AGA
American Gas Association

Net-Zero Emissions Opportunities for Gas Utilities

An American Gas Association Study
prepared by ICF

Executive Summary

LETTER FROM AGA

Climate change is a defining challenge for our country and across the globe. As businesses, communities, and governments focus on reducing greenhouse gas emissions, every sector of the economy will need to make not just pledges, but progress.

America's gas utilities have consistently provided solutions to our nation's most pressing energy needs and environmental goals, and they have crucial and enduring roles as the country advances ambitious greenhouse gas emissions reductions goals. Energy is the backbone of our economy and our quality of life, and the natural gas system will be central to our energy future. Natural gas provided 34 percent of all energy consumption in the U.S. during 2020. More than 187 million Americans use natural gas in their homes every day, and the industry added nearly 900,000 new residential customers in 2020, the largest increase since 2006. That equates to one new customer every minute and 21,000 new business customers each year. Investments in the natural gas system support well-paying jobs, power our nation's industries, fuel economic growth, improve air quality, support communities, and reduce pollution.

In 2020, on behalf of the nation's natural gas utility industry, the American Gas Association issued its "Climate Change Position Statement." It made 10 collective commitments toward achieving a significantly lower-carbon energy economy. Since that time, the industry has doubled down on its innovation and investment, driving increased progress and reimagining our energy future. These substantive efforts build on the progress already underway—gas utility industry methane emissions have decreased 69 percent since 1990, and the use of natural gas for power has enabled the expansion of renewables and led to carbon dioxide emissions in the sector reaching three-decade lows. And the industry is not done yet.

To further advance our emissions reductions, I am pleased to present *Net-Zero Emissions Opportunities for Gas Utilities*. It provides a comprehensive and rigorous analysis demonstrating the multiple pathways that exist to reach a net-zero future, and the role natural gas, gas utilities and delivery infrastructure will play in advancing decarbonization solutions. There is no single pathway to a net-zero economy, and planning must consider highly localized factors like geography, energy demands, resources, and weather. The study presents several pathways to underscore the range of scenarios and technology opportunities available as the nation, regions, states, and communities develop and implement ambitious decarbonization plans.

Recognizing the critical benefits of gas industry infrastructure and the energy choices it provides can help us better leverage all of the resources and tools required to innovate toward the energy system of the future. This industry is advancing practical solutions today and making investments that bring considerable advantages to meet the country's energy goals and achieve our ambitious emissions reductions goals well into the future.

Industry and government must work together to advance innovative policies, scale-up and deploy new technologies and invest in reliable and resilient infrastructure. Only through an integrated approach to decarbonization that leverages the advantages of the gas distribution system can we realize a reliable and resilient energy future that minimizes negative impacts for customers.

As our nation pursues ambitious decarbonization goals, the U.S. gas utility industry is committed to providing the solutions required to achieve a sustainable energy future. AGA will continue to develop and advance the supportive policies and regulatory changes needed at the federal and state levels, identify the investments necessary to deploy and scale advanced technologies, and support actions essential to help companies and communities successfully develop and implement effective decarbonization strategies. We can accelerate the deployment of emission reduction technologies, keep our system resilient and reliable, and still deliver the affordable energy that Americans need.

We look forward to the work and collaboration ahead to continue the course to a cleaner energy future.

Karen Harbert
President and Chief Executive Officer
American Gas Association

IMPORTANT NOTICE

This is an American Gas Association (AGA) Study. The analysis was prepared for AGA by ICF. AGA defined the cases to be evaluated and vetted the overall methodology and major assumptions. The EIA 2021 AEO Reference Case, including energy prices, energy consumption trends, and energy emissions, was used as the starting point for this analysis.

This report and information and statements herein are based in whole or in part on information obtained from various sources. The study is based on public data on energy and technology cost and performance trends, and ICF modeling and analysis tools to analyze the emissions impacts for each study case. Neither ICF nor AGA make any assurances as to the accuracