system resilience will require a careful assessment and recognition of the contributions provided by the gas system. Utilities, system operators, regulators, and policymakers need new frameworks to consider resilience impacts to ensure that resilience is not overlooked or jeopardized in the pursuit to achieve decarbonization goals.

1. Introduction

A resilient energy system is essential to the operation of nearly every critical function and sector of the US economy—and the need for energy system resilience is only increasing as emergency services, communications, transportation, banking, healthcare, water supply, and other critical systems become more interconnected than ever. Disruptions to the US energy system can have widespread economic and social impacts, including losses in economic productivity, health and safety issues, and—in the most extreme cases—loss of life.

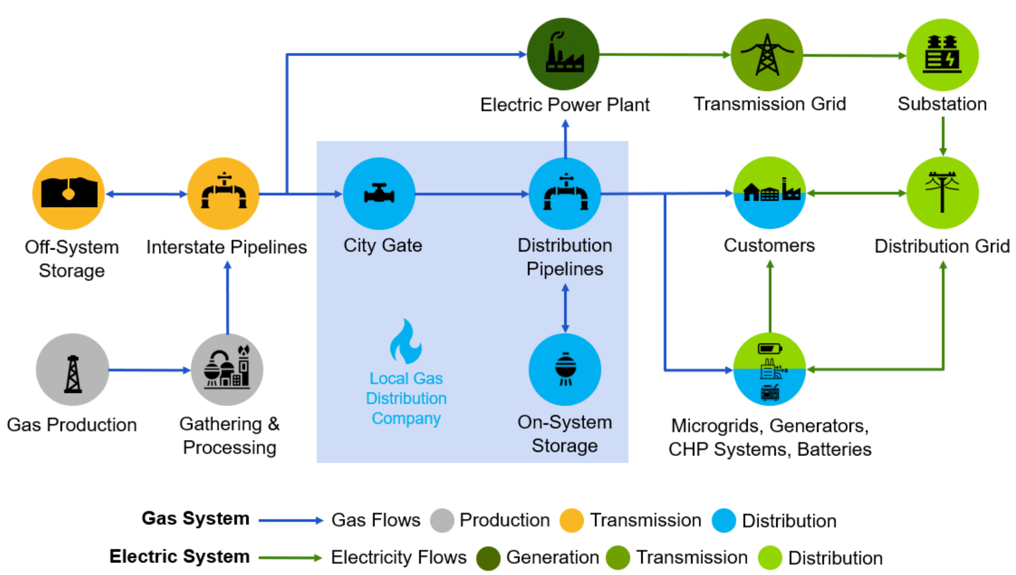
This report examines the resilience of the current gas system with a focus on the part of the system that is under the operational control of the gas local distribution company (LDC). It also examines how the gas system contributes to the resilience of the overall energy system. The work was directed to ask and answer four key questions:

1. What are the characteristics of the US gas system that contribute to its resilience?
2. How do those resilience characteristics allow the US gas system to contribute to the overall resilience of the US energy system?
3. How can the US gas system be leveraged more effectively to strengthen the US energy system?
4. What are the policy and regulatory changes needed to ensure that gas infrastructure can be maintained and developed to continue to support energy system resilience?

1.1 A Primer on the Energy System

An energy system is defined as the full range of components related to the production, conversion, delivery, and use of energy. Energy takes many forms; this report focuses on the natural gas system, herein referred to as the gas system, and its interdependencies with the electric system (Figure 1-1).

Figure 1-1. Interdependencies Between the Gas and Electric Systems

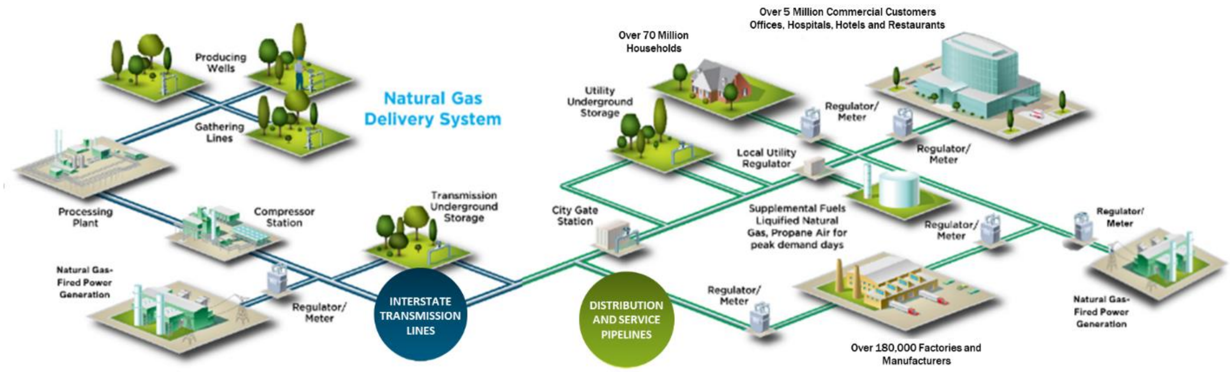


Source: Guidehouse

The gas system is the series of assets that transport energy molecules from the source of production to the site of consumption. The customers served by this system include residential, commercial, and industrial buildings and processes; gas-fired electric generation facilities; transportation fuel providers; and natural gas exporters.

Today, the gas system is used to transport mostly geologic natural gas and small amounts of renewable natural gas (RNG). In the future, the gas system can be leveraged, with only small upgrades, to transport a low carbon fuel supply including RNG, hydrogen, and synthetic methane.

Figure 1-2. Overview of the Gas System



Source: American Gas Association

The gas system can generally be divided into three sections (Appendix A presents further details):

1. **Production and Processing:** Encompasses the process of gathering the gas and treating it to remove impurities.

    - Wells extract natural gas primarily from geologic shale formations.
    - Gathering pipelines transport gas to processing facilities where impurities are removed.
    - Compressors move the gas through midstream pipelines to the connection with interstate transmission pipelines.

2. **Transmission:** Includes the network of high-pressure transmission lines that transport gas from supply basins to market demand centers and, in some cases, across local gas LDC systems.

    - Compressor stations are located approximately every 50 to 60 miles along long-haul transmission pipelines and within gas systems to regulate pressure and keep gas moving.
    - Storage assets connected to the transmission system (defined as off-system storage) exist along these transmission pipelines enabling operators to adjust flow to meet daily and seasonal demand requirements. Storage assets are either underground (i.e., depleted gas reservoirs, aquifers, or salt caverns) or aboveground (where gas is stored as LNG or CNG).

3. **Distribution:** Under the operational control of the LDC, the gas distribution system is primarily comprised of regulator stations, gas pipeline mainlines, and gas pipeline service lines that collectively reduce pressure and move gas from the transmission system to customers.

    - In many cases, gas passes through a city-gate where custody is transferred from the interstate transmission system to the LDC. At this point, gas volumes are measured, typically odorized, and pressure is reduced.
    - LDCs may have LNG, CNG, or underground storage assets on the distribution system (defined as on-system storage), allowing the LDC to maintain reliability and meet short-term demand increases.

1.2 A Primer on Resilience

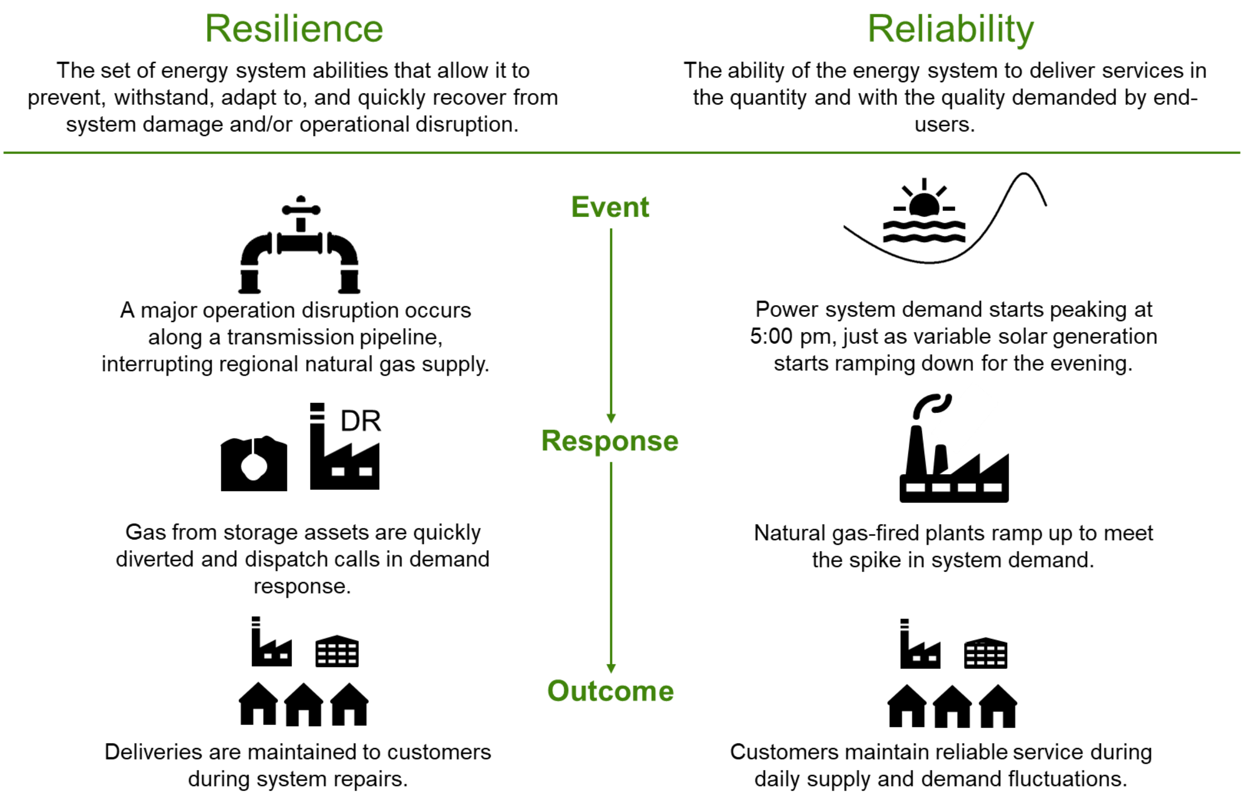
Resilience is defined as a system's ability to prevent, withstand, adapt to, and quickly recover from system damage or operational disruption. The term is defined in relation to a high-impact, low-likelihood event. The most common examples of these events are extreme weather events (which go beyond standard hot days or snowstorms) of a size and scale to cause significant operation disruption, system damage, and devastating human health impacts. Common threats that test the durability of the energy system include extreme weather events (e.g., hurricanes, wildfires, and extreme heat/cold), cyberattacks (e.g., malware and cyber intrusions), and accidents.

Recent examples of resilience events that affected the US energy system include the 2020 California heat waves, Hurricane Isaias, and the 2019 Polar Vortex; each of which are explored in greater detail in Section 3. Other recent resilience events that have exposed the value of the gas system in maintaining energy system delivery include the 2017 Bomb Cyclone,[4] the 2017 Californian wildfires and landslides, Hurricane Irma, and Hurricane Harvey.[5]

Resilience and reliability are often referenced in tandem, but there is a critical difference between the terms and their impact on the design and operation of energy systems. Reliability is defined in relation to a low-impact, high-likelihood event. The US energy system manages reliability daily—in the standard fluctuations in energy supply and demand. Figure 1-3 illustrates resilience and reliability events, along with typical energy system responses and associated outcomes.

[4] The Natural Gas Council; Prepared by RBN Energy. 2018. *Weather Resilience in the Natural Gas Industry: The 2017-18 Test and Results.*
[5] ICF. 2018. *Case Studies of Natural Gas Sector Resilience Following Four Climate-Related Disasters in 2017*.

Figure 1-3. Comparison of Resilience and Reliability

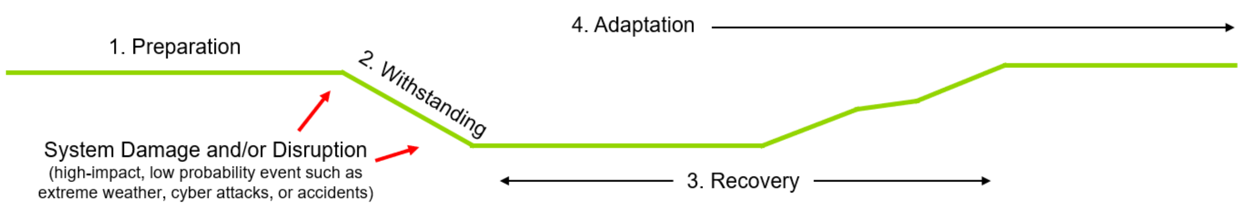


Source: Guidehouse

One way to conceptualize a resilience event is to separate it into distinct phases, where each phase is defined by a time period in relation to the event's onset. Figure 1-4. illustrates this approach with a resilience curve. Table 1-1Table 1-1. defines the four phases of this curve: preparation, withstanding, recovery, and adaptation.

The resilience curve provides a framework for understanding how an energy system's resilience can be strengthened. It is used in Section 2 to classify the resilience characteristics of the gas system.

Figure 1-4. The Energy System Resilience Curve



Source: Guidehouse

Table 1-1. Definition of the Phases of Resilience

Phase	Resilience Characteristics	Timeframe
1. Preparation	The ability to prepare for and prevent initial system disruption	Leading up to the disruption event

Phase	Resilience Characteristics	Timeframe
2. Withstanding	The ability to withstand, mitigate, and manage system disruption	During the disruption event
3. Recovery	The ability to quickly recover normal operations and repair system damage	Following the end of the disruption, until system functions are fully restored
4. Adaptation	The ability to adapt and take action to strengthen the energy system in face of future disruption events	Throughout, but especially during and following the recovery phase

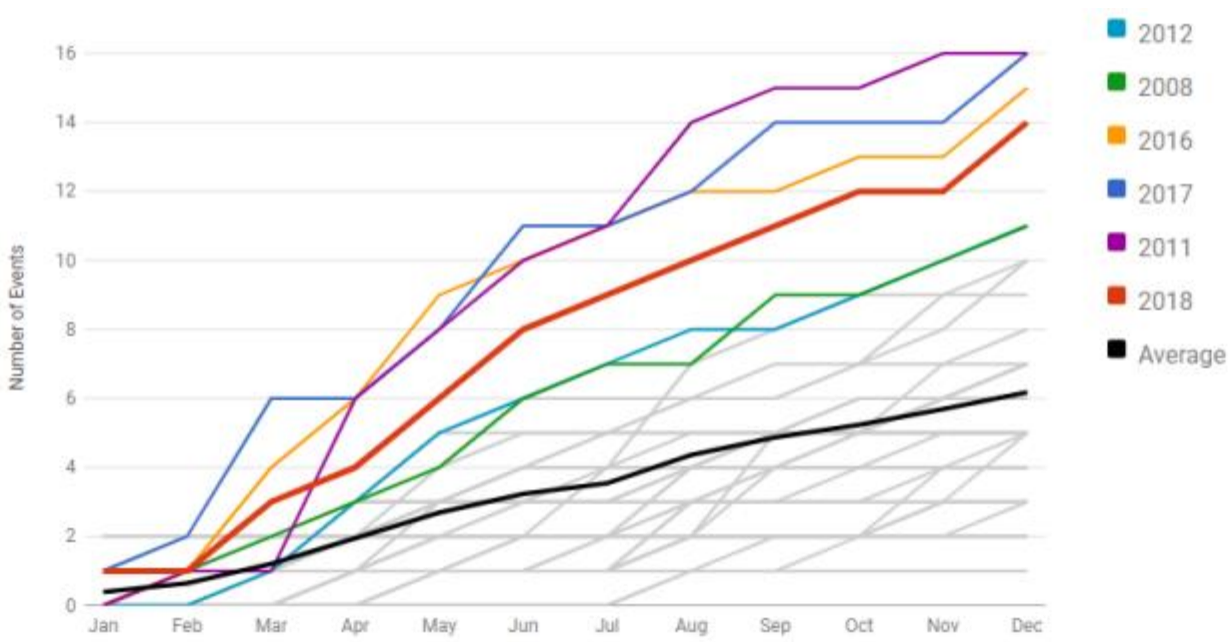
Source: Guidehouse

1.2.1 The Increasing Importance of Resilience

The increased frequency and severity of extreme weather events increasingly put the US energy system at risk. Over the last 50 years, much of the US has experienced increasingly extreme weather including prolonged periods of excessively high temperatures, heavy downpours, flooding, droughts, and severe storm activity.[6]

In the last decade, the US has experienced historic numbers of inflation-adjusted billion-dollar disasters. From 2016-2018 there were 15 billion-dollar disasters per year, up from an average of 6.2 billion-dollar disasters per year since 1980.[7] Figure 1-5. illustrates this trend and shows the cumulative inflation-adjusted billion-dollar disasters on an annual basis since 1980.

Figure 1-5. 1980-2018 Year-to-Date US Billion-Dollar Disaster Event Frequency (CPI-Adjusted, Events Statistics are Added According to the End Date)



Source: NOAA, 2018's Billion Dollar-Disasters in Context

[6] NOAA. 2014. *Fourth National Climate Assessment*.

[7] NOAA. 2019. *2018's Billion Dollar Disasters in Context*.

To further highlight the importance of placing focus on the resilience of the energy system, consider California in August 2020. California was in the middle of its hottest August (record warmest in 126 years),[8] a severe drought, and its worst wildfire season in modern history. These weather events resulted in increased demand on the electric system, driven by increased cooling load. Concurrently, the state was experiencing a decrease in the anticipated electricity supply from hydroelectricity imports and solar electric generation due to smoke from the wildfires.[9] The coincidence of these events resulted in a significant gap between electricity demand and supply on the California system that led to rolling blackouts on August 14 and 15.[10]

As explored in Case Study 3*,* in Section 3, because the gas system filled a considerable portion of the gap between abnormally high electric demand and low renewable energy generation, Southern California avoided catastrophic failure.

The increasing frequency and severity of climate events amplify the need to maintain and strengthen the resilience of the US energy system. The energy system needs redundancy and storage capabilities to respond to dramatic shifts in supply and demand quickly.

1.3 An Orientation to this Report

The remaining content in this report is separated into five major sections.

- *Section 2 The Resilience of the Gas System* describes the various inherent, physical, and operational characteristics of the gas system that contribute to the resilience of the US energy system.

- *Section 3 Proving It: Resilience in Action* details five case studies that demonstrate how gas distribution companies across the country have demonstrated gas system resilience through real-world examples.

- *Section 4 Current Regulatory, Policy, and Market Structure* summarizes how current regulatory, policy, and market structures create challenges for building gas resilience assets.

- *Section 5 Ensuring A Resilient Future* explores how decarbonization-driven changes to the electric system may present challenges for future resilience and lessons learned from other economic sectors.

- *Section 6 Conclusions* presents a call to action for how the findings in this report can be used and their implications for policymakers and regulators.

[8] NOAA. National Climate Report – August 2020. https://www.ncdc.noaa.gov/sotc/national/202008

[9] EIA. *Smoke from California Wildfires Decreases Solar Generation in CAISO.* September 30, 2020. https://www.eia.gov/todayinenergy/detail.php?id=45336

[10] California Independent System Operator. 2020. *Preliminary Root Cause Analysis.*

2. The Resilience of the Gas System

This section explores the fundamental resilience characteristics of the gas value chain and describes how it provides resilience services to customers. These characteristics are detailed further in Section 3 in case studies that demonstrate gas system resilience through real-world examples.

2.1 Fundamental Resilience Characteristics of the Gas System

Guidehouse examines the fundamental inherent, physical, and operational characteristics of the gas system in relation to their contribution along the resilience curve phases, i.e. how they help the gas system prepare for, withstand, recover from, and adapt to a resilience event. Table 2-1 outlines the key questions considered in evaluating these characteristics within the gas value chain.

Table 2-1. Key Questions Used to Identify Resilience Characteristics

Resilience Phase	Key Identifying Questions
1. Preparation	• Does it help the system prepare for or prevent threats? • Does it reduce the physical exposure of system infrastructure to the threat?
2. Withstanding	• Does it help minimize system impacts or sensitivity to potential disruptions? • Does it help prevent the occurrence of cascading failures? • Does it help the system maintain functioning if a disruption occurs?
3. Recovery	• Does it assist in restoring or repairing lost functionality?
4. Adaptation	• Does it help the system adjust to changing climate or operating conditions? • Does it facilitate learning and resilience investments to prevent future threats?

Source: Guidehouse

Gas system characteristics that contribute to energy system resilience are highlighted in Figure 2-1. they are also discussed in greater detail throughout this section.

Figure 2-1. Resilience Characteristics of the Gas System

Inherent Resilience of Gas

A molecular form of energy storage; the natural gas molecule is an abundant energy form with long-duration and seasonal storage capabilities.

- Compressibility
  - Storage
  - Linepack
- Abundance and Diversity of Supply

Physical Resilience of Gas System Assets

Most gas system assets are underground and shielded from major disruptions. In most cases, the system is self-reliant, reducing its exposure to disruption.

- Underground infrastructure
- Looped and Parallel T&D Network
- Self-Reliant Gas-Fired Equipment
- Distributed Customer Generation
- System Storage Capacity

Operational Resilience of the Gas System

Operational flexibility is designed into the gas system within a set of system standards that ensure the system's safety and security.

- Robust Management Practices
- Flexible Delivery
- Demand Side Management
- Large Customer Contract Design

Source: Guidehouse

2.2 Inherent Characteristics of Gas Resilience

As a molecular form of energy storage, natural gas molecules have several inherent characteristics that contribute to the resilience of the gas system. Chief among these characteristics is its compressibility, which allows additional volumes of gas to be packed into the pipeline or under- and above-ground storage. Natural gas supply is also abundant and geographically diverse, allowing it to meet current energy needs even in the event of a supply chain disruption. The inherent characteristics also hold true for low carbon forms of gas supply which may replace natural gas in the future gas system. Table 2-2 summarizes the inherent characteristics of gas resilience, which are also discussed further in this section.

Table 2-2. Inherent Resilience Across the Phases of Resilience

	Resilience Phases			
Characteristic	**Preparation**	**Withstanding**	**Recovery**	**Adaptation**
Compressibility Storage Linepack	Reduces sensitivity to disruptions		Buffers against cascading failures	
Abundance and Diversity of Supply		Maintains production in the event of a regionally isolated supply-side disruption		Low carbon options for a future energy system

Source: Guidehouse

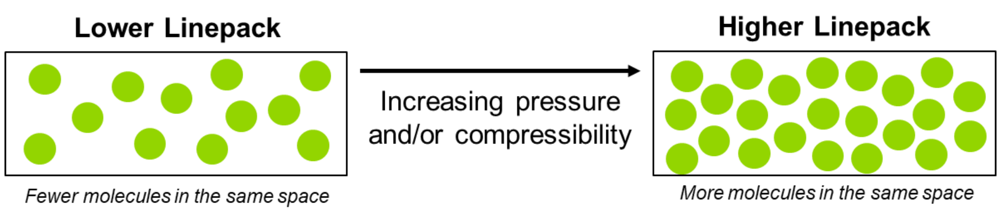
2.2.1 Compressibility

Natural gas is made up of inherently stable and compressible molecules, making it a desirable energy storage carrier and pipeline system buffer.

- **Storage –** Long-duration gas storage is frequently used to meet seasonal demand patterns and can be used as a complement to the electric system in meeting demand during low-likelihood, high-impact resilience events. Natural gas can be compressed and stored underground in geological formations (e.g., in depleted gas reservoirs, aquifers, or salt caverns) or aboveground in tanks (as LNG or CNG). As LNG, the volume of natural gas is about 600 times smaller than its gaseous form at atmospheric pressure; whereas, as CNG, it is 100 times smaller.

- **Linepack –** Excess natural gas molecules, i.e. more than what would be needed to meet customer demand can be compressed and stored within pipelines, acting as a buffer to minimize the impact of short-term hourly supply and demand fluctuations on the gas system (Figure 2-2).[11] Gas system operators, including LDCs, can control the amount of linepack in the pipes, allowing them to meet rapid, intraday changes in demand even if upstream supply is insufficient.

Figure 2-2. Linepack and Compressibility of Gas



Source: Guidehouse

Figure 2-2 provides a clear example of how linepack and storage can be used in tandem to prevent and mitigate the effects of a major gas system disruption. These characteristics are different from the electricity grid where disruptions can immediately impact all connected gas systems and increase the risk of cascading failures. Electric supply and demand must be balanced across the electric system near instantaneously and electricity can only be stored in specified storage assets, such as batteries.

2.2.2 Abundance and Diversity of Supply

Natural gas is supplied from a variety of sources across North America, including:

- **Conventional production:** Currently, natural gas is primarily produced from shale plays and formations; it is also produced in smaller quantities from conventional gas reservoirs, tight sands, carbonates, and coal-bed methane. Figure 2-3 highlights the geographic diversity of US shale plays and formations. Additionally, an evaluation by the Potential Gas Committee at year-end 2018 indicated that the US possesses a technically recoverable resource base of natural gas of nearly 3,400 trillion cubic feet (Tcf).[12] The US Energy Information Administration additionally reported that US proved

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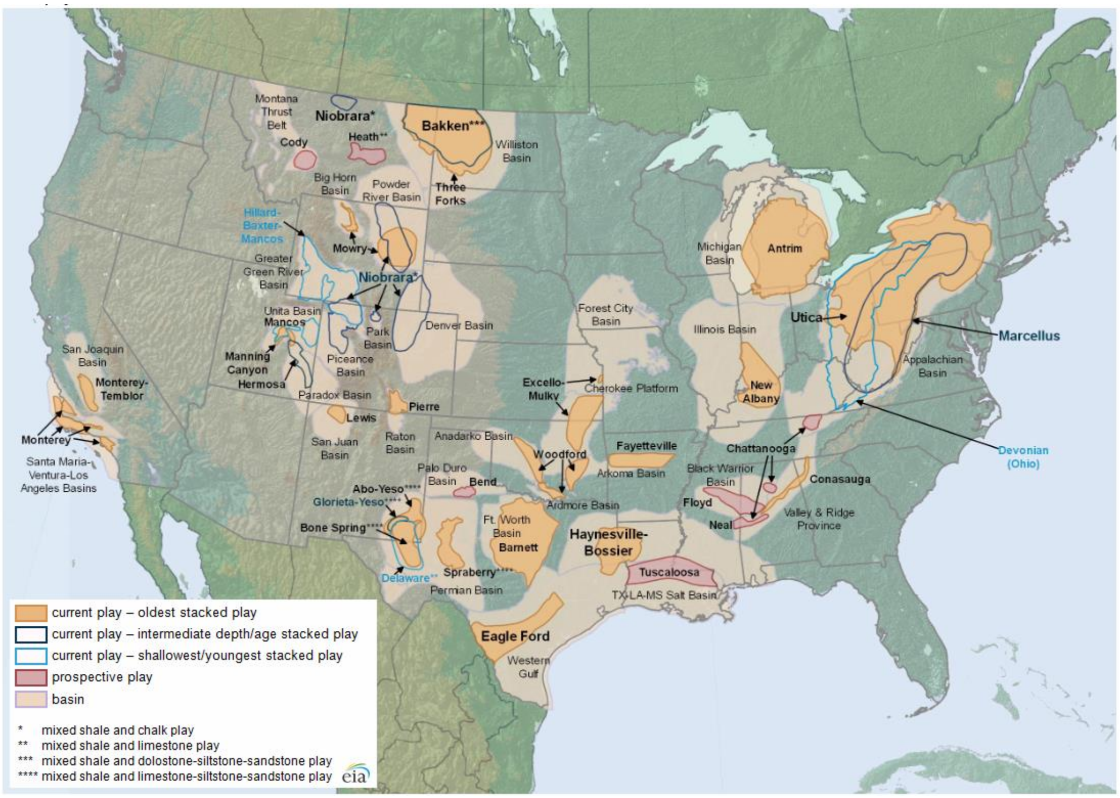
[11] Natural Gas Council. 2019. *Natural Gas: Reliable and Resilient.*

[12] Potential Gas Committee. 2019. *Potential Supply of Natural Gas in the United States.* Accessed November 2020.

reserves stood at 504.5 Tcf as of 2018. The combination of these supplies suggests a future gas supply resource enough to meet over 100 years of consumption at current levels.[13]

This abundance and diversity of natural gas supply ensures that natural gas can continue to meet customer demand even during regionally isolated supply-side disruptions such as a major storm event. For example, limited supply interruptions during recent hurricanes demonstrates the value of shifting natural gas production from the Gulf of Mexico to geographically diverse shale plays and formations.

Figure 2-3. US Shale Plays and Formations



Source: US Energy Information Administration

- **Low Carbon Production:** The abundance and diversity of resources transportable through the gas system will increase as RNG and hydrogen become increasingly commercially viable. Though it is only a small portion of current US gas supply, RNG supply is growing dramatically--produced from a variety of waste feedstocks from the sewage, agriculture, food, and forestry sectors, as detailed in Appendix B. Hydrogen is projected to serve a larger portion of future US gas demand, but it is earlier in the process of developing commercial viability in the US, though it is already flowing through the pipes in Europe as discussed in Appendix B.

[13] Natural Resources Canada. 2020. *Natural Gas Facts.* Accessed October 2020.

- **Pipeline Imports:** Natural gas is also imported via pipeline from Canada, and from elsewhere as LNG. These are critical supply sources during peak periods and lend to greater gas system flexibility.

2.3 Physical Characteristics of Gas System Resilience

The gas system's physical characteristics lend themselves to providing stability to the energy system. Most pipeline infrastructure is underground and looped, creating flexibility in a delivery system that is shielded from many major disruptive events. Much of the gas delivery system also runs on its own supply, making it self-reliant. The ability to store gas further strengthens the self-reliant attributes of the gas system, enabling it to respond to disruption or an extreme peak caused by unprecedented demand or upstream disruption. Table 2-3 summarizes these physical characteristics of gas resilience, which this section also discusses.

Table 2-3. Physical Resilience Across the Phases of Resilience

	Resilience Phases			
Characteristic	**Preparation**	**Withstanding**	**Recovery**	**Adaptation**
Underground Infrastructure	Reduces exposure to threat	Minimizes impact of potential disruptions		
Looped and Parallel T&D Network		Improves deliverability in the event of regionally isolated gas network disruption		
Self-Reliant Gas-Fired Equipment			Maintains gas delivery during an electric grid outage	
Distributed Customer Generation		Reduces electric grid demand during extreme weather event	Enables customer flexibility in the event of an electric grid disruption outage	
System Storage Capacity	Prepares system for expected demand increase	Balances supply and demand fluctuations	Improves deliverability during disruption	Facilitates supply-side diversity (renewable integration)

Source: Guidehouse

2.3.1 Underground Infrastructure

Natural gas is one of the few energy resources predominantly delivered to customers by pipeline. In contrast, other common energy forms, such as electricity, are mostly delivered by aboveground wires. Although each delivery method has advantages, the underground gas delivery system has significantly reduced exposure to disruptive events from extreme weather such as hurricanes and snowstorms. Because of this, significant weather events rarely disrupt localized segments of the network and damage is typically limited to aboveground facilities where pipeline assets may be exposed.[14]

[14] EIA. *Natural Gas Explained: Natural Gas Pipelines*. Accessed October 2020.

2.3.2 Looped and Parallel Transmission and Distribution Network

The gas system is extensively interconnected with multiple pathways for rerouting deliveries. This interconnectivity enables the sourcing of natural gas from various production centers across the country. Additionally, distribution mains are typically interconnected in multiple grid patterns with strategically located shut-off valves. These valves allow operators the ability to isolate segments of a gas system, which minimizes customer service disruptions. To reinforce the resilience of gas delivery, the valves are paired with on-system storage and mobile pipeline solutions.

> *A 2019 study by the Rhodium Group on natural gas system reliability indicated that, "the US natural gas system typically deals with a handful of disruptions every month that last a day or more. Despite these disruptions, deliverability to end-use sectors, including electric power generators, is rarely impacted because of the redundancy built into the system."[15] While this study focused on reliability, it highlights the system redundancy that is available to respond to higher-impact resilience events.*

In addition to the interconnectivity of the gas system design, pipeline capacity is often increased by installing two or more parallel pipelines in the same right-of-way (called pipeline loops), making it possible to shut off one loop while keeping the other in service. Further, in the event of one or more equipment failures, gas pipelines can continue to operate at pressures necessary to maintain deliveries to pipeline customers, at least outside the affected segment. Considering customer impacts of individual equipment failures in the design of gas pipelines and facilities to determine where investment in redundant infrastructure is prudent, is part of the gas utility risk management process.

2.3.3 Self-Reliant Gas-Fired Equipment

Much of the equipment used on the gas system, including compressors, dehydration equipment, pressure regulators, and heaters, are usually powered by the gas that flows through the pipes they serve. Powering equipment by the gas in the system limits the gas system's reliance on external supply chains. If gas continues to flow through the pipes—which has demonstrated to be a resilient supply chain itself—the gas system will continue to operate, and gas will flow to customers.

In some cases, the pursuit of decarbonization goals has resulted in the replacement of gas compressors with electric compressors. While electric compressors are not yet widespread, their use does reduce this resilient aspect of gas system operation.

2.3.4 Distributed Customer Generation

The US Department of Energy has documented how combined-heat and power (CHP) systems serve as a resilience solution, with specific case studies on how CHP has provided resilience for critical facilities during major weather events, giving them the flexibility to produce thermal energy and electricity onsite.[16] Example 1 highlights one such case study. CHP systems at

[15] Rhodium Group. 2019. *Natural Gas Supply Disruption: An Unlikely Threat to Electric Reliability*.
[16] US Department of Energy. 2018. "CHP Technology Fact Sheet Series."

these facilities are largely dependent on the resilience of the US gas system and its ability to continue delivering natural gas during resilience events.

At the end of 2019, there were 3,186 commercial and industrial (C&I) CHP sites fueled by natural gas with a total capacity of 58,140 MW.[17] This distributed generation is equivalent to over 5% of total US electric power generation capacity. Distributed CHP systems exemplify how the gas system supports the resilience of end-use customers by giving them alternative options to generate heat and electricity in the case of unplanned energy system disruptions. The costs and inconvenience of a power outage can be substantial, including losses in productivity, product, revenue, and customers. Gas-fired standby generators also provide a resilience benefit by helping to avoid the impact of a power outage. This benefit is discussed further in Case Study 5.

Example 1. CHP and Distributed Generation Support Critical Infrastructure During Extreme Weather Events[18]

Hurricanes. In 2008, Hurricane Ike flooded over 1 million square feet of the University of Texas Medical Branch (UTMB) in Galveston, Texas. The hurricane interrupted utility services and resulted in the complete loss of UTMB's underground steam distribution system. Learning from this experience, the UTMB installed a 15 MW CHP facility (11 MW fueled by natural gas) to improve resilience and allow for an immediate return of hospital and clinical operations.

This resilience solution was tested during Hurricane Harvey in 2017 when the campus lost power. In circumstances that would have otherwise caused a blackout, the CHP system continued to operate during and after the storm, allowing the hospital to maintain regular operations. As a co-benefit, the CHP system saves UTMB approximately $2 million per year in utility costs and reduces campus emissions by 16,476 tons of CO_2 per year.

2.3.5 Gas System Storage Capacity

The ability to store large quantities of energy supply is a fundamental strength of the gas system allowing it to respond to, prepare for, withstand, and recover from disruption. In addition, gas storage facilities offer further geographic supply diversity to the gas system, as these storage assets can often maintain supply if disruptions are experienced on the system. Gas system storage capacity is built as a result of long-term planning in response to forecasted seasonal and peak demand. Gas system storage can be classified by where it is connected to the gas value chain.

- **On-System Storage:** This storage is operated and controlled by the LDC, allowing it to respond quickly to peak demand requirements and emergency situations. On-system storage is often aboveground, and in some situations underground. One advantage of on-system storage is that it can be sited at specific locations on the gas distribution system to best provide a resilience benefit (both supply and pressure support) in the event of an upstream disruption. This benefit is exemplified in Case Study 4.

[17] U.S. Department of Energy. 2019. *U.S. Department of Energy Combined Heat and Power Installation Database*. Accessed October 2020.

[18] Southcentral CHP Technical Assistance Partnerships. 2019. *Project Profile: University of Texas Medical Branch 15 MW CHP System*. Accessed October 2020.

- **Off-System Storage:** This storage is connected to a transmission line and is not directly tied to an LDC's distribution system. In most cases, off-system storage is underground, which makes it resilient to many climate-driven disruptions.
- **Mobile Storage:** Stored as LNG or CNG, natural gas can be moved via truck to serve short duration needs such as providing temporary supply for emergency response, pipeline maintenance, and construction and peak shaving.

The gas system's storage capacity is critical to its ability to respond to disruption. For example, the gas system storage capacity allows the gas system to respond to extreme heat and cold events when large amounts of gas are drawn in a short period. In addition, system storage provides a supply buffer allowing the LDC vital time to respond to unplanned delivery constraints in the pipeline and distribution network, resulting from gas system disruptions. The capacity of US gas storage and the associated value of that storage is further explored in Example Box 2.

Example 2. The Value of Gas Storage

In 2019, the US consumed approximately 31 trillion cubic feet of natural gas. If this natural gas was consumed in the same amount every day, the US would consume approximately 85 Bcf per day (Bcfd). But natural gas usage is seasonal – in January 2019, the US consumed nearly 110 Bcfd on average compared to approximately 71 Bcfd in June.[19]

With seasonal fluctuations in use and additional fluctuations in daily consumption, gas storage plays a vital role in balancing supply and demand. The US has nearly 400 underground storage facilities in the lower 48 states with a total storage capacity of more than 4,000 Bcf. In 2019, approximately 2,300 Bcf of natural gas supply was delivered from storage facilities, roughly the energy equivalent of 700 million megawatt-hours (MWh).[20]

NW Natural operates the Mist underground storage facility in Oregon. Its 20.1 Bcf of gas storage capacity is equivalent to 6 million MWh. Installing a battery of equivalent size on the electric system would cost approximately $2 trillion in 2020 dollars.[21]

Storage assets are additionally well positioned to support future state resilience demands and are capable of using low carbon commodities. These long-lived assets can be re-missioned to meet evolving energy system resilience requirements.

2.4 Operational Characteristics of Gas System Resilience

The industry has several operational tools at its disposal to prepare for, withstand, recover from, and adapt to disruptions. The gas system has robust management practices for the flows of gas on the system and there are several opportunities to provide flexibility in delivery and to manage demand. Table 2-4 summarizes these operational characteristics of gas resilience, which are also discussed further in this section.

[19] https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm

[20] https://www.eia.gov/naturalgas/ngqs/#?report=RP7&year1=2019&year2=2019&company=Name

[21] https://www.nrel.gov/docs/fy19osti/73222.pdf

Table 2-4. Operational Resilience Across the Phases of Resilience

	Resilience Phases			
Characteristic	**Preparation**	**Withstanding**	**Recovery**	**Adaptation**
Robust Management Practices	Activates backup resources, prevents and mitigates cyber threats, improves response to disruptions, facilitates learning from unanticipated disruptions			
Flexible Delivery			Improves gas deliverability during extreme conditions	
Demand-side management and energy efficiency	Reduces demand before and during extreme events		Provides gas system operators demand-side control during disruptions	
Large customer contract design		Flexibility to curtail non-firm transport customers		

Source: Guidehouse

2.4.1 Robust Management Practices

The gas industry maintains safe and resilient operations using a variety of tools including long-term resource planning, emergency response planning, standard operating procedures, and incident-response protocols. The industry also has a well-established Mutual Aid Program that allows utilities to provide and receive aid from other utility members in the event of disaster or emergency situations.[22] Pipeline operators are trained per the US Department of Transportation's pipeline safety requirements.

Gas utilities also follow robust cybersecurity protocols,[23] and align their cybersecurity programs to several key frameworks and standards including the NIST Cybersecurity Framework, the ISA/IEC 62443 Series of Standards on Industrial Automation and Control Systems (IACS) Security, ISO 27000, NIST 800-82, the TSA Pipeline Security Guidelines, and API Standard 1164.[24] Gas assets are also designed with manual override and manual backups in case of cyber disruption.

2.4.2 Flexible Delivery

In addition to on-system storage, some LDCs use mobile pipeline solutions. These non-pipeline solutions are frequently LNG or CNG tanker trucks that deliver needed supplies directly to an injection point on the distribution system in the event of a gas system disruption. The ability to deliver through multiple pathways is a valuable characteristic of the gas system.

[22] American Public Gas Association. *Mutual Aid Program.* Accessed November 2020.
[23] Oil and Natural Gas Sector Coordinating Council; Natural Gas Council. 2018. *Defense-in-Depth: Cyber Security in the Oil and Natural Gas Industry.*
[24] Natural Gas Council. 2019. *Natural Gas: Reliable and Resilient.*

Example 3. Operational Management Helps Prepare for and Withstand Extreme Weather Events

During the January 2019 polar vortex, a severe wave of cold weather swept over the midwestern US, bringing temperatures to well below -20°F in several states. Minnesota experienced its lowest air temperatures since 1996, reaching a low of -56°F and wind chills below -60°F in some areas.[25]

Leading up to the event, CenterPoint Energy used gas system modeling and SCADA to predict how its gas system would react to the extreme cold temperatures. Based on this data, CenterPoint Energy deployed two CNG trailers to strategic locations where additional supply might be needed and placed field crews on standby across the state. Engineering, operations, and gas control were in constant communication, as is standard practice for most cold-weather events. Though CenterPoint Energy's gas system met demand during record temperatures without the need of the CNG trailers, this example highlights how gas LDCs use robust management practices to prepare for and withstand extreme weather events.[26] CenterPoint Energy's response to the 2019 polar vortex is highlighted further in Case Study 1 in Section 3.

2.4.3 Demand Side Management and Energy Efficiency

Gas system operators have a robust toolbox to safely, effectively, and efficiently accommodate demand. Many gas utilities offer demand side management (DSM) and energy efficiency programs to support their customers in managing their gas consumption, while some are also piloting demand response (DR) programs that can include controllable devices such as connected thermostats. Implementation of these programs frequently results in resilience benefits. For example:

- Residential customers participating in weatherization programs to reduce their energy use associated with heating and cooling will enjoy a home that is more efficient and can better maintain comfortable indoor temperatures. These residents will be better able to shelter in place if they experience disruptions in their energy supply.
- Participation in energy efficiency programs in general will result in more efficient energy usage and lower annual spend on energy.
- DSM and DR programs offer grid operators the opportunity to improve the efficiency and stability of the power system by reducing the severity of demand spikes. Although these programs are often developed to increase reliability, they also offer significant resilience benefits in allowing grid operators the ability to adjust the demand side of the equation when a significant disruption is experienced.

2.4.4 Large Customer Contract Design

Gas system operators contract with large-volume customers in a way that mitigates potential physical constraints around deliverability. Large-volume customers voluntarily enter into either a firm contract (i.e., they are contractually guaranteed an agreed amount of supply, regardless of potential gas system capacity constraint issues) or an interruptible contract (i.e., their service can be interrupted if the gas system is experiencing capacity constraint issues) with the gas system. This means that gas system operators have the flexibility to contractually curtail delivery to large-volume interruptible customers in the event of disruption, a form of demand response, which is one reason why the gas system rarely experiences service disruptions.

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[25] Minnesota Department of Natural Resources. 2019. *Cold Outbreak: January 27-31, 2019.* Accessed October 2020.
[26] CenterPoint Energy, Interview. October 2020.

The definitions of firm and interruptible customers may need further clarification as the gas system sees more large-volume users with dramatic swings in their maximum and minimum usage throughout a day. However, the gas system's ability to contract differently with users that use the gas system differently is a resilience characteristic that must be recognized.

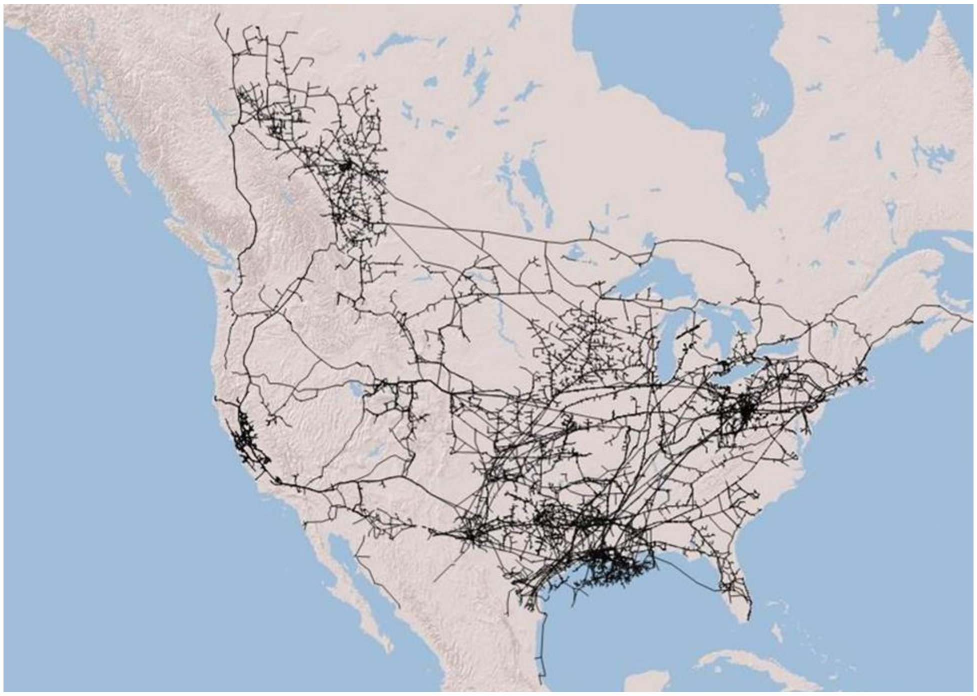
2.5 Resilience Limitations

The overall US gas system's network contributes to its stability but the degree of interconnectedness on the network can vary across LDCs based on the following two primary factors:

- The availability of operational capacity on upstream pipelines and storage
- The physical location of the LDC service territory in relation to pipelines and storage facilities

As Figure 2-4 illustrates, some US regions have more access to the transmission system than others. For example, the Pacific Northwest is supplied by fewer pipelines compared to the Upper Midwest and the Gulf Coast. A gas utility or geographic region with limited access to multiple transmission pipelines will need to leverage other resilience solutions to develop transportation and supply diversity, such as storage.

Figure 2-4. Major North American Natural Gas Pipelines



Source: S&P Global Market Intelligence

3. Proving It: Resilience in Action

The inherent, physical, and operational capabilities of the gas system—from receipt of supply from the upstream pipelines to the ability to provide short-notice storage withdrawal and injection rates—enable it to meet the volatile demand profiles resulting from resilience events. This section includes six case studies that exemplify how the gas system contributes to the resilience of the US energy system.

It is a testimony to the preparedness and true resilience of the industry that there are so few case studies of extra measures ever needing to be taken to respond to periods of extraordinarily high demand.

Polar Vortex (January 2019)

- In Case Study 1, the use of a diverse mix of gas resilience assets (upstream pipelines, storage, LNG and propane storage, flexible non-pipeline assets) allowed the gas system to meet record peak demand resulting from extreme cold temperatures.

- In Case Study 2, the integral role the gas system plays in supporting the space heating needs of customers in colder climates is explored. The case study also demonstrates that during a peak event, the gas system currently delivers substantially more energy than the electric system is built to deliver.

- In Case Study 3, the resilience attributes of the gas system were put to the test when a fire caused a failure on a critical gas compression and storage facility. Despite losing almost one-third of its on-system storage, the gas utility withstood this failure during a period of peak demand without involuntary loss to a single residential customer.

Polar Vortex (February 2014)

- In Case Study 4, the role of natural gas storage, both underground and aboveground, as a critical resilience solution to meet record gas demand is demonstrated.

Hurricane Isaias (August 2020)

- In Case Study 5, natural gas was used as a backup power source to ensure essential power functions could continue to be met for residential and commercial customers in the middle of a hurricane.

Heat, Drought, and Wildfires (August 2020)

- Case Study 6, storage capacity resources were used to meet the supply needs of gas-fired generation plants when the California electric system experienced high demand from a record-breaking heatwave and unplanned reductions in other sources of generation.

Case Study 1: Meeting Record Peak Demand (Minnesota)

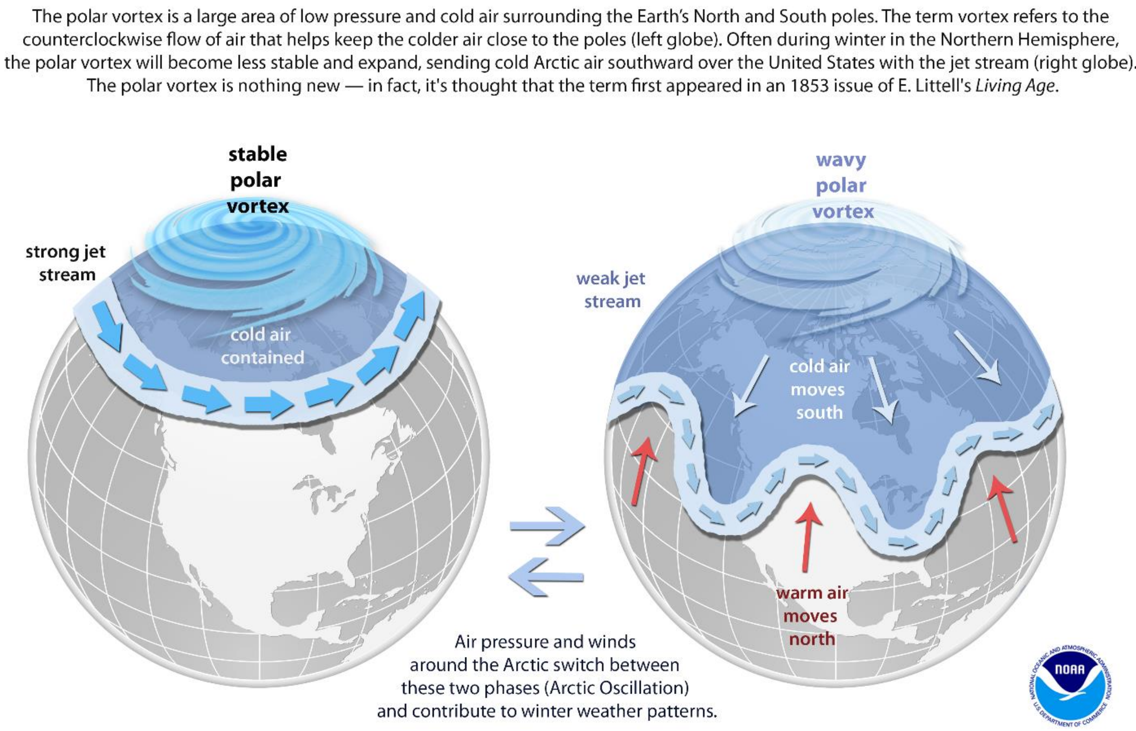
Key Finding

CenterPoint Energy used a diverse mix of gas resilience assets (upstream pipelines, storage, LNG and propane storage, flexible non-pipeline assets) to meet record peak demand resulting from extreme cold temperatures across the Midwest.

Introduction

The first three case studies pertain to the January 2019 Polar Vortex, when a weakened jet stream resulted in the coldest temperatures in over 20 years to most affected regions across the US and Canada (Figure 3-1). The event resulted in at least 22 deaths and grounded around 2,700 flights across the Midwest and Northeast.

Figure 3-1. The Science Behind the Polar Vortex



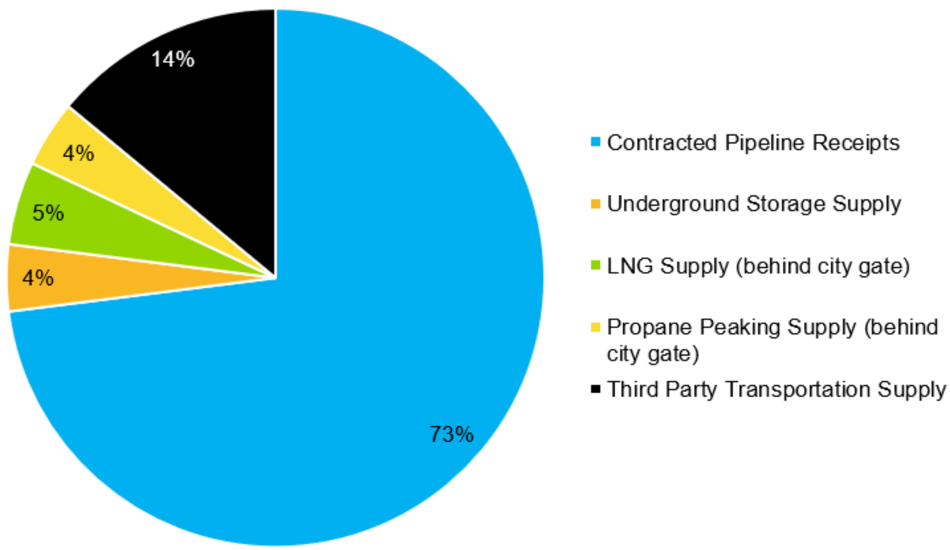
Source: National Oceanic and Atmospheric Administration

Overview

During the January 2019 Polar Vortex, in Minneapolis, Minnesota, the average temperature was -19°F from January 29 to 30. The coldest hour occurred at 6:00 a.m. on January 30 when the temperature was -30°F (before wind chill). On these days, CenterPoint Energy (which serves 870,000 customers in the greater Minneapolis region) experienced record daily delivery of natural gas of 1,495,000 Dth on January 29 and 1,448,000 Dth on January 30. This compares to 1,000,000 Dth of daily sendout in a typical January day, or a 49% and 44.8% increase over average for January 29 and 30, respectively.

Because the demand for gas was so high on CenterPoint's gas system on January 29 and 30, interruptible customers and interruptible transportation service deliveries were curtailed to maintain distribution system integrity for firm demand customers. Even after curtailing these customers, CenterPoint Energy needed to pull gas supply from every available source, as Figure 3-2 illustrates. Approximately 13% of the gas delivered to CenterPoint's customers in Minneapolis on these very cold days was supplied by storage, including LNG and propane assets, which played a critical role in providing additional supply and pressure to maintain gas system integrity.

Figure 3-2. Gas Supply by Source, CenterPoint Energy, Minneapolis, Minnesota, January 29-30, 2020



Source: Guidehouse, CenterPoint Energy

Like many gas utilities, this planning consists of a thorough review of gas supply plans and monitoring of distribution system performance in addition to heightened staffing to be prepared for quick response to issues.

Table 3-1. CenterPoint Energy Actions to Maintain Gas System Viability During the 2019 Polar Vortex

Phase of Resilience	CenterPoint Actions to Maintain Gas System Deliveries in Response to the 2019 Polar Vortex
1. Preparation	• Daily review of supply plans by gas supply, gas control, peak shaving, and engineering. • Daily preparation and execution of cold weather engineering plans. • Daily staging of operations technicians in critical locations to monitor/react. • Daily staffing of engineering personnel in the cold weather ops center to support system operations and gas control. • Dispatch Center: Extra staff added to coordinate with field operations. • Field operations: Implementation of cold-weather operating plans.

Phase of Resilience	CenterPoint Actions to Maintain Gas System Deliveries in Response to the 2019 Polar Vortex
	• The areas requiring CNG trailer deployment were identified using system modeling and SCADA to help predict how the system would react during the cold event. • Two CNG trailers were deployed and on standby. These flexible non-pipeline solutions provided just in time delivery to reinforce system operations
2. Withstanding	• Aside from the CNG locations, CenterPoint Energy positioned several field crews at different locations throughout its service territory on standby to be responsive should an unexpected issue arise. In addition, critical groups, including engineering, operations, and gas control were in constant communication to monitor the system.
3. Recovery	• The system did not incur any damage or major disruptions, so there was no recovery phase for this event.
4. Adaptation	• System reinforcements were identified and later completed for the areas where CNG trailer were deployed. • Regular review of distribution system performance as cold weather occurs. • Adjustments are made if needed and as possible. • Testing and operation of stations and equipment.

Source: Guidehouse, CenterPoint Energy

Conclusion

CenterPoint Energy's use of a diverse mix of gas system resilience assets to meet record peak demand from a climate event exemplifies how the gas system contributes to the energy system's overall stability. Upstream pipelines, storage, LNG and propane storage, and flexible non-pipeline assets were deployed for addressing unplanned or unforeseen events within the integrated energy system.

Case Study 2: The Role of Natural Gas (Illinois)

Key Finding

During the 2019 Polar Vortex, Nicor Gas, Peoples Gas, and North Shores Gas' daily distributions of natural gas (7.32 Bcf) were equivalent to 90GW of electricity—more than 3.5 times the amount of electricity that ComEd, the electric utility serving a similar territory has delivered in a single day. The gas system provides value in the volume of energy that can be delivered during peak events, which will require significant infrastructure buildout to be replaced.

Introduction

During the record-breaking cold weather that occurred January 30 and 31, 2019, Nicor Gas, the LDC serving 2.2 million customers in Illinois delivered more than 4.88 Bcf of natural gas per day. This is more than double the natural gas delivered on a typical day in January day. In terms of energy delivery, this amount of gas, an average of 0.20 Bcf per hour, compares to approximately 61 GW of electricity.[27] This is the single largest delivery of natural gas in the company's history—surpassing previous records set when 4.5 Bcf was delivered between January 6 and 7, 2014.

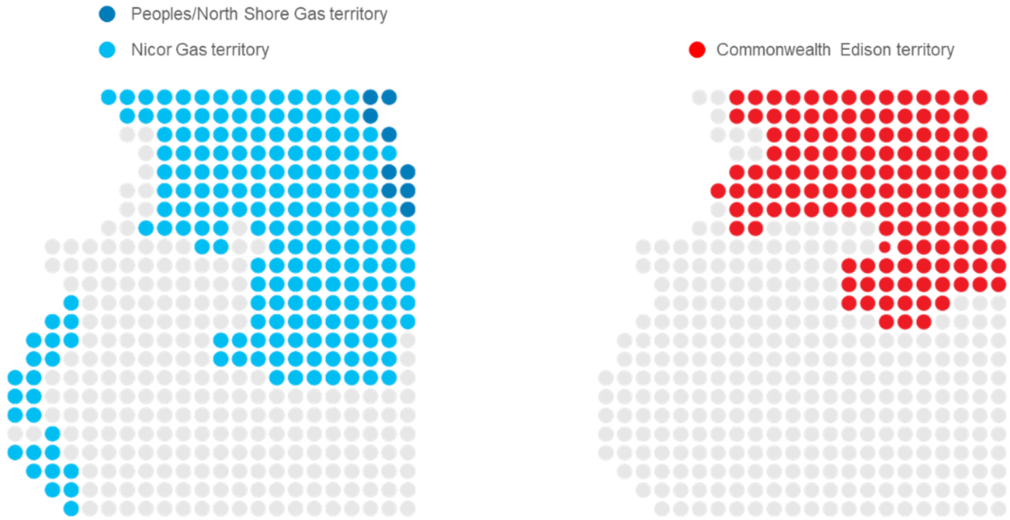
Nicor Gas employees worked around-the-clock during this cold weather to monitor the distribution system to ensure the safe performance and reliability of the infrastructure. More than 7,000 customer calls were received at the customer contact center and field operations responded to nearly 1,500 emergency calls for service during the two days. There were no major service outages during the weather event.

Overview

On January 30, 2019, together Peoples Gas, North Shore Gas, and Nicor Gas distributed more than 7.32 Bcf of natural gas—this is comparable to approximately 90 GW of electricity and represents more than 3.5 times the amount of electricity that ComEd, the electric utility serving northern Illinois, has ever delivered in single day (Figure 3-3). Even on a typical day, the Nicor Gas system alone delivers an amount of energy that is approximately equal to the maximum amount of energy that ComEd has ever delivered on a single day. The historic peak delivery day for the ComEd system is 24.8 GW, which occurred on July 20, 2011.

[27] Calculation: 4.88bcf/24 hours*10^9 scf* 1,020 Btu/scf * 1 kWh/3,412 Btu = 60, 785, 463 kW (or 60.8 GW)

Figure 3-3. Energy Distribution by Northern Illinois Utility



Utility	Peak demand (gas)	Peak demand (electricity)
Peoples Gas/North Shore Gas	~2.44 Bcf	~30.4 GW*
Nicor Gas	4.88 Bcf	~60.8 GW*
ComEd Historic Peak Demand on July 20,2011		24.8 GW

Source: Nicor Gas Company

There are several takeaways for regulators and policymakers that emerge from this case study. First off, it is critical to understand the implications of electrification on infrastructure investment, not just for a typical day, but for a peak event.

The gas system plays an integral role in supporting the space heating needs of customers in colder climates. Moreover, in the wintertime, space heating requirements typically begin to increase in the early morning and late afternoon hours; these are times when intermittent, renewable resources may not be available. Without the gas system, battery storage with significant duration and capacity capabilities would be required to bridge the gap between generation from intermittent, renewable resources and heating demands.

The gas system provides value in the volume of energy that can be delivered during peak events, which will require significant infrastructure buildout to be replaced.

Case Study 3: Ray Compressor Station Fire (Michigan)

Key Finding

Despite the loss of availability of the largest storage facility on its gas system, Consumers Energy was able to serve all of its customers without any involuntary disruption during a period of record cold temperature and peak demand.

Introduction

As the CenterPoint Energy and Nicor Gas case studies demonstrate, the Polar Vortex of January 2019 placed enormous stress on the gas delivery system under record-setting conditions. When extreme cold weather hit Michigan from January 29 to February 1, Consumers Energy was prepared to fulfill demand utilizing gas storage and pipeline supply as the primary supply sources. Consumers Energy had 61.9 Bcf of working natural gas inventory, above its target of 61.4 Bcf during a typical winter.

Gas storage fields play a critical role in enabling Consumers Energy to serve its customers during times of peak demand. They are used to meet demand at various levels:

- **Baseload demand:** Along with pipeline supply, baseload storage fields run daily during the winter to meet a foundation level of demand.
- **Intermediate demand:** Intermediate storage fields run during longer periods of higher demand.
- **Peak demand:** Peaker (and needle peaker) storage fields run during the extreme hours and days when demand changes quickly, typically in the early morning when customers start their day and their gas appliances.

Consumers Energy operates 15 storage fields with a total working capacity of 149 Bcf. The largest, the Ray Peaker field, has a capacity of 47.52 Bcf, or almost one-third of Consumers Energy's working storage capacity. The Ray facility is a combination compressor station and adjacent storage field.

Consumers Energy planned to fulfill demand during this cold period using baseload production storage fields, Ray field, and pipeline supply as the primary sources. Its other peaker fields were in reserve to support gas system packing and address any potential interruptions in pipeline supply, baseload fields, and compressor stations.

Incident

At approximately 10:30 a.m. on January 30, a fire occurred at the Ray Natural Gas Compressor Station. The fire reduced the amount of natural gas Consumers Energy could deliver to customers from underground storage in the Ray field near the compressor station. The damage to its largest storage and delivery system, which occurred during historically high natural gas demand due to cold temperatures, prompted Consumers Energy to take steps to ensure gas deliveries to its customers continued uninterrupted.

Response

Consumers used a variety of inherent, physical, and operational resilience characteristics to respond to the supply disruption during historic cold temperatures. Throughout the entire event, not a single critical, priority, or residential customer lost service involuntarily.

Table 3-2. Summary of Resilience Characteristics Used by Consumers Energy

Date	Key Resilience Characteristics
2018	• Consumers Energy held a training exercise in 2018 with a scenario involving a fire at Ray Compressor Station. This prepared employees by providing an opportunity to **rehearse emergency response** roles and responsibilities.
January 24, 2019	• In preparation of forecasted extreme cold temperatures, notice was given to **interruptible customers** that interruptible service would not be available beginning January 25.
January 30, 2019	• System **linepack** provides immediate buffer to sudden loss of storage supply from approximately 10:30 a.m. to 8:00 p.m. • At 10:45 a.m., Consumers Energy leveraged its **networked system** by calling five major interconnected pipelines that agreed to provide supply on a best effort basis. • **Peaker storage fields** were dispatched and began flowing at approximately 11 a.m., reducing sole reliance on linepack. • At 1 p.m., Consumers Energy began requests for **voluntary load reductions** from 104 of its highest volume customers. • Procurement of additional supply. • Formal **curtailment** for large transport customers began at approximately 3 p.m. • At 8 p.m., Consumers Energy worked with the governor to use the **Emergency Broadcast system** to ask residential customers for voluntary natural gas reductions. • Near 11 p.m., some of the Ray facilities supply capabilities were returned to service.
January 31, 2019	• Continued curtailment enables additional 40,000 Mcf of demand reduction.
February 1, 2019	• Announcement of cessation of curtailment at 8:22 a.m.

Source: Guidehouse, Consumers Energy

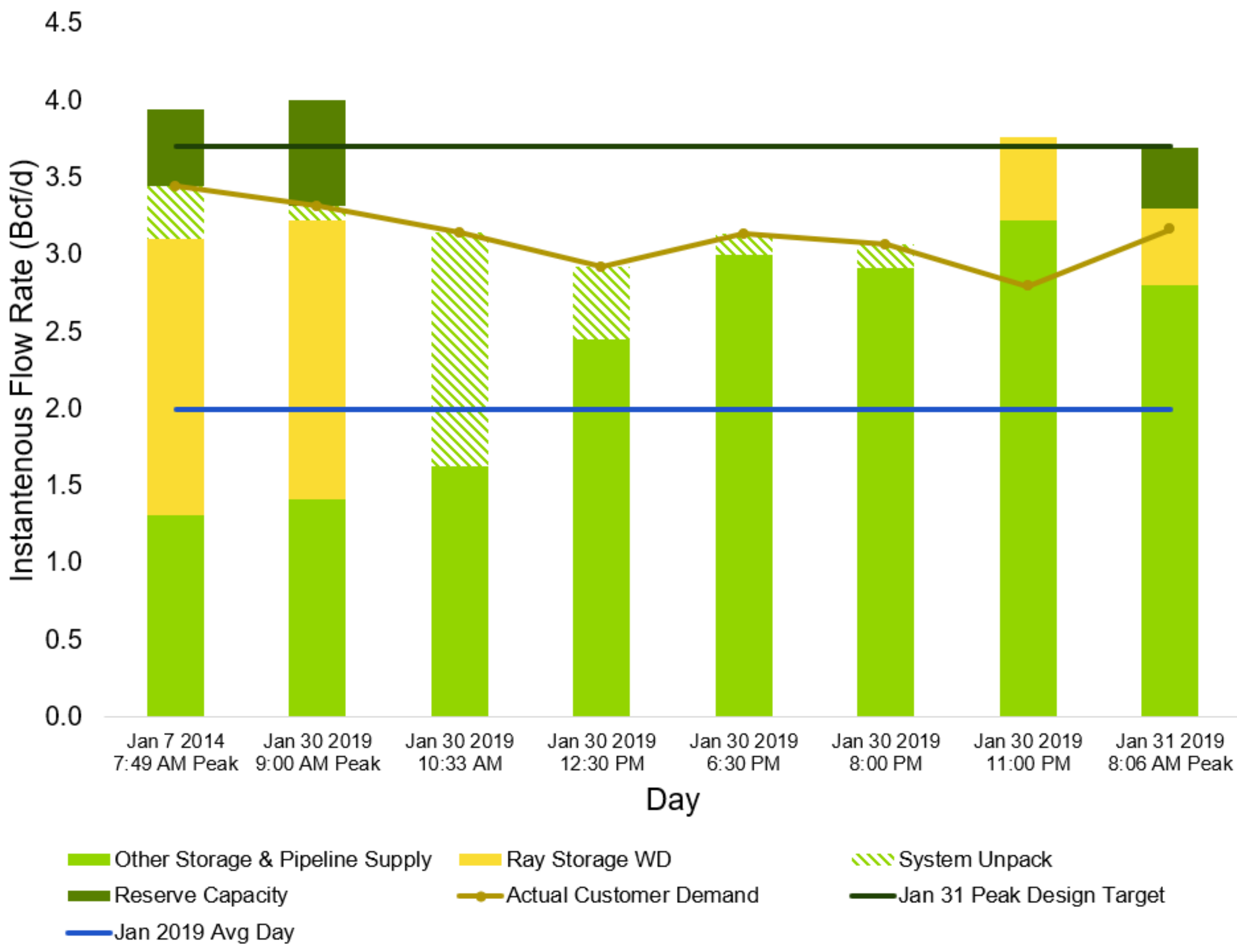
As Figure 3-4 shows, the loss of gas supply from the Ray facility caused the gas system to begin unpacking at an excessive rate. Unpacking means the amount of gas and the available pressure in the pipeline are decreasing and it occurs when the rate of total supply is lower than the rate of total delivery to customers. Figure 3-4 depicts the status of supply, demand, rate of gas system unpack,[28] and Ray Field flow on January 7, prior to the event. It also shows several points including the peak hour of January 30 at 11:00 p.m. and the peak hour of the next day at

[28] Unpack refers to the system's use of linepack.

8:06 a.m. on January 31. The loss of Ray and the rate at which the pipeline system was unpacking caused key gas system pressures to decline at excessive rates.

Shortly after the fire-gate alarm was received, Consumers Energy Gas Control adjusted the storage field rate orders to dispatch all peaking storage fields at maximum flow rates including those fields on standby. The peaking storage fields added approximately 975 MMcf/day of supply. The dispatch of the peaking fields maximized the total amount of storage supply delivered and reduced the gas system unpack rate. In addition, additional supplies provided by neighboring pipelines helped to mitigate the loss of supply from the Ray storage field (shown in light green in Figure 3-4 and the corresponding reduction in gas system unpack is shown in light green cross-hatching).

Figure 3-4. Consumers Energy System Supply, Demand, and Reserve Capacity January 30-31, 2019



Source: Guidehouse, Consumers Energy

Consumers Energy took several steps to mitigate the impact of the loss of access to the Ray storage field. These steps included requests for voluntary reductions in gas usage of all customers. Consumers Energy also implemented an Operational Flow Order (OFO) for the first time in its history for natural gas transportation customers, which required those customers to match their natural gas deliveries to Consumers Energy's system to their usages. When the requests for voluntary actions and the OFO did not result in the reductions in gas usage necessary to stabilize the gas system, Consumers Energy implemented a mandatory curtailment of gas deliveries to large business customers for the first time in its history, which required a reduction in their natural gas usage down to minimum loads required to protect equipment. In cooperation with Governor Whitmer, Consumers Energy also requested all-natural gas customers in Michigan to conserve natural gas by dialing down their thermostats. On Thursday, January 31, Consumers Energy announced that the appeal for assistance would end at 12:00 a.m. on February 1 for all customers—commercial, industrial, and residential.

Conclusion

This Ray Compressor fire event and the subsequent recovery by Consumers Energy is a unique story of the resilience characteristics of the gas system. Despite the loss of availability of the largest storage facility, not a single critical, priority, or residential customer lost service involuntarily during a peak of record cold temperature throughout the region, due to the fire-gate event.

Consumers Energy was able to withstand, recover, and adapt due to diligent advanced preparation and execution of its emergency response plan during the event. Access to physical assets is a key contributor to resilience. The ability to use alternate flow paths within facilities enables the recovery of the gas system and the return to customer's ability to use gas normally. Consumers Energy's ability to use existing storage assets as a first response demonstrates this opportunity. However, practice, preparation, and planning are also critical contributors to resilience, as demonstrated by Consumers Energy's response.

The company's capabilities in emergency management, including the use of an Incident Command System (ICS), enabled it to respond rapidly and organize into an ICS structure that included both a command post and an Emergency Operations Center (EOC). The well-defined chain of command, incident objectives, and tactics allowed for effective internal coordination of resources. It also enabled fast, complete, and transparent engagement with the MPSC, State Emergency Operations Center (SEOC), and the Governor's office throughout the event. Furthermore, it provided an organized approach to protect life and safety, to stabilize the incident, and to protect property and the environment.

Case Study 4: The Role of Winter Gas Storage (Oregon)

Key Finding

Storage assets, in combination with diligent planning and dedicated employees, play a critical role in providing natural gas during periods of critical demand in response to cold weather events.

Introduction

Northwest Natural (NW Natural) provides service to approximately 2.5 million people in Oregon and southwest Washington state (Figure 3-5). The Portland metro area represents the largest portion of NW Natural's customer demand, and its weather is characterized by a temperate oceanic climate with warm, dry summers and mildly cold, wet winters.

Figure 3-5. NW Natural Service Territory

Source: NW Natural

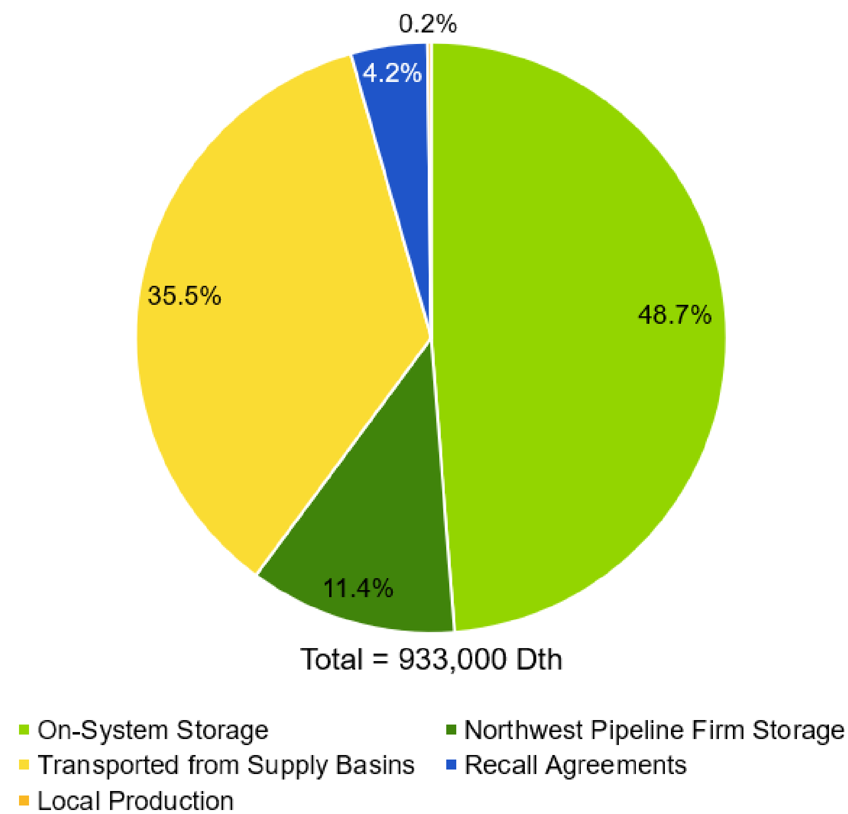
NW Natural personnel oversee the safe operation of 14,000 miles of transmission and distribution mains, monitor deliveries at over 40 interconnections with the upstream interstate pipeline system, and coordinate the usage of three on-system storage facilities (one underground storage and two LNG plants) along with off-system storage. The Gas Control department, as an example, is responsible for forecasting near-term loads, monitoring pressures, flows and other conditions using telemetry data fed from field devices, electronically controlling certain field equipment, and determining the usage rates of the on-system storage facilities, all on a 24/7 basis.

NW Natural's resource planning is designed to meet customer needs during an extreme cold weather event, occurring in late January or early February. One such event occurred in February 2014.

The Winter of 2013-2014

Extreme cold weather in early December 2013 set the stage for a challenging winter. Storage facilities are usually full at the start of the heating season, and large quantities can be withdrawn to meet sudden surges in sales. Stored gas is akin to a large battery, representing energy reserves that can be held indefinitely while remaining ready at short notice to satisfy customer requirements. On extremely cold days, stored gas is expected to supply approximately 60% of NW Natural's firm sales load (Figure 3-6). On February 6, 2014, total sendout set a record of 900,000 Dth that still stands today. NW Natural's prior record was 890,000 Dth, set on January 5, 2004. Stored gas played a critical role in meeting this record demand and provided nearly 50% of total sendout on this day.

Figure 3-6. NW Natural Peak Day Firm Resources, as of Nov 1, 2013



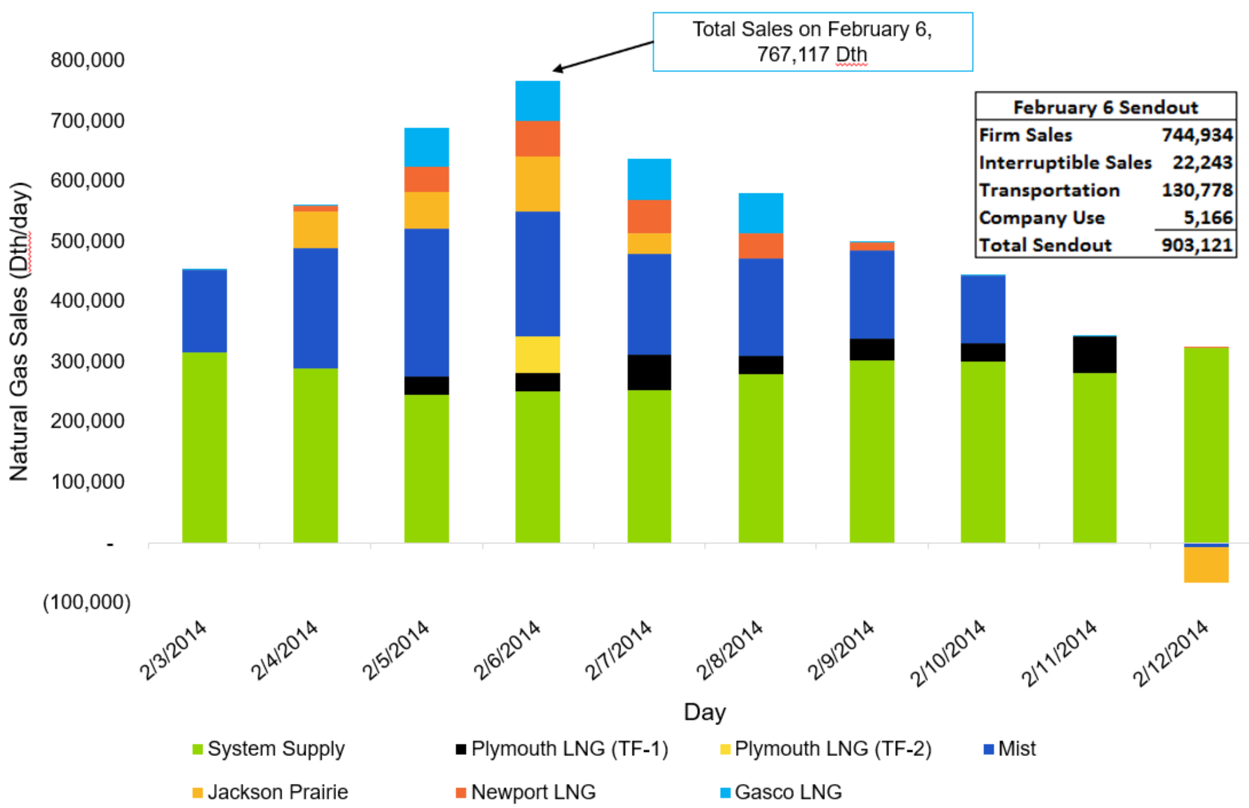
Source: Guidehouse, NW Natural

Stored gas, once withdrawn, will likely not be replenished until the following summer. Also, deliverability from storage can decrease as volumes are withdrawn, so the decision was made in December to procure additional supplies in the market in order to conserve the usage of storage gas. This planning proved extremely valuable later in the season.

The Peak Event

During early February, cold temperatures were accompanied by about a foot of snow and freezing rain. While this winter storm episode was not quite as long and cold as that experienced in the December event, a very high wind chill factor increased customer demand by an estimated 10 percent over what would be normal based on cold temperatures alone. During this period, storage resources were relied on heavily for both economic and delivery resilience reasons, growing to over 50% of daily sales requirements and then subsiding within a week's time (storage resources are all non-green colors in Figure 3-7).

Figure 3-7. NW Natural Resource Utilization During Cold Weather Event, February 3-12, 2014



Source: Guidehouse, NW Natural

Similar to the December event, in February, NW Natural had employees monitoring and controlling gas pressures at specific locations in North and East Vancouver (Washington), Southwest Salem, and South Eugene. The company also rotated two CNG trailers to support the morning peak demand in an isolated area of Northwest Vancouver, Washington.

Employee dedication and resourcefulness during the peak event included field crews manually controlling pressure regulators to ensure the maximum amount of gas could move through the pipes, storage operators working around the clock to maximize gas availability, Gas Control working with the upstream interstate pipeline to increase gate station throughput, and service technicians responding to four times the normal volume of customer calls.

Snow and ice took their toll on the gas system, requiring exceptional emergency response. For example, trees burdened by snow fell onto buildings and gas meters, some members of the public lost control of their vehicles and ran into gas meters, and parts of buildings collapsed onto gas meters. Some employees had to carry chainsaws in order to remove fallen trees blocking their way.

Aftermath

Several parts of NW Natural's service territory had seen significant customer growth over the prior two decades, and experience gained during the 2013-14 winter confirmed the need to reinforce the supply system to these areas. Besides reports of a handful of isolated customer outages, the only significant distribution system problem was in Clark County, Washington, where service had to be curtailed to four industrial interruptible customers during the morning burn hours.

Curtailment of service to interruptible sales and interruptible transportation customers is an explicit feature of NW Natural's resource planning. During the winter of 2013-14, interruptible customer curtailments were minimal because supplies were abundant, capacity was relatively unconstrained, and the gas system showed its resilience during weather conditions that tested but did not reach the extremes of the company's resource planning standards.

Case Study 5: Hurricane Response (New Jersey)

Key Finding

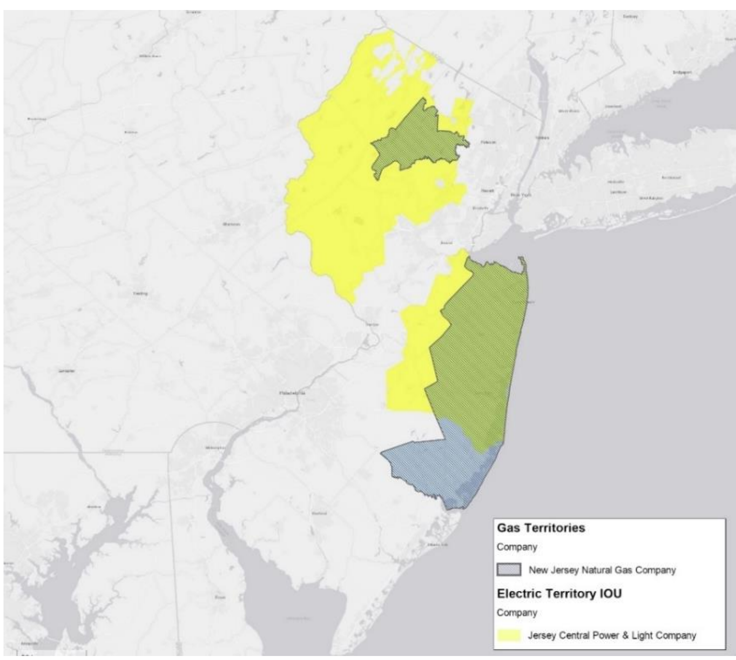
New Jersey Natural Gas Company delivered significantly more gas than normal in a short period to support backup electric power generation for residential and commercial customers in the middle of a hurricane.

Introduction

Hurricane Isaias was a destructive Category 1 hurricane that caused extensive damage across the Caribbean and the US East Coast. The hurricane made landfall near Ocean Isle Beach, North Carolina on August 4, 2020. Shortly after landfall, it was downgraded to a tropical storm.[29] When the storm reached the New Jersey region, it caused extensive damage and caused power outages that affected more than 1 million New Jersey homes and businesses.

Of the +1 million homes and businesses that lost power during Hurricane Isais, 788,000 were customers of Jersey Central Power & Light. As these customers saw an outage in their electric service, many turned to their natural gas generators to meet their power needs. New Jersey Natural Gas (NJNG), the gas provider for much of Jersey Central Power & Light's territory (Figure 3-8), experienced a massive increase in gas demand as these gas generators turned on.

Figure 3-8. Service Territories for Jersey Central Power & Light Company and New Jersey Natural Gas Company



Source: S&P Global Market Intelligence

[29] Len Melisurgo. August 8, 2020. "As bad as Tropical Storm Isaias was, here's why experts say N.J. dodged a bullet." *NJ.com*.

Overview

On Monday, August 3, the day before Hurricane Isaias caused the power outages, NJNG supplied 54,000 Dth to customers. On Tuesday, in response to the significant electric outages, NJNG supplied 84,536 Dth to customers, an almost 60% growth in daily demand in 24 hours. By the end of the week after most of the power was restored, the daily gas supplied by NJNG had dropped back to 58,394 Dth, in line with pre-storm sendout. Table 3-3 details the natural gas supplied by NJNG between August 3 and August 9, 2020.

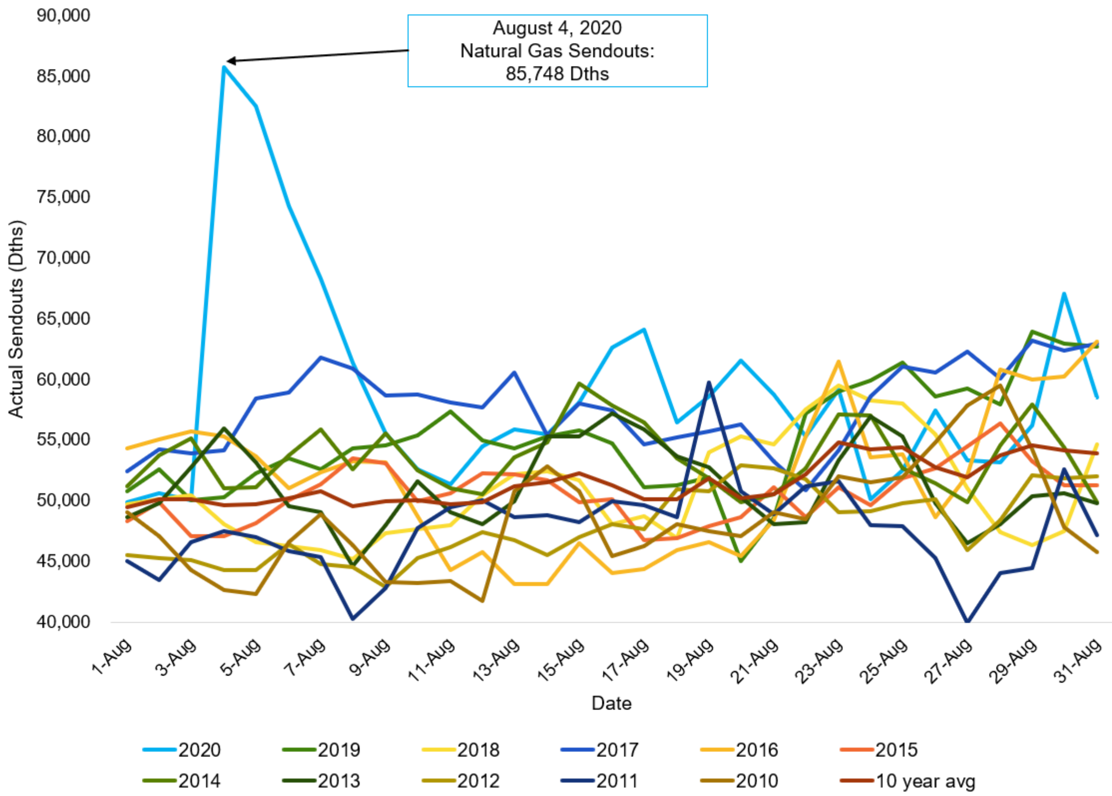
Table 3-3. NJNG Load Sendout: August 3, 2020 through August 9, 2020

Day	Date	Base Load Sendout (Dth)	Notes
Monday	8/3/2020	54,000	Pre-Storm Baseline
Tuesday	8/4/2020	85,536	Storm Hit 788,000 JCPL customers impacted
Wednesday	8/5/2020	84,198	Widespread Power Outages
Thursday	8/6/2020	78,688	Widespread Power Outages
Friday	8/7/2020	71,497	Widespread Power Outages
Saturday	8/8/2020	62,945	Majority of Power Restored
Sunday	8/9/2020	58,394	Majority of Power Restored

Source: Guidehouse, New Jersey Natural Gas

The daily natural gas output supplied by NJNG from August 4 through August 7, 2020 was higher than the daily output of any other August day for the previous 10 years. Figure 3-9 shows the 10-year average sendout from NJNG, the sendout from NJNG for the month of August 2020 identifying the dramatic peak from August 4 through 7, and the actual sendout from NJNG for August 2010-2019.

Figure 3-9. NJNG Comparison of August Actual Sendouts (Firm)



Source: Guidehouse, New Jersey Natural Gas

NJNG accredits most of the 30,000 Dth to 35,000 Dth increase in natural gas sendout during the storm to powering whole house generators, which served as backup power for customers who lost their electric supply. This load increase is estimated by NJNG to correlate with approximately 4,200, 20 kW generators running at full load (calculated using the assumptions in Table 3-4), or likely a larger number of natural gas generators running at partial load.

Table 3-4. Home Natural Gas Generator Assumptions

Generator Size (kW)	therms/ hour	dth/ hour	dth/ day	At 30,000dth/day number of 20 kW generators
20	3.00	0.30	7.20	Approximately 4,200

Source: Guidehouse, New Jersey Natural Gas

Conclusion

In August 2020, NJNG was not only able to withstand the hurricane, but it was also able to ramp up natural gas sendout quickly by relying on storage, allowing thousands of homes and businesses across New Jersey to keep their gas systems in operation when electric service was disrupted. Because of the built-in flexibility and dispatchable nature of the gas system, the gas system can complement the broader energy system as it responds to extreme climate events and keeps power flowing.

Case Study 6: Gas-to-Power Interface (California)

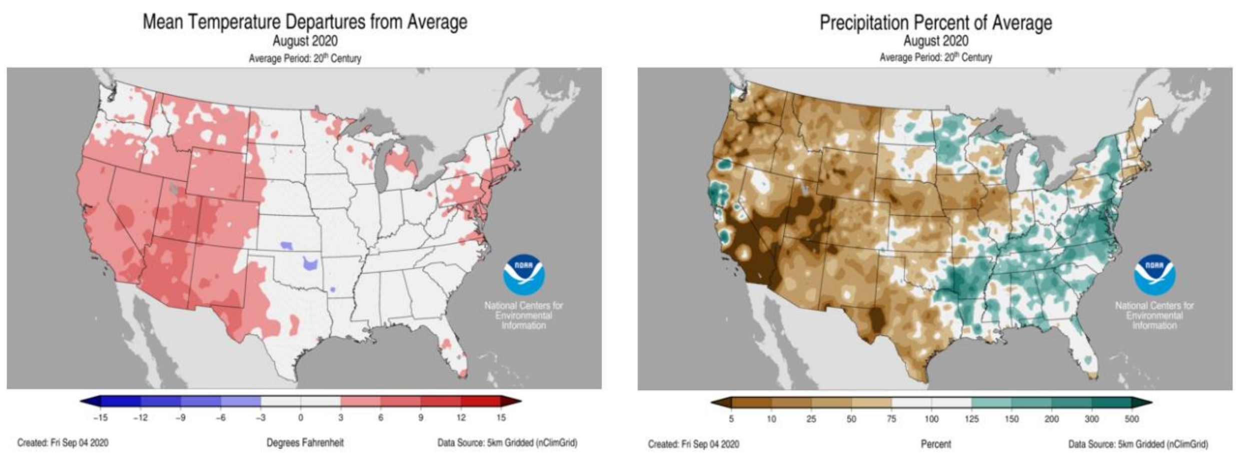
Key Finding

SoCalGas used storage capacity resources to meet the supply needs of gas-fired generation plants when the California electric system was experiencing multiple days of high demand from a record-breaking heatwave and unplanned decreases in other sources of electric generation.

Introduction

In August 2020, California was in the middle of its hottest August (record warmest in 126 years),[30] a severe drought (Figure 3-10), and its worst wildfire season in modern history. While California experienced increased demand on the electric system driven by increased cooling loads, it also experienced a decrease in the renewable output (due to smoke from the fires)[31] and imports than had been anticipated by electric supply planners. During these severe multi-day climate events, the gas system provided the flexible support required to ensure the broader energy system could provide power and prevented more extensive power outages.

Figure 3-10. August 2020 Mean Temperature and Precipitation, Departure from Average



Source: National Oceanic and Atmospheric Administration

On a standard summer day, California's electric grid is supplied by a wide variety of electric generation, renewables, natural gas, hydro, nuclear, coal, and imports from other regions. July 12, 2020 exemplifies a standard summer day in California (while the state was starting to experience a severe drought in July, average temperatures were within the normal range).[32]

[30] NOAA. National Climate Report – August 2020. https://www.ncdc.noaa.gov/sotc/national/202008

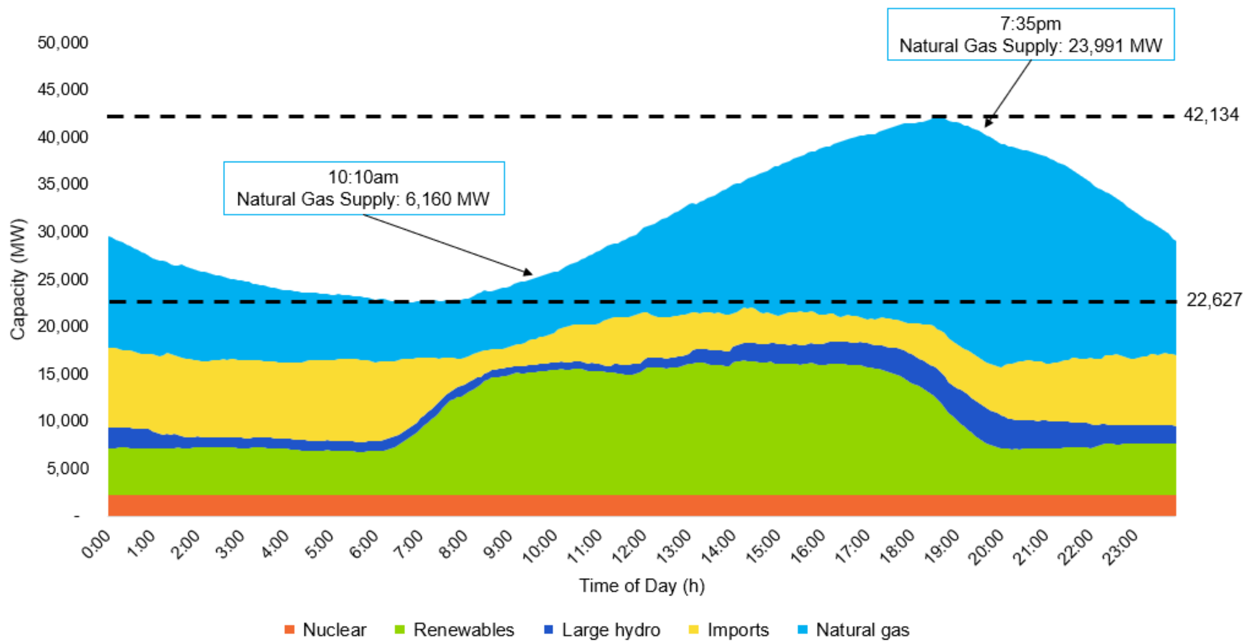
[31] EIA. *Smoke from California Wildfires Decreases Solar Generation in CAISO.* September 30, 2020. https://www.eia.gov/todayinenergy/detail.php?id=45336

[32] NOAA. National Climate Report – July 2020. https://www.ncdc.noaa.gov/sotc/national/202007

Overview

As Figure 3-11 shows, on July 12, 2020 renewable generation began to increase at around 06:30 hrs and remained relatively steady until approximately 17:00 hrs, driven primarily by solar generation during sunlit hours. By 08:00 hrs renewables provide 50% of the state's electric power generation, natural gas provides 25%, and the other sources provide the remaining 25%. As the day continues, gas-fired generation ramps up. By 20:00 hrs natural gas provides 60% of the electric power generation required to meet the peak load.

Figure 3-11. CAISO Supply Trend to Meet Electric Demand, July 12, 2020[33]



Source: Guidehouse, California Independent System Operator

Gas generation plants ramp up to meet peak demand, but the fuel demand of the generation plants is not ratable. Ratable is generally described as levelized demand where deliveries are made evenly throughout a delivery day. The hourly demand for gas to supply these generation plants often exceeds supply receipts, as arranged by the power plants, into the gas system. To overcome the imbalance between supply and use and to respond to the volatile demand needed to maintain the integrity of the electric system, underground storage plays a vital role.

Storage capacity and the stored commodity are contracted for in advance. Underground gas storage is expected to be used to maintain grid load balance and operation on high heat summer days (a hallmark of grid resilience). However, reliance on gas storage systems and the dispatchable nature of gas generation when the energy system is under higher stress (experiencing a resilience event), as seen in August 2020, requires a more significant drawdown of underground storage assets.

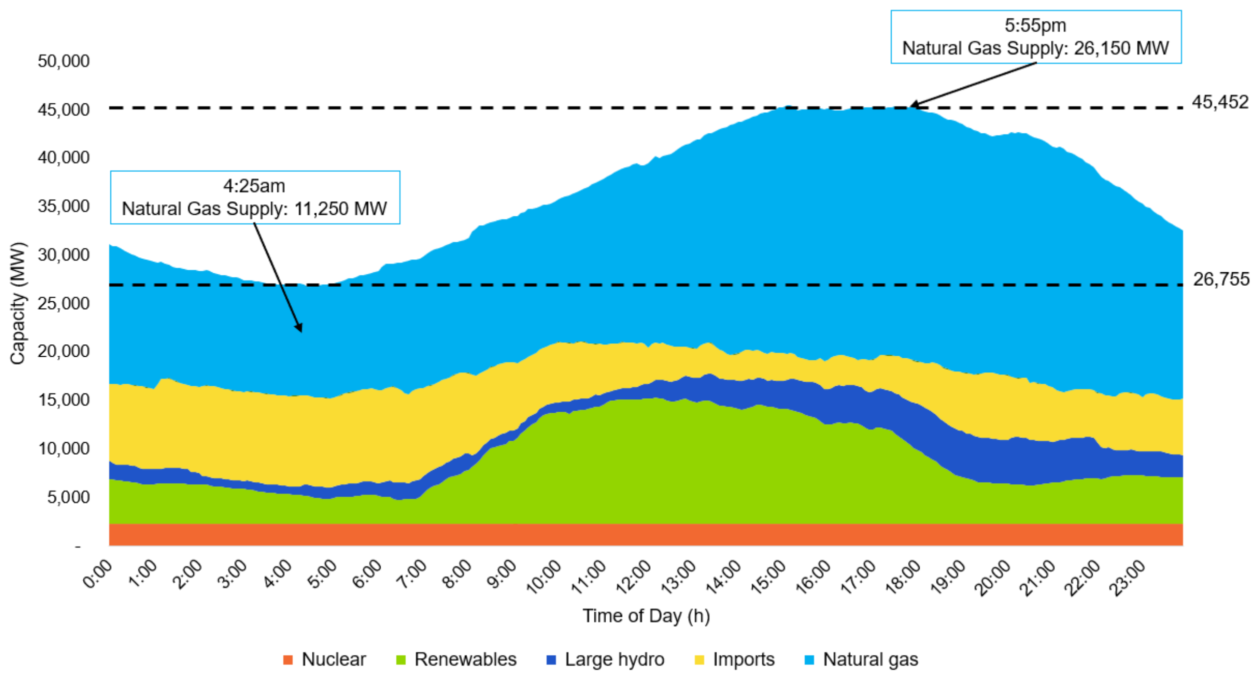
> *During the hours of highest electricity demand, gas generation provides the bulk of California's electric power generation.*[34]

[33] Batteries and coal contribute negligible amounts (± 50 MW) and are not shown within the figure.
[34] CAISO. 2020. "Supply and renewables."

The week of August 11, 2020 is a prime example of the California electric grid under a resilience event—coinciding extreme heat, drought, and wildfires. During this week, California experienced severe climatic events and associated higher electric consumption. Renewable output was also more variable and diminished due to heat, clouds, and wildfires, and power imports were lower than expected, since the entire western half of the US was experiencing the same heatwave as California.

Figure 3-12 illustrates the resources that contributed to CAISO's electric generation on August 17, 2020. Renewable generation supplied less electricity on August 17 compared to July 12 (peaking at around 13,000 MW at 12:00 hrs compared to over 14,000 MW at 14:00 hrs). Peak load was 45,452 MW on August 17, while on July 12 peak load was 42,134 MW. To meet the higher peak load and make up for the lower renewable generation, on August 17, gas-fired generation made up a higher percentage of CAISO's electric power generation capacity.

Figure 3-12. CAISO Supply Trend to Meet Electric Demand, August 17, 2020[35]



Source: Guidehouse, California Independent System Operator

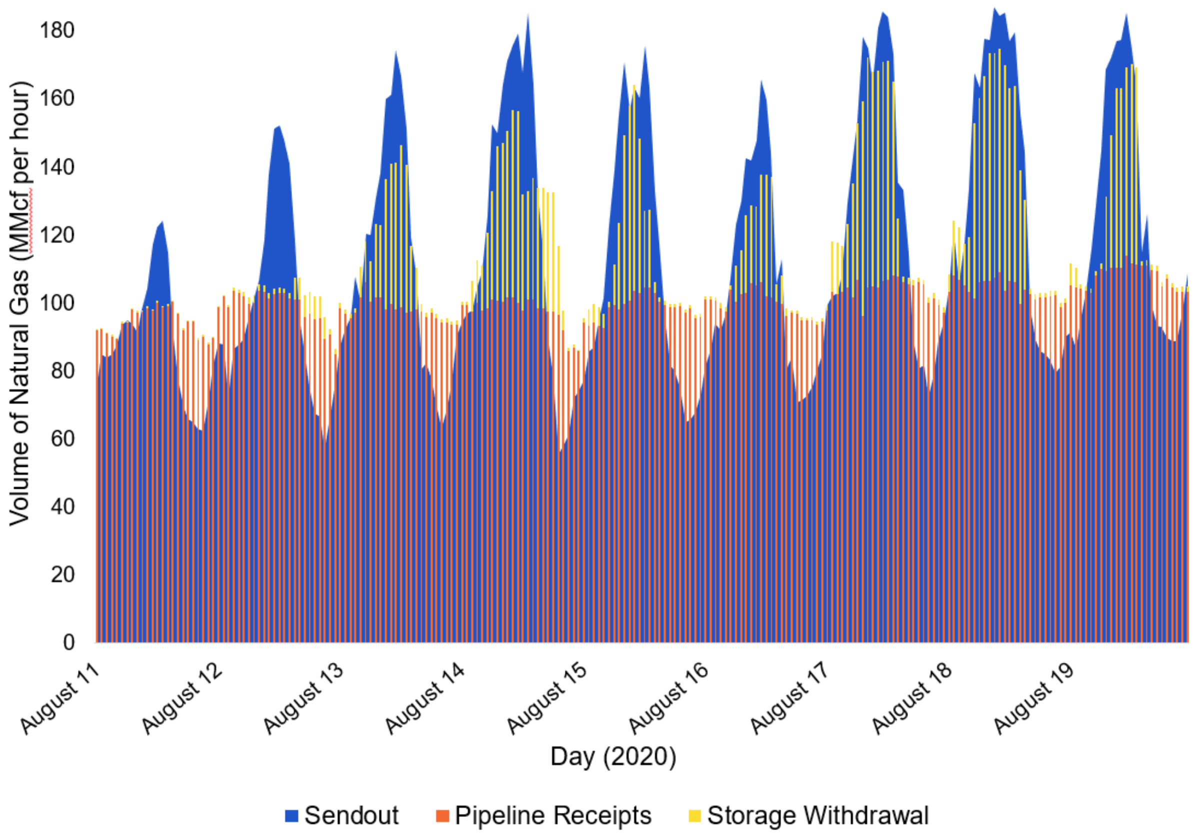
To meet the pressure on the CAISO system during the week of August 11, electric system operators turned to gas-fired generation facilities. To ensure that these generation plants had the natural gas supply to maintain the integrity of the electric grid, SoCalGas had to draw significantly on its gas system storage assets.

Figure 3-13 provides an hourly view of pipeline receipts into the SoCalGas distribution system, sendout, and withdrawals from storage. The blue vertical bars illustrate the hourly demand and sendout from the SoCalGas system. The orange vertical bars depict the quantities that were received into the system, which is generally received in steady hourly quantities over the course of the day. The yellow vertical bars above the receipts illustrate the volumes required to be withdrawn from storage on an hourly basis to meet the far more variable and changing intraday needs of electric generators, which exceeded the gas supplies arranged for delivery into the

[35] Batteries and coal contribute negligible amounts (± 100 MW) and are not shown within the figure.

SoCalGas system each day. The imbalance between daily pipeline receipts and sendout (mostly to serve the load of electric generators) was most significant on August 17 and 18, when sendout for each day was ~3.1 Bcf, while receipts were 2.5 Bcf, resulting in a deficit of ~0.6 Bcf daily, which was required to be made up by on-system storage.

Figure 3-13. Hourly Supply and Demand on the SoCalGas System



Source: Guidehouse, SoCalGas

From August 11 to 19, pipeline receipts on the SoCalGas system were approximately 100 MMcf per hour (2.4 Bcf per day/24 hours). In this same period, deliveries to SoCalGas customers exceeded 100 MMcf per hour during approximately 110 of 168 hours, or 65% of the time. August 11 was the only day SoCalGas was able to meet the peak delivery in excess of pipeline receipts through utilization of linepack (i.e., no storage withdrawal). On all following days, withdrawals from underground storage played a critical role when hourly consumption exceeded pipeline receipts.

Hourly withdrawals in excess of the equivalent of 800 MMcfd were experienced more than a dozen times between August 15 and 19. Those withdrawal rates were only possible with withdrawals from all SoCalGas' storage fields, including Aliso Canyon. The week of August 11, 2020, the totality of SoCalGas' system assets were employed to address the shortfall between abnormally high electric demand and low renewable energy generation experienced in Southern California.

Conclusion

Due to COVID-19-related impacts, C&I demand during this period was lower than normal. Although storage was critical to filling the gap between supply and demand, SoCalGas estimates that—had C&I demand been closer to average historic levels—it is likely that the capacity of the SoCalGas transmission and storage system would have been exceeded, which could have resulted in curtailment of electric generation. This is due to SoCalGas' planning standards and priority of services that are primarily focused on core customers, the SoCalGas tariff deprioritizes service to electric generators and allows curtailment during constrained/high demand periods. This situation is not unique to California, in other jurisdictions, electric generation, in the event of a curtailment, is given a lower level of prioritization compared to residential customers.

> *If the gas system was not able to fill the gap between abnormally high electric demand and low renewable energy generation to support the overall resilience of the electric system, Southern California would likely have experienced severe power outages during the system resilience event experienced in August 2020.*

The gas system fosters electric system reliability and serves as a resource that is capable of readily addressing unplanned or unforeseen events within the integrated energy system. When these resilience events occur, electric generators can experience large intraday swings in their need for gas supplies, often with little to no notice. In regions where the intermittent use of the gas system for electric power generation is a significant portion of total gas use on the system, this unpredictable non-ratable flow can stress the physical gas delivery system. Although the physical infrastructure including pipeline transportation and storage assets are in place and able to accommodate this type of intermittent usage, the underlying market framework and regulatory structure were not designed to provide this type of support service to the overall energy system. In general, the regulatory structure does not provide a means to construct and operate investments that provide resilience protection. That the gas system can provide this service demonstrates how resilience is a byproduct of the engineered reliability features of gas delivery system. The result being that the gas system and the gas LDC ratepayers provide this resilience service to the overall energy system without receiving compensation commensurate to its value.

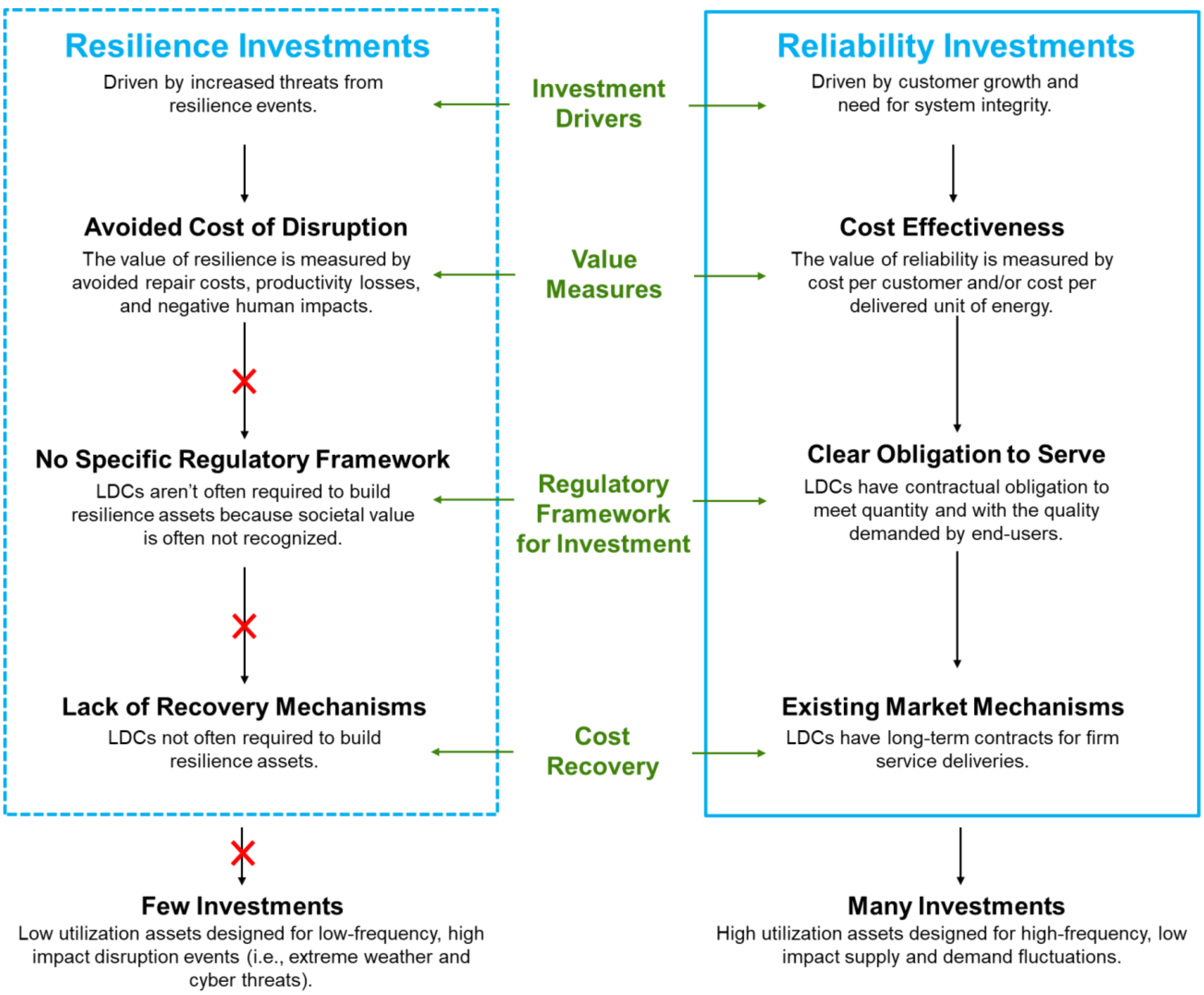
4. Current Regulatory, Policy, and Market Structures

The first half of this report established that the gas system provides resilience to the US energy system. The second half focuses on the regulatory, policy, and market structures that underpin the US energy market. This section explores the current state, including how these structures have developed and the challenges they create. Section 5 considers forward-looking considerations to ensure future energy system resilience.

4.1 The Difference Between Resilience and Reliability Investments

The current market economic framework is designed to support the development of physical assets with high utilization or those backed by long-term contracts. These assets provide reliability services to the energy system. Reliability assets often contribute to the resilience of the energy system as a byproduct, but they are not designed to meet the full needs of a resilience event. Figure 4-1 explores the differences between resilience and reliability investments.

Figure 4-1. Comparison of Resilience and Reliability Investments



Source: Guidehouse

4.2 Historical Context of Gas System Development

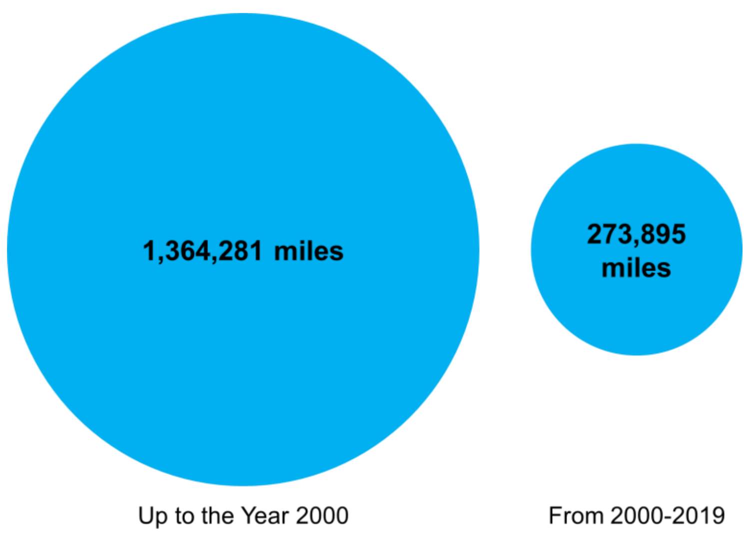
To fully understand some of the challenges in regulatory, policy, and market structures around the development and support for the use of natural gas as a resilience asset, it is necessary to understand the historical context around how these frameworks have developed. In this section, we consider the historical context of the development of the gas system and what implications that has had on the structure and the gas system's current support of energy system resilience.

Natural gas was first used in the early 1820s. However, lacking efficient transportation options, its usage was limited to powering light sources, usually close to natural gas wells. In the late 1890s, gas pipeline construction began and partnered with technological advances, this more efficient transportation of the resource fueled the growth of the US pipeline and connected natural gas wells to users—homes, businesses, and heavy industry. It was not until the late 1990s (really after 2000) that natural gas became a significant source of US electric power generation.

4.2.1 Residential, Commercial, Industrial Load (Pre-2000)

The majority of US natural gas gathering, transmission, and distribution pipeline infrastructure that exists today (approximately 83%) was built out prior to 2000, as Figure 4-2 shows. This infrastructure was built based on a paradigm of predictable and relatively stable demand from residential, commercial, and industrial loads—and stable investor returns. There are several mechanisms that pipeline companies and LDCs use to maintain the integrity of their systems in accordance with Federal law. Across the US, state utility commissions have approved infrastructure modernization programs and pipeline replacement programs to address aging infrastructure. A total of 41 states and the District of Columbia have adopted an approach to support the prioritization, financing, and execution of gas infrastructure upgrades. These programs not only increase the safety of the energy system, but also enhance the future resilience of the energy system.[36]

Figure 4-2. Incremental US Natural Gas Pipeline Additions

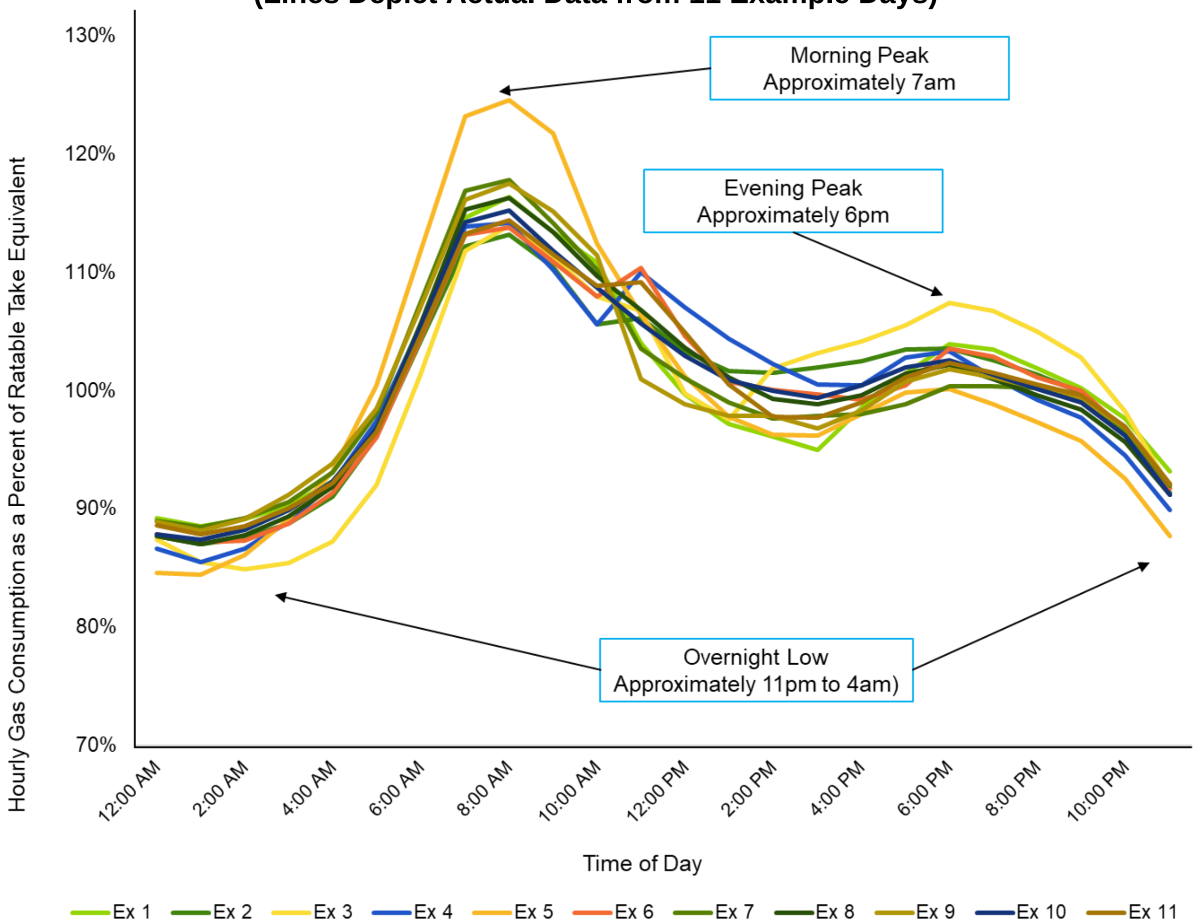


Source: Guidehouse, US Bureau of Transportation Statistics

[36] NARUC, January 2020. Natural Gas Distribution Infrastructure Replacement and Modernization.

The aggregate daily gas demand to serve residential, commercial, and industrial customers is predictable and relatively stable. Gas usage for these customers increases significantly in the morning before slowly decreasing over the course of the day. There is an additional, relatively minor, increase in the evening around dinner time before gas usage drops over the night. Figure 4-3 presents the aggregate load profile for these customers. The figure's y-axis indicates percent variation in hourly gas consumption as a percent of ratable take equivalent[37] and the minimum and maximum peaks only vary -16% to +25% from that daily average.

Figure 4-3. Aggregate Daily Natural Gas Load Profiles, for Residential, Small Commercial, and Industrial Customers (Lines Depict Actual Data from 11 Example Days) *



*Source: Guidehouse, Consumers Energy**

The gas usage pattern is predictable for these customer groups, even in varying climatic conditions. In colder conditions, the usage pattern features less volatility as demand for space heating is more constant throughout a cold day. In warmer conditions, the peaks and troughs widen, and the total daily usage is lower. The predictability of this trend enables gas LDCs to construct and operate the gas system and build new assets with a high degree of confidence in the use of those assets.

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[37] *Ratable take equivalent* refers to the comparable amount of gas consumed in one day on a levelized basis over a 24-hour period, i.e., in even 1/24th increments. This is further discussed in Appendix A, Section A.3.1.

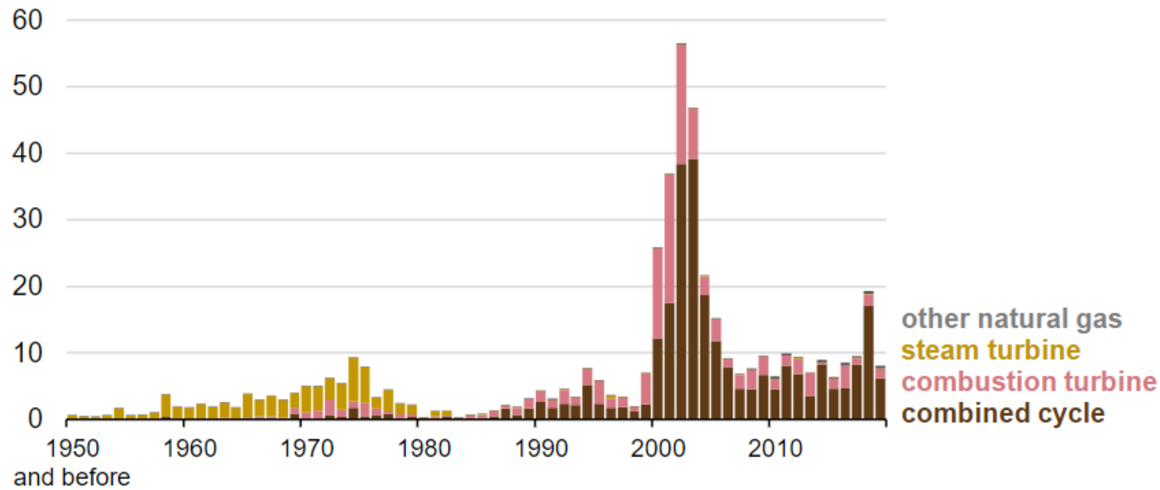
> *The gas system that serves the US today was built to serve the residential, commercial, and industrial sectors, where the relative predictability of usage over the course of a day (ratable takes) and throughout the year for these customer segments enabled LDCs to design, construct, and operate the gas system with a high degree of confidence in how the gas system would be used to serve demand.*

The entirety of the gas value chain's economic and operational framework is underpinned by this ratable system of supply and demand.

4.2.2 Gas-Fired Electric Generation (Post-2000)

When much of the current gas system was designed, the electric sector was a small component of overall demand. Between 1949 and 2000, gas-fired generation provided an average of just 16% of total electric power generation in the US on an annual basis. Since 2000, this has increased significantly. In 2019, natural gas accounted for 38% of US electric power generation and provided 43% of operating US electric power generating capacity.[38] Figure 4-4 explores this trend and shows that most of the growth in gas-fired generation capacity occurred between 2000 and 2020. More information on the role of natural gas in the electric power generation sector can be found in Appendix B.

Figure 4-4. US Gas-Fired Electric Power Generation



Source: US Energy Information Administration

4.3 Natural Gas in Electric Power Generation

There are critical differences in the way that gas-fired generation interacts with the gas system. This section explores those differences. In general, gas-fired generation plants fall into one of two classifications:

1. **High-capacity factor generation:** These low-heat rate/high-efficiency plants support electric power generation by operating often at close to full capacity 24/7.

[38] EIA. 2020. Electricity: Current Issues and Trends.

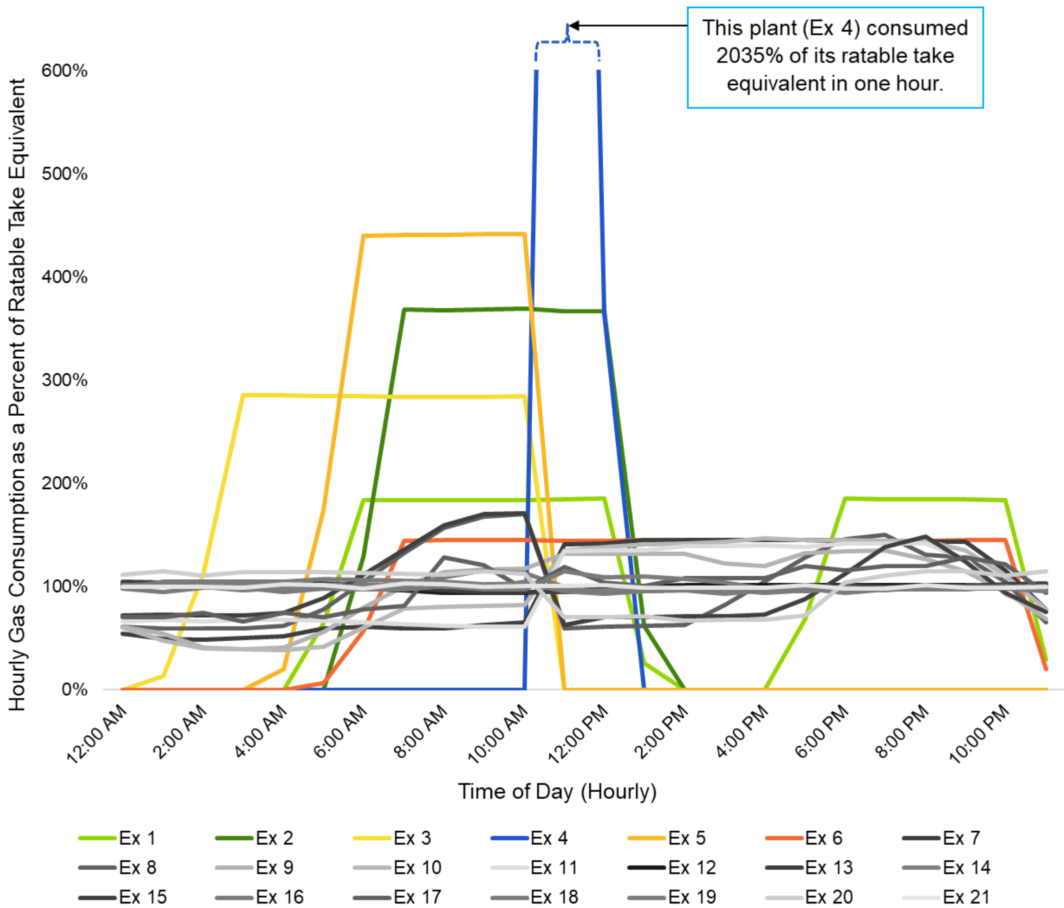
2. **Intermittent generation:** These plants serve as dispatchable resources for electric system operators, ramping their generation up and down quickly to fill the gaps between intermittent generation sources (such as renewable sources) and consumer demand.

4.3.1 Gas-Fired Electric Power Generation Load Profiles

Figure 4-5 illustrates the load profiles of six different gas-fired electric power generation plants over a period of 21 days. Gas load profiles of gas-fired electric power generation plants exhibit far more variance on a daily and hourly basis than the load profiles of residential, commercial, and industrial customers. In Figure 4-5, high-capacity factor generation plants are identified generally in gray (Ex 7 through Ex 21) and those serving intermittent generation capabilities are identified with varying colors (Ex 1 through Ex 6).

The load profile for high-capacity factor gas-fired plants (Ex 7 through Ex 21 in Figure 4-5) generally features a morning and evening peak, and the variation between the highest hour of usage and the lowest hour of usage from ratable take equivalent is 71% to -61%, similar in pattern to the load profiles for residential, commercial, and industrial customers but the magnitude of the swings are larger.

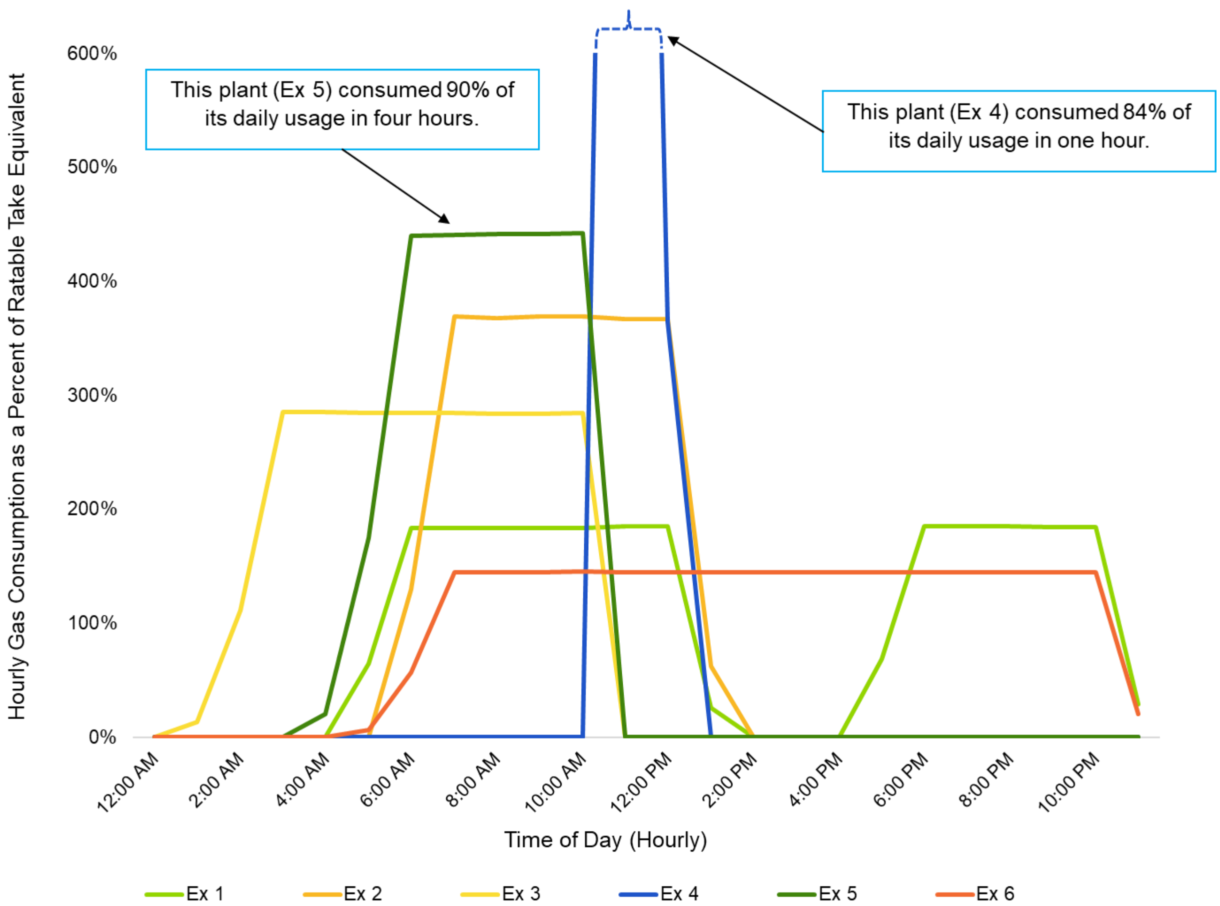
Figure 4-5. Daily Natural Gas Load Profiles for Gas-Fired Electric Power Generation (Lines Depict Actual Data for 21 Example Days, Data is Inclusive of Six Facilities)



Source: Guidehouse, Consumers Energy

Gas-fired plants that run intermittently exhibit a different load profile from the relatively predictable daily variation of high-capacity factor plants. In Figure 4-6, the high-capacity factor generation daily load profiles were removed to focus on the load profiles of intermittent gas-fired plants. The load profiles associated with these plants exhibit a high level of variability and intraday swings, as the plants quickly ramp up and down from their peak rates.

Figure 4-6. Daily Natural Gas Load Profile for Intermittent Gas-Fired Plants (Lines Depict Actual Data for Six Example Days, Data is Inclusive of Six Facilities)



Source: Guidehouse, Consumers Energy

The gas supply required by intermittent gas-fired plants is characterized by large volumes of fuel that are subject to a level of variability and intraday demand swings that are vastly different from how the residential, commercial, and industrial sectors consume gas over the course of a 24-hour period.

> *Intermittent gas-fired plants are primarily used to fill gaps between other intermittent generation sources (such as renewables) and customer demand for electricity. They are only capable of fulfilling this role because the gas delivery system enables the delivery of supply to serve the swings needed to provide such a quick-start response. Although the gas system fulfills these needs, the physical delivery system and the supporting market mechanisms and commercial terms that govern day-to-day operations were not designed for this type of usage*

4.3.2 Implications for the Gas Delivery System

Upstream pipeline deliveries to the gas distribution system occur at relatively steady hourly quantities throughout a day, but gas is not consumed in even hourly increments over the course of a day. Gas distributors have a variety of tools including linepack, storage, and mobile delivery capabilities to accommodate this intraday swing in demand and enable deliverability and respond to increases and decreases in consumption.

The gas transmission system is designed to accommodate the delivery needs of the predictable and low variability patterns required of residential, commercial, and industrial customers. Meeting the variable delivery needs of high capacity factor and intermittent gas-fired plants is a greater challenge as the gas consumption of these plants is much more variable, especially for intermittent gas-fired plants. Gas system operators supplement hourly pipeline receipts with linepack and storage withdrawals to maintain integrity and meet the needs of intermittent plants.

The gas distribution system's ability to provide this intermittent deliverability service is highly dependent on the amount of gas in the pipeline, the inventory levels in storage, the inventory in other storage assets, and contractual obligations to other customers. Providing service to gas-fired generators, particularly intermittent gas-fired generators requires coordinated planning from operators of the gas and electric systems.

4.4 The Regulatory Context

This section discusses how the current regulatory structures hinder the construction, utilization, and operation of new gas assets to serve resilience needs. Often, current regulatory structures tie the development of interstate pipeline and storage assets strictly to the needs of customers (producers, gas utilities, and other end users) willing to execute long-term firm service contracts. These do not easily support the construction, utilization, and operation of resilience assets that, by their nature, will be used infrequently to support low likelihood, high impact events. As a result, gas systems may not be appropriately compensated for the resilience services they provide.

Two critical principles often underlie the regulatory approval of infrastructure development:

- **Alignment between who benefits and who pays:** The ability to demonstrate how an asset provides a benefit to those who pay for its development is a standard principal of utility ratemaking.
- **The business case hinges on high utilization:** The construction and operation of most gas assets are founded upon the willingness to execute long-term firm service contracts; higher utilization translates to lower cost per unit.

This framework begins to break down when asset development activities or business model economics are not aligned with these principles. Applying these regulatory principals to the consideration of the construction, utilization, and operation of gas assets for resilience purposes, two key challenges are exposed:

- Current gas system resilience is a byproduct of reliability investments
- Gas systems may not be appropriately compensated for the resilience service they provide

The remainder of this section discusses these two challenges.

4.4.1 Current Regulatory Framework for Infrastructure Approval

To construct a new energy system asset, a gas utility must receive approval from its regulator, typically a state-level public utility commission. The investment is typically approved if the gas utility demonstrates the investment is prudent and serves the needs of its customers.

The principle of alignment between who benefits and who pays is applicable to regulating the expansion or new construction of interstate pipeline and storage infrastructure. A utility is responsible for the burden of proof of necessity on behalf of its customers. For interstate pipeline and storage assets, the burden of proof is on the market need demonstrated by customers who have executed precedent agreements.

The Federal Energy Regulatory Commission (FERC) regulates interstate pipeline and storage markets. Pipeline and storage operators seeking regulatory approval to construct or expand an asset must provide FERC with a demonstration of market interest to receive approval. FERC grants approval if this market interest can be demonstrated. Due to the long life of pipeline and storage assets, the regulators seek to balance the interests of customers with landowners and the public around environmental concerns,[39] as well as the financial viability of the project. Market interest is demonstrated in the form of customer execution of long-term firm service contracts, where firm service entails a right to a predetermined amount of capacity on the pipeline during the agreement period.

Natural gas utilities are regulated by state public utility commissions (PUCs). PUCs approve infrastructure investments based on the concept that the investment provides utility service and supports the utility's obligation to serve. Gas utilities enter long-term firm capacity contracts because they are required to fulfill an obligation to serve their customers, particularly during periods of peak usage. For example, a gas utility with a significant winter peaking load will subscribe to a long-term contract to serve that load even if its firm rights to pipeline capacity will be underutilized in the summer—resulting from the utility's obligation to serve.

> *A fundamental underpinning of regulatory approval for interstate pipeline and storage construction is the demonstration of market need, as supported by customer willingness to enter long-term contracts for firm capacity.*

When pipeline or storage customers are not willing to enter long-term firm contracts, the market structure creates barriers to obtain the right to a predetermined capacity that is not subject to a prior claim from another customer. This is an issue for certain gas-fired electric power generators. Electric power generators profit if their cost of producing power (fuel plus operations and maintenance) is lower than the average price they sell electricity. Given most gas-fired powered generators are unable to store fuel onsite, they must rely on quick response delivery of natural gas, resulting in two unequal options:

- **Sign a long-term firm contract.** While an option, it is not typical because it could increase the cost such that it is not competitive with other sources of generation, i.e. coal and fuel-oil plants that can store fuel onsite, and solar and wind power that do not require fuel input.
- **Sign a secondary or interruptible contract.** Most gas generators take this action because the economics are more favorable. Interruptible capacity refers to pipeline transportation capacity that is available when the holder of the firm right to this capacity

[39] FERC. 2020. "The Natural Gas Pipeline Application Process at FERC."

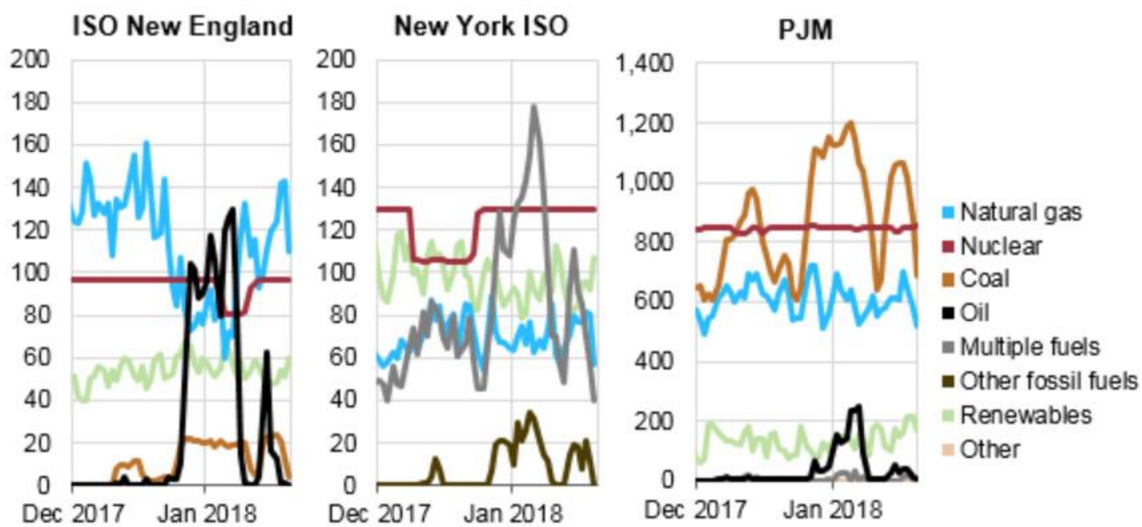
is not using it. The risk is that the pipeline or storage capacity may not be available when it is needed.

4.4.2 Regulatory Framework and Implications to Resilience

In periods of peak usage (e.g., during periods of high use), holders of firm pipeline transportation are likely to use their full allotment of capacity, leaving little to no capacity to secondary or interruptible contract holders. In these periods, gas-fired generators without firm capacity will likely be constrained. During periods of high use, a constrained gas pipeline can create economic or operational conditions that lead to increased fuel switching to oil-fired or dual-fuel generation. This has caused and can cause risk that electric generators lose the ability to serve peak electric load when customer demand for gas supply is also at its peak. This constraint is further illustrated in Figure 4-7.

Figure 4-7 details fuel switching in three electricity markets in the northeast (New England, New York, and PJM) during the January 2018 bomb cyclone. In early January, as the Northeast experienced the cold weather related to the bomb cyclone event, demand for electric power generators increased as natural gas transportation was constrained.

Figure 4-7. Comparison of Electric Power Generation During the January 2018 Bomb Cyclone[40]



Source: US Energy Information Administration

- In ISO New England (ISO-NE), oil generation jumped from almost nothing to a high of 36% of the daily generation mix. In comparison, gas-fired generation decreased from approximately 50% to less than 20% of supply.
- On New York ISO's (NYISO's) system, the output of dual-fuel generators, mostly gas-fired generators that can switch to fuel oil, and other fossil fuel generators rose significantly.
- In PJM, oil and coal generation increased while gas-fired generation remained consistent.

40 EIA. 2018. Northeastern Winter Energy Alert.

Gas-fired generation did not make up the required increase in demand to meet the increased electric power generation needs during the 2018 bomb cyclone event. The structure of the underlying electricity markets, specifically the reliance on unused pipeline capacity for fuel delivery for gas-fired generation to maintain competitiveness, poses a challenge to investments in gas infrastructure in the electricity markets such as ISO-NE, NYISO, and PJM.

4.4.3 Current Gas System Resilience Is a Byproduct of Reliability

The current model for developing gas infrastructure supports construction of assets that support reliability of service and that can be underpinned by long-term contracts. This model has been supportive for maintaining the resilience of the gas system, but it must be recognized that the model does not reflect how the gas system will be operated in the future. It also does not support construction of assets that support resilience requirements.

As demonstrated by the case studies, gas infrastructure provides resilience benefits to the entire energy system. However, the strength of the current gas system is a byproduct of an outdated regulatory system, optimized around daily reliability instead of long-term resilience. Fortunately, the overlap between the two outcomes is considerable enough that the energy system currently experiences a reasonable level of resilience. However, the current regulatory structure does not provide a means to construct and operate investments primarily for resilience. As the transformation of the energy system continues, we anticipate the need for more resilience and a changing mix of assets required to provide that service. The manner in which this energy system is regulated and managed is becoming outdated; thus, an update is necessary to maintain resilience in the evolving future energy system.

4.4.4 Gas Systems Are Not Appropriately Compensated for Resilience Services

From a regulatory perspective, LDCs have an obligation to serve and must develop supply and transportation plans to provide gas reliably at the lowest sustainable cost. Typically, gas distribution utilities do not procure more gas supply than necessary for a given day and instead use storage and linepack to balance intraday supply and demand. In most cases, LDCs cannot secure regulatory recovery to procure and store additional gas supply for low likelihood, extreme climate events beyond that incorporated in reserve margin planning. When a customer draws significantly more gas from the gas system than its average demand, this additional supply comes from gas stored that is already allocated to another customer.

> *Any incremental supply that is available to serve electric power generation on short-notice will be gas that has been reallocated from other customers unless the pipeline or LDC offers a no-notice service.*[41]

Some interstate pipelines and gas distribution companies offer no-notice service on a firm basis by dedicating pipeline and storage infrastructure to support the delivery of gas on short notice—no-notice service is typically supported via interstate pipeline tariffs. An electric power generator may pay the cost of expansion of pipeline or storage assets to support the maximum volume consumed. Example 4 (page 57) is a good illustration of this scenario.

In other cases, providing gas supply on short notice to serve resilience events is limited by several features of the gas delivery system. From a physical perspective, the incremental supply

[41] No-notice service refers to the delivery of natural gas on as-needed basis, without the need to precisely specify the delivery quantity in advance (quantities within contract entitlements).

consumed on an intraday basis needs to be in the pipeline at the moment the electric power generator requires delivery throughout the period that the electric generator is producing power. The accommodation of non-ratable flows in the gas system depends on how other shippers use their contracted entitlement in the pipeline and the operational flexibility of the pipeline (e.g., line pack and storage availability). If the pipeline is already full, extreme spikes in demand from non-ratable users may not be met.

The LDC delivery system was not designed to provide large volumes of no-notice service to the electric power generation sector. However, in many circumstances, LDCs provide non-ratable service when capacity is available and when it does not threaten operations. In these cases, the gas system supports the energy system's overall resilience but is not adequately compensated for its service. This lapse in compensation occurs because an additional service is being provided with assets that were not designed for the circumstances.

4.5 Impacts on Consumers

This section considers the varying level of the impact of the findings on the current state on gas ratepayers and electric ratepayers. At a high level, gas ratepayers are more closely aligned with gas system resilience investments than electric ratepayers, as there is no misalignment around who benefits and who pays. Electric system ratepayers, who benefit from the gas system through gas-fired generation have greater misalignment with the development of gas system resilience investments.

4.5.1 Gas System Resilience to Benefit Gas Ratepayers

LDC customers benefit from the resilience provided by assets that are built to provide reliability. Assets are built to serve gas ratepayers. There is a disconnect between who benefits and who pays. The resilience byproduct of these assets benefits these customers. Construction of an asset that is primarily designed for resilience is problematic, because:

- **Lack of a Regulatory Framework:** Resilience of the gas system is not a current regulatory requirement.
- **Lack of Metrics:** Unlike reliability, which can be measured, resilience does not lend itself easily to quantification. For example, value of avoiding the socioeconomic consequences and costs of a prolonged disruption is difficult to measure.

The lack of a regulatory framework and the difficulty of measuring the value complicates the prudency review and cost-effectiveness evaluation of an asset whose business purpose is resilience. As such, reliability drives investment in gas infrastructure. Assets are designed and approved to meet reliability requirements driven by projected gas supply needs and delivery requirements for peak day usage based on historical data. A specific regulatory mechanism to support cost recovery for gas assets whose primary service is to serve resilience events does not exist and needs to be developed.

4.5.2 Gas System Resilience for Electric Ratepayers

There is a larger disconnect between current market structures and the development of resilience assets when the beneficiaries of gas system reliance are not direct gas system customers, such as electric market customers.

- **Difficulty to recover costs across complementary energy markets:** While there is a connection between the resilience of the gas and electric systems, there is no mechanism for electric market participants to collect revenue or provide cost recovery for investments in gas system resilience.

The gas delivery system was not constructed to handle the increasing frequency of large intraday swings in service demand by gas-fired generators that serve intermittent load. As discussed in Section 4.3.2 and as described in Case Study 6, the gas system accommodates the non-ratable flow of the electric sector on a best-efforts basis. In many cases, pipeline transportation arrangements, tariffs, and coordination efforts exist between an LDC and specific electric power generators. However, these are generally workarounds that do not address the core issue: the current state market framework was designed to promote reliability and does not support the construction of assets whose primary function is to serve resilience, especially when the beneficiaries of that resilience are outside of the gas infrastructure-ratepayer ecosystem (i.e., the electric sectors' customers), nor does it fairly compensate the LDCs as the provider of these resilience services.

To further highlight the cost associated with the development of resilience assets, in Example 4 we discuss a gas infrastructure project specifically designed to serve the resilience needs of the electric sector. This example illustrates the benefits that the gas system can provide to the overall energy system when there is alignment between who pays and who benefits and there is a long-term contract to support development.

Example 4. Gas-to-Power Coordination

Portland General Electric (PGE), an electric utility in Oregon, has traditionally relied on hydroelectric generation resources to provide electric system flexibility. However, it sought new ways to achieve flexibility to meet the expansion of solar and wind generation capacity. PGE needed an efficient technology capable of quick-starting, as well as fast ramp-up and ramp-down rates to fulfil the grid's need for flexibility. PGE constructed a 220 MW electric power plant to provide intermittent power during winter and summer periods, as well as load following and renewable integration throughout the year. The plant can ramp to full load in less than 10 minutes.

To assure deliverability of natural gas to accommodate this quick start-up time, PGE partnered with NW Natural, an Oregon-based LDC, to contract for no-notice storage service. To provide this service, NW Natural embarked on a $149 million project that included a 13-mile gas pipeline, a compressor station, and a 4.1 Bcf expansion of the NW Natural' North Mist natural gas storage reservoir. Through this storage service, PGE can draw on its natural gas resources from NW Natural's facilities in Mist, Oregon to meet its fueling needs and rapidly respond to peak demand and variability of wind, hydro, and solar generation. The facility is contracted for an initial 30-year period with a renewal option of up to 50 years beyond that.

Currently, no specific compensation mechanism exists for the resilience services that gas-fired electric power generation provides the electric sector. In the future, as the percentage of electricity generation from intermittent renewable sources increases, the volume of natural gas used for electric power generation may decline; however, in responding to resilience events the necessity of the services provided by gas-fired electric generators may increase. As current compensation models for the gas system serving the power generation sector are tied to the volume of gas delivered to the facility, there becomes an increasing disconnect between the value of the services provided and associated remuneration for said services.

> *Reliability assets are designed and economically justified based upon historical averages and relatively stable utilization. Resilience assets are essential to operation under infrequent and extreme conditions. The benefits of their existence often extend beyond the energy system for which they were designed, i.e., resulting in a greater socioeconomic benefit such as reduced economic loss resulting from an extreme event.*

5. Ensuring A Resilient Future

The energy system of today will not be the energy system of tomorrow. Decreases in the cost of technologies and increasing pressures to decarbonize the energy system are manifesting in increasing levels of renewable generation, a more distributed generation profile, and a less carbon intensive energy supply—there is some indication that certain versions of this future may have negative impacts on energy system resilience.

In a recent review of the root cause of CAISO outages during the August 2020 heatwave, one of the three factors identified was:

> "*In transitioning to a reliable, clean and affordable resource mix, resource planning targets have not kept pace to lead to sufficient resources that can be relied upon to meet demand in the early evening hours. This makes balancing demand and supply more challenging. These challenges were amplified by the extreme heat storm."*[42]

As the resilience of the gas system grows in importance, cost recovery mechanisms need to be developed to support investments in assets that strengthen resilience. These cost recovery mechanisms should define the resilience requirement for both gas and electric ratepayers.

5.1 Lessons from Others

This section details key lessons learned from recent regulatory and legislative activities governing resilience in the electric, water, and healthcare sectors. These lessons highlight some opportunities that may exist to develop regulatory structures to support gas resilience investments.

5.1.1 FERC Order 841, Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators

FERC Order 841,[43] issued in February 2018, directed regional grid operators to remove barriers to the participation of electric storage in wholesale markets. The order creates a legal framework for storage resources to operate in all wholesale electric markets and expands the universe of solutions that can compete to meet electric system needs. Order 841 was upheld in a federal appeals court decision in July 2020 that declared FERC has jurisdiction over how energy storage interacts with the interstate transmission markets it regulates, even if those energy systems are interconnected with state-regulated electric distribution grids.

> *By directing regional grid operators to establish rules that open capacity, energy, and ancillary services markets to energy storage, Order 841 affirms that storage resources must be compensated for all services provided and moves toward leveling the playing field for storage with other energy resources.*

A key component of the ruling is that "many participation models were designed for traditional generation resources—resulting in limitations or barriers to participation, which constrain competition,"[44] because novel resources technically capable of participating are precluded from doing so as they are forced to operate under participation models designed for existing

[42] CAISO. 2020. Preliminary Root Cause Analysis Mid-August 2020 Heat Storm.
[43] FERC. 2018. Order 841.
[44] US Court of Appeals. 2020. On Petitions for Review of Orders of the Federal Energy Regulatory Commission.

technologies. Energy storage resources (ESRs) such as batteries are especially affected by participation barriers because they have “unique physical and operational characteristics” distinct from traditional resources: ESRs can “both inject energy into the grid and receive energy from it.”

Although this order has limited direct applicability to the natural gas market, it does provide evidence that there are avenues to adapt the current market framework for valuable emerging technologies. Moreover, FERC Order 841 recognizes that the energy system is being used in a different way today than the current regulatory framework envisioned. The acknowledgment that the regulatory framework needs to be reconsidered to remove participation barriers supports the durability of the electric system.

5.1.2 FERC: ISO-NE, Cost-Recovery for Critical Infrastructure Protection (CIP)

Recent FERC orders approving cost recovery for CIP in the electric system showcase how the appropriate cost recovery mechanism can be designed. Federally mandated CIP requirements for electric systems assign protection standards at the low, medium, and high level, with higher standards carrying higher compliance costs. Left unresolved, however, was how generators in wholesale markets would recover the costs of compliance that cannot be competitively offered into the energy and capacity markets. This is because more stringent CIP requirements that result in higher compliance costs provide a disadvantage to a generator that is competing with a generator with lower compliance costs. In May 2020, FERC issued an order approving a proposal submitted by ISO-NE[45] to permit the recovery of incremental costs incurred when low-impact energy systems are reclassified as medium impact energy systems. The order permitted ISO-NE to allocate and collect those costs from transmission customers and disburse the funds to the pertinent facilities.

The concept behind CIP provides several lessons for the consideration of creating cost-recovery mechanisms to support resilience in the natural gas sector. The first is that there are examples in energy markets where resilience is legally mandated. Second, although these mandates can be a source of economic disadvantage to market participants in deregulated energy markets, FERC has approved RTO designed cost recovery mechanisms that socialize the costs.

FERC has mandated a set of protections for critical infrastructure in recognition of the vital role that the electric system plays in supporting the livelihoods of Americans and commerce in the US. The FERC CIP requirements can be viewed as a mandatory resilience requirement with a defined, measurable set of standards.

5.1.3 Energy Resilience in the Water Sector

Water utilities and their regulation offers key lessons on regulatory innovation and resilience. On September 13, 2008, Hurricane Ike made landfall on the upper Texas coast, causing significant damage. Millions of customers lost power, including 99% (more than 2.1 million) of CenterPoint Energy’s[46] customers. A critical pumping station that enables delivery of approximately 75% of Houston’s water supply was one of the casualties and was without power for approximately 10 days—Houston nearly had to declare a water emergency as a result.

[45] FERC. 2020. Docket No. ER20-739-002.

[46] CenterPoint Energy is the electric utility serving the Houston Area.

The Texas legislature enacted legislation[47] in 2015 mandating that water and wastewater treatment facilities have emergency backup power. The requirement also established a definition of resilience: duration at least equal to the longest power outage on record for the past 60 months, or at least 20 minutes, whichever is longer.

In addition, the America's Water Infrastructure Act (AWIA), passed by the US Congress in 2018 and reauthorized in May 2020, requires community water systems to conduct a risk and resilience assessment and develop an emergency response plan (ERP). The ERPs need to focus on more than merely being able to respond. They must include risk mitigation actions such as alternative source water, interconnections, redundancy improvements, asset hardening, and physical and cybersecurity countermeasures if and as justified through assessment. More specifically, the AWIA requires the following:

- Strategies and resources to improve the durability of the energy system, including physical security and cybersecurity.
- Plans and procedures that can be implemented, and identification of equipment that can be used, in the event of a malevolent act or natural hazard that threatens the ability of the community water system to deliver safe drinking water.
- Actions, procedures, and equipment that can obviate or significantly lessen the impact of a malevolent act or natural hazard on the public health and the safety and supply of drinking water provided to communities and individuals, including the development of alternative source water options, relocation of water intakes, and construction of flood protection barriers.
- Strategies that can be used to aid in the detection of malevolent acts or natural hazards that threaten the security or resilience of the energy system.

5.1.4 Energy Resilience in the Healthcare and Emergency Response Sectors

In 2012, Hurricane Sandy made landfall on the US coastline near Atlantic City, New Jersey, with winds upwards of 80 mph. The storm killed over 100 people, flooded coastal cities, destroyed structures, and tore down power lines. As the hurricane devastated the coast, 8.5 million people in 15 states lost power. The widespread power outages severely impacted medical facilities, leaving society's most vulnerable people in life-threatening situations.

Hospitals in New Jersey were forced to evacuate patients after floodwaters damaged backup generators needed to run elevators, lights, and ventilators. Transporting critically ill patients resulted in the loss of life and highlighted the need for more resilient solutions.[48] The total socioeconomic impact of Hurricane Sandy was also enormous, resulting in economic losses ranging from $27 billion to $52 billion.[49] According to the Executive Office of the President in

[47] Texas Administrative Code. 2015. Rule 217.63: Emergency Provisions for Lift Stations.

[48] Modern Healthcare. 2012. *Left in the dark: Seven years after Katrina, Sandy is teaching hospitals more lessons on how to survive nature's fury*.

[49] Executive Office of the President. 2013. *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*.

2012, “these costs of outages took various forms including lost output and wages, spoiled inventory, delayed production, inconvenience and damage to the electric grid.”[50]

In response, legislation arose from the crisis. Assembly Bill 1561, the New Jersey Residents’ Power Protection Act,[51] was passed in 2015, which requires “medical facilities, pharmacies, first aid squads, fire stations, gas stations,’ and newly constructed grocery stores all have backup generators.” These generators are expected to run for 96 hours in case of emergency. Additionally, generators must activate within 10 seconds and be inspected weekly. [52]

Senate Bill No 854 was also approved after the storm. It mandates healthcare facilities and retirement homes install emergency electric power generation should the need arise.

New Jersey’s legislation focuses on investing in resilience and is impactful for the community and the economy. The legislation exemplifies the growing acceptance of the need for a resilient energy system. In the form of backup generation, the strength of the energy system can withstand shocks and protect vulnerable community members. It will mitigate the emergency costs hospitals face over time, “saving the economy billions of dollars and reducing the hardship experienced by millions of Americans when extreme weather strikes.”[53]

5.2 Key Opportunities

Across the gas delivery value chain, the use of existing infrastructure assets is shifting. This shift in usage will undermine the current and future economics of how assets are compensated and limit the development of resilience-focused assets.

- **High-pressure intrastate and interstate pipelines** are developed based upon long-term agreements supported by shippers. Shippers are contract counterparties who provide the economic framework for development of pipeline infrastructure assets. These shippers have historically derived economic value from projects using high load factor ratable forecasts. In the past decade, most material projects were supported by a combination of electric power generation projects or increasing demand from LDCs. Primarily, these have been FERC regulated assets and regulatory approval is based upon a demonstration of demand by the referenced shippers. As utilization of gas-fired generation shifts due to the advent of more renewables and utility demand moderates under decarbonization pressure, forecasted utilization is likely to be significantly lower. As the use of the gas system changes, the way gas service is charged needs to change as well.
- **Storage assets** provide significant resilience benefits. Some utilities have the benefit of on-system storage due to the geologic formations being within the operating jurisdiction or they use aboveground storage assets. Other utilities subscribe to services from storage owners and operators upstream of city gates. Historically, the economic drivers for storage were seasonal pricing differentials and balancing services provided to the integrated gas infrastructure system. In the future state, these assets will continue to provide seasonal and long-duration supply services. Storage is an important resilience asset and will continue to be essential to an integrated energy system. The economics of legacy seasonal pricing

[50] Executive Office of the President. 2013. *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*.
[51] State of New Jersey. 2014. *Assembly Bill No. 1561.*
[52] Facilities Net. 2013. *NFPA 110’s Fuel Requirements Can Help Guide Backup Power Plan For Hospitals*.
[53] Executive Office of the President. 2013. *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*.

differentials and balancing services may not provide sufficient revenue to encourage continued development and maintenance of these critical assets. If storage owners and developers were provided revenue for providing resilience benefits, however, the economic framework would sustain the availability of these necessary assets.

- **Distribution systems** have special duty assets including peak shaving storage, LNG storage, and non-pipeline solutions that provide resilience benefits. These assets historically have been designed to meet design day peak demand based upon historical heating degree days. However, as noted in the case studies, climate events create operating stress on existing gas systems. Like the interstate gas systems, the high frequency, high utilization economic framework that was used to justify investments in these legacy assets is not fit for stimulating future investments in a mix of assets that is becoming more intermittent.

The gas system is highly resilient and plays a critical role in supporting the stability of the overall energy system. Current regulatory, economic, and policy frameworks are not conducive to creating the vibrant energy system of the future. The gas and electric sectors are fortunate that the energy system designed to provide reliability has provided resilience benefits. However, the resilience benefits currently enjoyed are a regulatory byproduct and will not serve the needs of the future energy state.

6. Conclusions

The transformation of our energy system is well underway, driven by changes in the cost and availability of new technologies and increasing political and social pressure to decarbonize. The way energy is generated and used is changing rapidly, moving from a one-way power from centralized generation to end customers to a multidirectional network supporting two-way energy flows. As the energy system migrates to one increasingly powered by intermittent renewable sources, it also experiences increasingly frequent and intense climatic events—together these fundamental drivers are creating ever increasing operating stress on the energy system.

As discussed throughout this paper, the gas system is currently providing resilience benefits to the entire energy system. But, the strength of the current resilience is a byproduct of a regulatory environment that has valued investment in a reliable, ratable, and safe set of assets designed around a legacy demand forecast and historical heating degree day planning. As the transformation of the energy system continues, we anticipate a need to place a greater focus on resilience and a re-evaluation of the diversity of assets providing that service.

Full utilization of resilience assets is infrequent by nature. Yet, when a resilience service is demanded it is an essential product of the energy system and key to mitigating catastrophic risk and limiting socioeconomic costs to customers and communities. Utilities, system operators, regulators, and policymakers must make informed decisions to identify an economic framework to incent investments in resilience assets required to support a vibrant and strong future energy system. Resilience should be an energy system requirement like safety and not a byproduct of the existing framework.

6.1 Implications for Policymakers and Regulators

Looking into the future, evolving technology and the speed of transformation of the energy system will require a different economic and regulatory framework to support the appropriate mix of assets and fair compensation for continued investment. Achieving this is easier said than done. It will require a realignment of the valuation and cost recovery mechanisms that currently define the development of the US energy system.

Energy system resilience needs to be defined as a measurable and observable set of metrics, similar to how reliability is considered. To design a truly resilient system requires an ability to measure, evaluate, and optimize the benefit. Resilience needs to be considered as another dimension of system planning, similar to the way that reliability is considered today.

Resilience solutions must be considered from a fuel-neutral perspective and across utility jurisdictions, requiring electric, gas, and dual-fuel utilities to work together to determine optimal solutions. As this paper clearly illustrates through the case studies, when low likelihood, high impact events impact our energy system—the energy system responds through integrated responses that rely on fundamental characteristics of a diversity of assets. Energy system resilience solutions cannot be engineered through a siloed approach that considers only a portion of the energy system, they must consider the opportunity and value that can be brought to the energy system across a diversity of assets.

Methodologies need to be built for valuing resilience, such that it can be integrated into a standard cost-benefit analysis. Value must consider the avoided direct and indirect costs

to the service provider, customers, and society. LDCs and other pipeline infrastructure providers are not fully compensated for the true value of resilience services they provide to the overall energy system. Because the resilience of the gas system is largely a function of the reliability of the gas system, the true cost of resilience (i.e., return of and return on capital invested in physical infrastructure) is treated as a sunk cost. In other words, ratepayers are paying for reliability and enjoying resilience as a benefit—a disconnect that will become increasingly evident as extreme events become more frequent and the share of intermittent renewable generation increases.

In addition to the legacy evaluation criteria that determine cost-effectiveness, policymakers and regulators need to consider ways to evaluate the socioeconomic benefits and avoided costs to the communities resulting from a resilient energy system.

- What is the cost to the community of catastrophic loss of service during a climate event?
- If energy is not available to essential services can this value this be considered by analysis that primarily focuses on the costs per MMBtu or kWh?
- What level of insurance would these communities be willing to pay to have a future energy system that is robust enough to recover quickly and vibrantly from man-made and climate-driven events?

> *Resilience assets mitigate exposure to catastrophic impacts to the communities they serve and should be viewed as an insurance policy to limit risk.*

Cost recovery should be spread over the entire energy system when considering endorsement of capital projects for resilience assets. Further, cost recovery stimulated by utilization is not an appropriate metric for low load factor usage associated with low likelihood, high impact future scenarios.

6.2 A Call to Action

The development of a new regulatory framework will require innovation and collaboration from utilities, system operators, regulators, and policymakers to identify workable solutions that are fit for purpose and tailored to the requirements of regional markets. Preparing the future state to respond effectively to the current transformation requires the communication, coordination, cooperation and collaboration with all industry partners and stakeholders to identify, develop, and implement solutions.

Any future actions undertaken by regulators and other stakeholders should be evidence-based, fuel neutral, and based on objective criteria that scrutinized by all stakeholders. FERC has left it to the RTOs to assess how to best enhance the resilience of the power system and recognizes that solutions to improve gas/power resilience will need to be resolved at the RTO level, however federal direction may also be needed to coordinate productive discussion and facilitate collaboration.

Recent FERC regulatory activity and RTO-led stakeholder planning engagements indicates a precedent for this type of cross-industry collaboration. This activity suggests that the innovation required to address shifting requirements for energy system resilience and facilitate cost recovery for resilience assets is not only possible but achievable.

State PUCs have a vital role to play as well. As the primary regulator of LDCs, PUCs are charged with ensuring customer protection, fostering competition, and promoting high-quality infrastructure. Moreover, solutions to the issues identified in this report will require locally identified solutions that are tailored to the unique needs and circumstances of individual LDCs and the regions they serve.

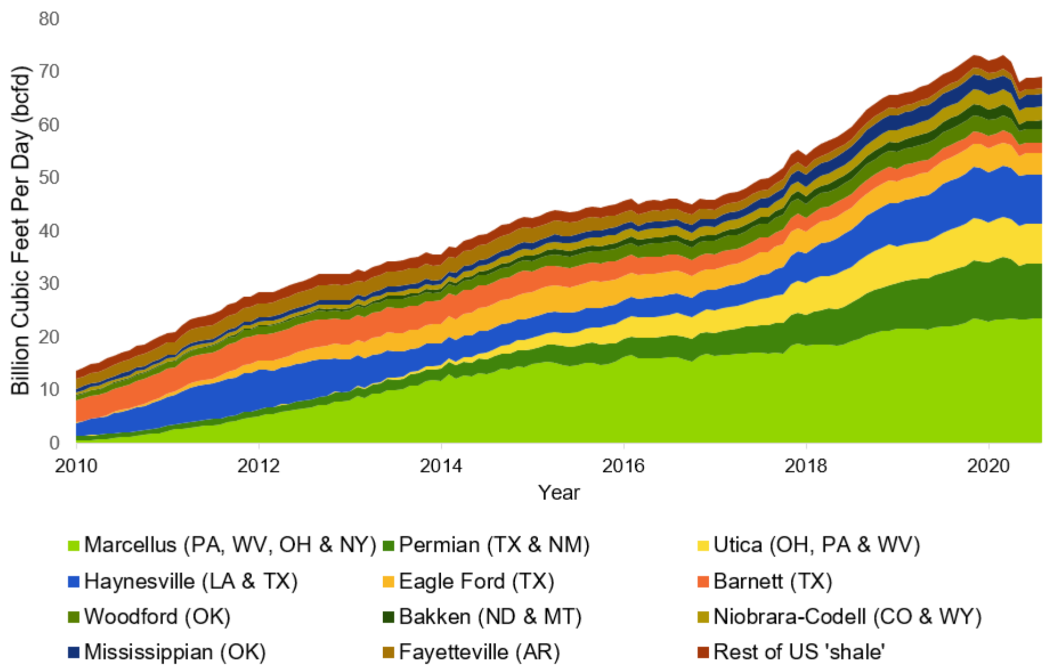
For energy system stakeholders at every level, resilience is not just a term that is currently in vogue, it is a characteristic that needs to be valued and engineered. Ensuring future energy system resilience will require careful assessments of all available solutions, maximizing the fundamental benefits of a diversity of assets. Utilities, system operators, regulators, and policymakers need new frameworks to consider resilience impacts as part of the energy system transformation, to ensure that resilience is not overlooked in the pursuit to achieve decarbonization goals.

Appendix A. The Natural Gas Value Chain

A.1 Production and Processing

Exploration and production companies explore, drill, and extract natural gas from geologic formations. In 2019, 81% of production came from shale.[66] Production from these formations has grown rapidly over the past decade, as Figure A-1 shows.

Figure A-1. US Dry Shale Gas Production, 2010-2020



Source: Guidehouse, US Energy Information Administration

Once produced and extracted, gathering pipelines transport natural gas to processing facilities where impurities are removed, resulting in pipeline-quality natural gas. Gathering systems use compressors to move gas through the midstream pipelines. Most compressors are fueled by natural gas from their own lines. This self-reliance increases resilience by allowing the movement of molecules without dependency on other fuel sources.

A.2 Transmission

From the gathering system, natural gas moves into the high-pressure transmission system for long-haul transportation to market centers. These pipelines efficiently move large amounts of natural gas thousands of miles.[54] In the US, there are approximately 3 million miles of mainline and other pipelines that connect gas production with consumption.[55] Over 30 companies in North America own and operate interstate pipelines, which the FERC regulates. Intrastate pipelines are generally owned by publicly traded entities and are regulated by the states in which they are located.

[54] American Gas Association. *How Does the Natural Gas Delivery System Work?*. Accessed October 2020.
[55] EIA. *Natural Gas Explained: Natural Gas Pipelines*. Accessed October 2020.

A.2.1 Compressor Stations

The pressure of gas in each section of the transmission system ranges from 200 psi to 1,500 psi, depending on where the pipeline operates. Compressor stations are located approximately every 50 to 60 miles along transmission pipelines to regulate pressure and keep gas moving.

A.2.2 Gas Storage

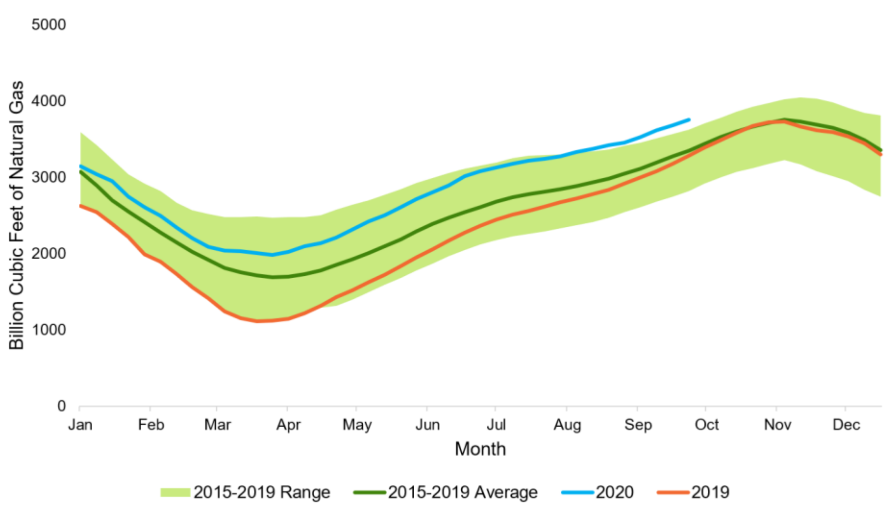
Storage capacity enables the delivery of reliable gas service to consumers and end-users throughout the year. While natural gas production remains relatively constant year-round, storage enables gas providers to adjust to daily and seasonal demand fluctuations (Figure A-2).

Storage can be owned or operated by natural gas transmission companies or LDCs. Off-system storage is not directly tied to a natural gas utility's distribution system, but that is accessible via the transmission system. Most off-system storage is underground; however, there are examples of aboveground off-system storage. Underground storage facilities can be developed from depleted gas reservoirs, aquifers, or salt caverns and are connected to one or more transmission pipelines; whereas aboveground storage is often provided through LNG or CNG.

In addition to offering storage services, some pipeline companies may provide a park and loan that enables shippers to borrow or lend gas. These services are typically used to balance daily or intraday markets. Some Pipelines also offer tariff-based delivery services called No Notice, which allows an LDC to receive gas at variable quantities throughout the day without placing nominations to the provider. These no-notice services are backed by storage and pipeline delivery assets.

In the lower 48 states, it is common for the gas system to have at least 2,000 Bcf to 3,000 Bcf of working natural gas in underground storage, as Figure A-2 shows. The entire US commercial sector consumed 3,500 Bcf in 2019. Base gas (or cushion gas) is the volume of natural gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season. Working gas is the volume of gas in the reservoir above the level of base gas. Base gas inventories remain relatively steady at approximately 4,300 Bcf throughout the year.

Figure A-2. Working Gas in Underground Storage, Lower 48 States



Source: Guidehouse, US Energy Information Administration

A.2.3 City Gate Stations

Natural gas typically passes through a city gate to move from the transmission pipeline to the pipelines under operational control of LDCs. At the city gate, the pressure is reduced from transmission to distribution levels, an odorant is added, if not already provided by the upstream pipeline, and incoming flow is measured to ensure it matches the LDC's distribution requirements. Deliveries from transmission pipelines are normally scheduled a day or more prior to delivery and include the estimated total quantities for demand in the day forward. Some transmission systems provide operators the ability to make intraday changes to nominations in attempt to sync scheduled demand with actual demand.

In addition, pipeline midstream companies and inter-connection pipelines (i.e., LDC or other midstream pipeline companies) have OBAs in place in which parties agree to specified procedures for balancing between nominated levels of service and actual quantities transferred between the two pipelines.

A.3 Distribution

After leaving the city gate, natural gas moves into distribution pipelines. Each distribution system has sections that operate at different pressures, with mechanical regulators controlling the pressure to optimize efficiency. Generally, the closer natural gas gets to a customer, the lower the pressure.

Many distribution systems also feature on-system storage. This is typically aboveground and includes small-scale LNG or CNG storage that enables the distribution company to meet short-term requirements for increased gas demand and pressure balancing needs. Such facilities enable LDCs to supplement, or shave, the amount of natural gas needed from external suppliers through on-system resources. Some distribution systems also feature underground storage.

A.3.1 Customer Delivery

As gas travels through the main lines of the distribution system, it is routed to customers through smaller service lines. Flow meters and mechanical regulators reduce the pressure to under 0.25 psi, the normal pressure for gas within a household, equivalent to less pressure than a child blowing bubbles through a straw.

The types of customers served by the system include the following:

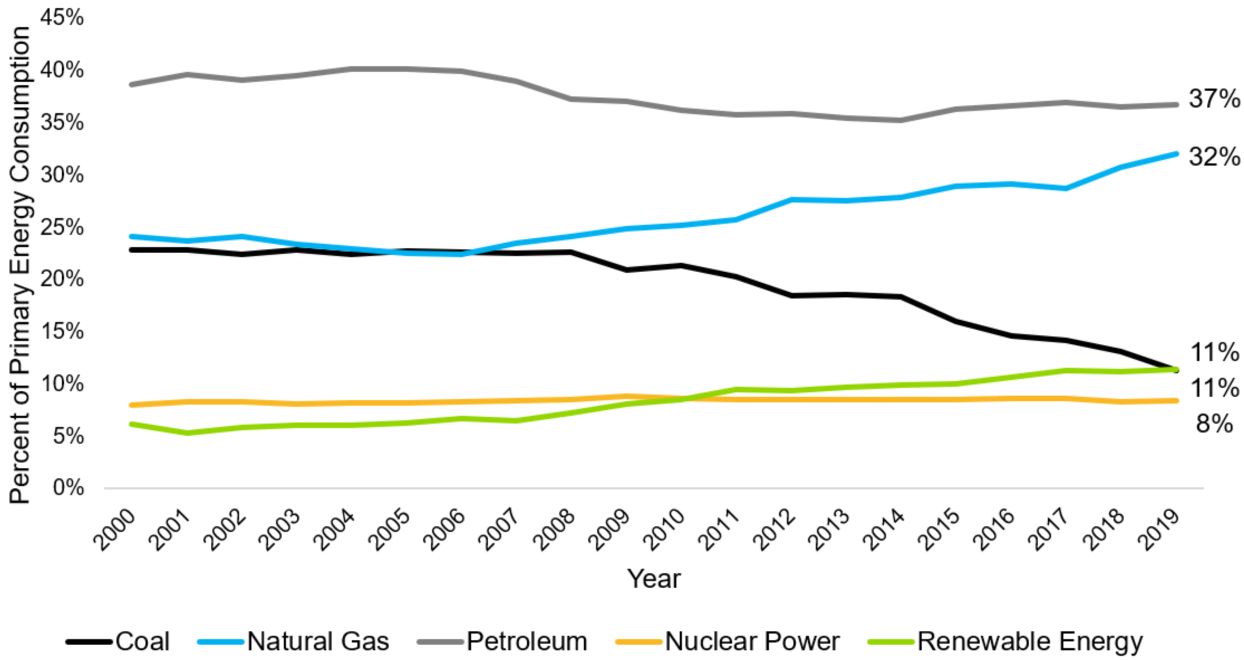
- **Interruptible vs. Firm Demand:** Interruptible customers are often large commercial or industrial customers that have selected to contract for natural gas service that can be interrupted when the delivery system is experiencing constraints. When a natural gas utility experiences a situation where gas consumption exceeds demand, such as during a peak heating day, system operators can curtail these interruptible customers while maintaining service to firm demand (or uninterruptible) customers.
- **Ratable vs Non-Ratable Flow:** Ratable flow refers to customers that will be delivered one-twenty-fourth of their nominated and scheduled daily quantity every hour—they receive the same amount of natural gas every hour of every day. Non-ratable flow refers to customers that receive uneven or varying consumption throughout the day.

Appendix B. The Current State of US Gas Consumption and Production

The US natural gas industry is larger today than ever before—gas consumption and production have grown since the 1950s and are currently at record levels. In 2019, the US consumed 31 trillion cubic feet of natural gas. Concurrently, the US produced approximately 33 trillion cubic feet of natural gas (dry production) in 2019.[56]

In 2019, natural gas accounted for 32% of US primary energy consumption.[57,58] Natural gas has been accounting for an increasing portion of the energy consumed in the US since 2000, as Figure B-1 illustrates.

Figure B-1. US Primary Energy Consumption by Source



Source: Guidehouse, US Energy Information Administration

B.1 Gas Consumption by Customer Segment

Natural gas is a significant energy source used to generate electricity in the electric sector and meet the end-use heating demands in the residential, commercial, and industrial sectors. It is also used in distributed electric power generation primarily through CHP in the industrial sector and as a transportation energy source.

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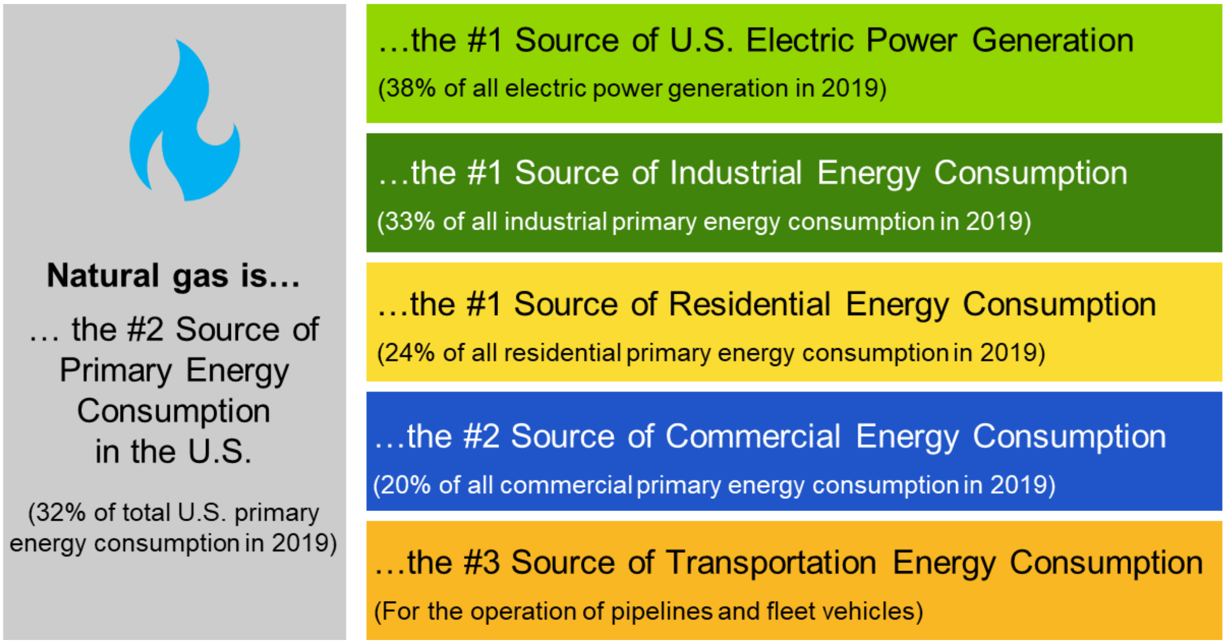
56 EIA. 2020. *Annual Energy Outlook*.

57 Primary energy consumption is a measure of total energy demand, covering the consumption of fossil fuels by end users like homes and businesses, the energy used to produce electricity, and losses during the transformation and distribution of energy.

58 EIA. 2020. *Annual Energy Outlook*.

Figure B-2 illustrates the role that natural gas plays in powering each of these sectors. Natural gas supply is also detailed further throughout the remainder of this section.

Figure B-2. Natural Gas Deliveries and Consumption by Sector



Source: Guidehouse, US Energy Information Administration

B.1.1 Electric Power Generation

Growth in shale gas production has led to a decline in natural gas prices and has contributed to steady growth in the amount of electric power generated by natural gas (Figure B-3).

> *In 2019, 6,025 utility-scale gas generation facilities produced 38% of total US electricity, the largest share of any individual source. This is up from 5,722 gas generation facilities producing 33% of total US electricity in 2016.*[59]

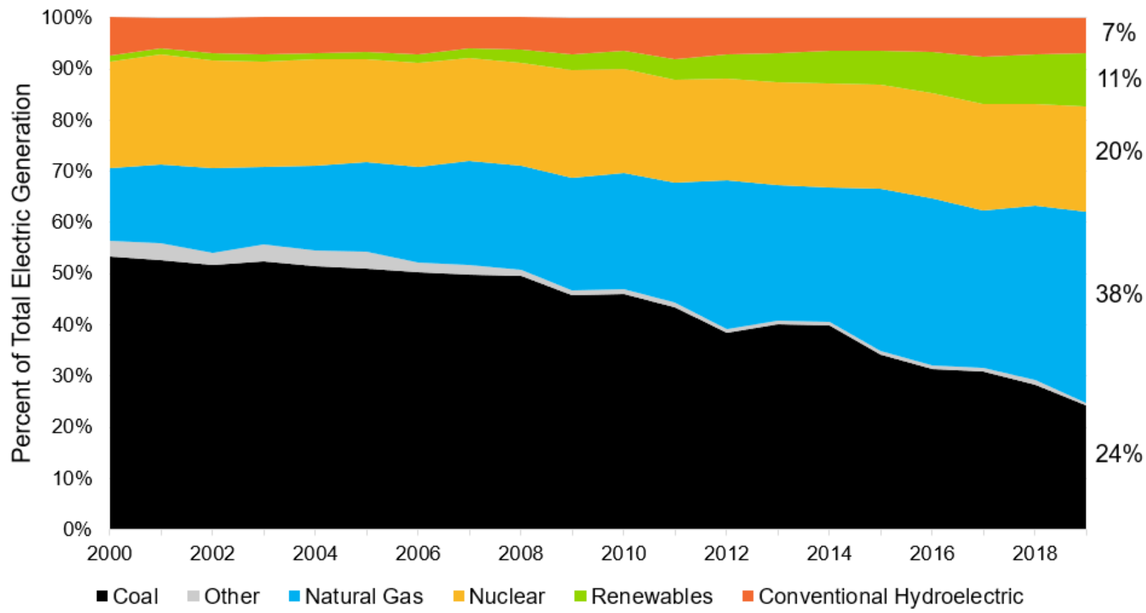
The price of natural gas is a key driver behind its growth as a source of electricity production. This trend continues today, with the 2025 EIA outlook for the levelized cost of electricity of next-generation coal plants hovering around $76/MWh, and combined cycle natural gas plants around $38/MWh. This is in-line with EIA projections for non-dispatchable technologies such as onshore wind ($40/MWh) and solar PV ($33/MWh), and cheaper than projections for offshore wind ($122/MWh) and hydroelectric ($53/MWh).[60]

Grid operators find value in gas-fired electric power generation because of its flexibility as an energy resource, serving as both high capacity factor baseload and dispatchable generation. The fast ramp-up and ramp-down times of natural gas generators are especially important in regions with a large share of renewables generation where natural gas plants are often required to balance the steep increase and decrease in generation capacity.

[59] EIA. 2020. *Preliminary Monthly Electric Generator Inventory, September 2020*.

[60] EIA. 2020. *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020.*

Figure B-3. Net Electric Power Generation by Source, 2000-2019



Source: Guidehouse, US Energy Information Administration

B.1.2 Industrial

Natural gas is critical to meeting the energy needs of the industrial sector. In 2019, the industrial sector accounted for 33% of total US natural gas consumption, which in turn accounted for 33% of the industrial sector's total energy consumption.[61]

Within the industrial sector, natural gas supports a wide range of uses including building heating, a feedstock for CHP, and as a feedstock for high energy-intense processes such as the production of chemicals, fertilizer, and steel.

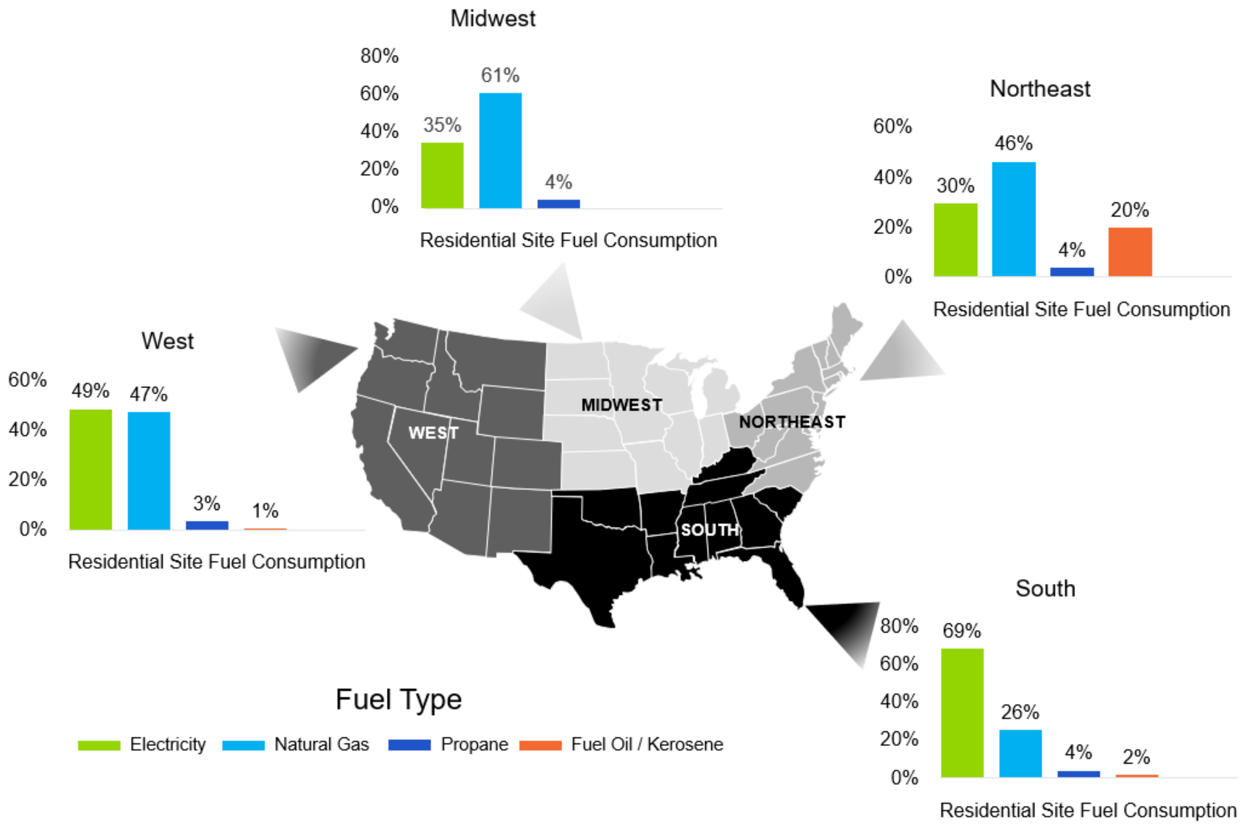
B.1.3 Residential

In the US residential sector, natural gas is used to heat homes and water, cook, and dry clothes. Although the use of natural gas varies by geography (as Figure B-4 illustrates), about half of the homes in the US use it for space and water heating. In 2019, the residential sector accounted for approximately 16% of total US natural gas consumption, which translates to 24% of the residential sector's total primary energy consumption.[62]

[61] EIA. *Natural gas explained: Use of natural gas*. Accessed September 2020.

[62] EIA. 2020. *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020.*

Figure B-4. Natural Gas Share of Total Residential Energy Consumption, 2015



Source: Guidehouse, US Energy Information Administration

B.1.4 Commercial

In the US commercial sector, natural gas is primarily used to heat buildings and water, to operate refrigeration and HVAC equipment, to cook, dry clothes, and provide outdoor lighting and heating. In 2019, the commercial sector accounted for approximately 11% of the total US natural gas consumption, which translates to 20% of the commercial sector's total primary energy consumption.[63]

B.1.5 Transportation

Natural gas plays a niche role in the US transportation sector, accounting for only 3% of the sector's total energy needs in 2019. Within the transportation sector, natural gas is used to operate compressors to move natural gas through pipelines and as a vehicle fuel in the form of CNG and LNG.

Most vehicles that use natural gas as a fuel are government and commercial fleet vehicles. CNG medium duty vehicles have gained increasing popularity over diesel due to lower prices and clean air benefits. In 2018, there were a total of 19,151 CNG public transit busses nationwide, compared to 32,671 diesel and 13,872 hybrid busses.[64] In 2020, there are 1,677

[63] EIA. 2020. *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020.*

[64] DOE. *Alternative Fuels Data Center, Transit Buses by Fuel Type*. Accessed October 2020.

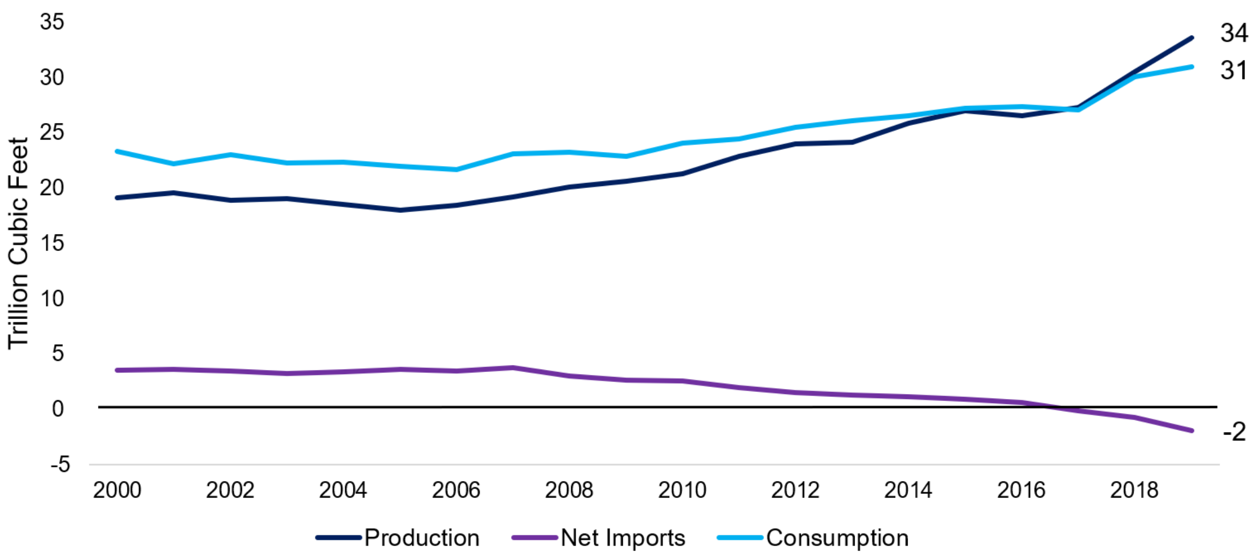
CNG and LNG refueling sites in the US compared to 29,738 EV stations. However, this infrastructure supports decarbonization of heavy and medium to light duty vehicles where EV infrastructure primarily supports light duty vehicles.[65]

B.2 US Gas Production

US natural gas production continues to grow; domestic production has exceeded consumption since 2017. The US now produces nearly all the gas it consumes, decreasing its reliance on imports from other countries. In large part due to accessible shale formations, most natural gas (97%) is produced onshore in a diversified base of over 30 states. Five states (Texas, Pennsylvania, Oklahoma, Louisiana, and Ohio) account for approximately 70% of the US total dry natural gas production.[66]

In 2019, 34 trillion cubic feet of natural gas was produced (Figure B-5).[67] Increased domestic production has contributed to a decline in prices, which has led to the significant increase in natural gas consumption across sectors, primarily in the electric power generation and industrial sectors.

Figure B-5. US Natural Gas Consumption, Dry Production, and Net Imports, 2000-2019



Source: Guidehouse, US Energy Information Administration

B.3 Low Carbon Gas Production

Since the early 2000s, US energy-related GHG emissions have been decreasing.[68] A significant driver of the emissions reduction has been a transition from higher-emissions fuels (e.g. coal) to natural gas. This transition is expected to continue, as natural gas supply is further decarbonized through the increase in low carbon gas production.

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[65] Oak Ridge National Laboratory. 2020. *Transportation Energy Data Book Edition 38, Table 6.12.*

[66] EIA. *Natural Gas Explained: Where our natural gas comes from*. Accessed October 2020.

[67] EIA. *U.S. Energy facts explained*. Accessed October 2020.

[68] EIA, *EIA Projects U.S. Energy-Related CO2 Emissions Will Remain Near Current Level Through 2050.*

Fueled by city and state commitments to decarbonize, investors are driving the capital necessary for companies to invest in the further research, development, and production of low carbon gases such as RNG, hydrogen-enriched natural gas, and hydrogen. Meanwhile, political and regulatory agencies are clearing the path for the growth of this low carbon gas development. Although low carbon gas production is nascent in the US, its growth potential provides a pathway for the natural gas industry to meet energy sector decarbonization goals. It also increases the resilience of the energy system by providing a locally sourced supply of clean energy.

B.3.1 Biogas

Biogas is produced primarily through landfill gas collection, thermal gasification, or anaerobic digestion of waste feedstocks from the sewage, agriculture, food, and forestry sectors. Biogas can be used to produce heat and electricity, or it can be further processed to remove impurities to meet the standards of conventional natural gas (defined as RNG) for distribution through the gas pipeline system, as Figure B-6 illustrates. Though most RNG produced is consumed onsite for electric power generation or heating, the American Gas Foundation found that there will be about 50 trillion Btu of RNG produced in the US for pipeline injection in 2020, a number that has grown at a compound annual growth rate (CAGR) of 30% over the past 5 years.[69]

> *The number of renewable natural gas (RNG) production facilities in North America grew by 145% from 2014 to 2019.*[70]

There are over 2,200 biogas production sites in the US. Investments into new biogas systems totaled $1 billion in 2018, a number that has been growing at a CAGR of 12%.[71] In 2019, the US produced approximately 230 billion cubic feet of biogas primarily from solid waste (83%), industrial (6%), wastewater (6.5%), and agricultural (4.5%) feedstocks.[72]

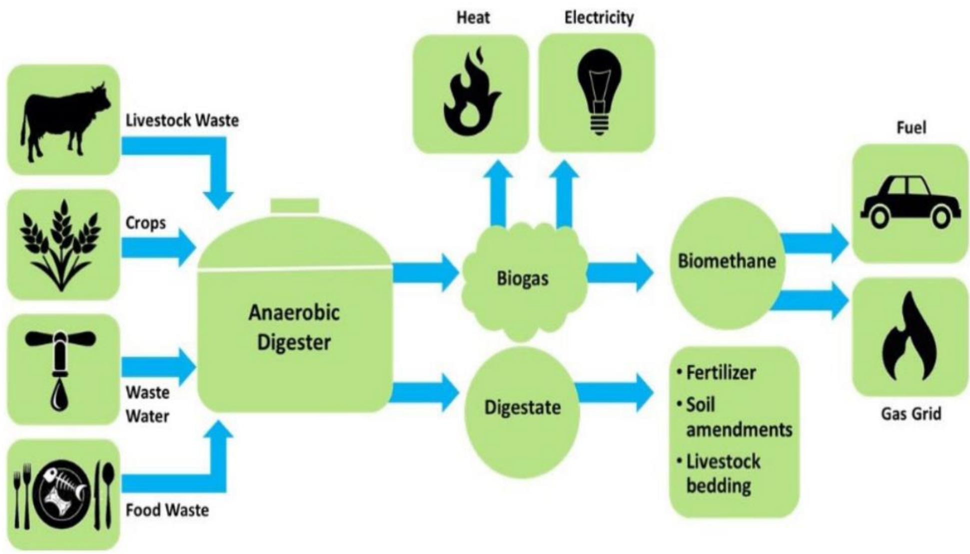
[69] American Gas Foundation. 2019. *Renewable Source of Natural Gas: Supply and Emissions Reduction Assessment.* Accessed October 2020.

[70] Coalition for Renewable Natural Gas. 2019. *Renewable Natural Gas Market Surpasses 100-Project Pinnacle in North America*. Accessed October 2020.

[71] American Biogas Council. 2019. *Why Biogas?*.

[72] Guidehouse Insights. 2020. *Renewable Natural Gas: Overview of the Current State of Biogas and Renewable Gas Markets*.

Figure B-6. Low Carbon Gas Production Through Anaerobic Digestion

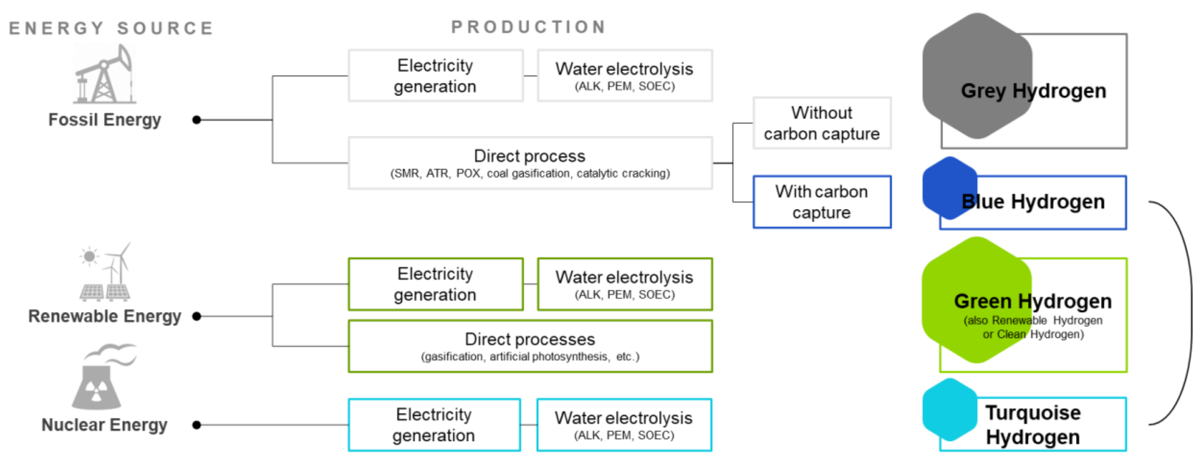


Source: Environmental and Energy Study Institute

B.3.2 Hydrogen

Hydrogen is produced through electrolysis, a splitting of water atoms into their component parts of hydrogen and oxygen. Producing hydrogen requires an input of energy, the type of energy that is used defines the carbon intensity of the process and ultimately whether it is considered low carbon. Figure B-7 describes the various types of hydrogen across a color spectrum (grey, blue, green, and turquoise hydrogen).

Figure B-7. Hydrogen Production Technologies



Source: Guidehouse

Steam methane reforming is used to form most hydrogen production. Hydrogen is often produced for use alongside its two largest consuming sectors, petroleum refining and fertilizer production. There are1,600 miles of hydrogen pipeline in the US, and most states have a large hydrogen production facility producing approximately 10 million metric tons of hydrogen annually.[73] However, a recent California Energy Commission study estimates that with market and policy action to facilitate scale-up of production capacity, California alone could produce an excess of 2,000 metric tons per day by 2030.[74]

[73] U.S. Office of Energy Efficiency & Renewable Energy. 2019. *10 Things You Might Now Know About Hydrogen and Fuel Cells*.

[74] California Energy Commission. 2020. *Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California.*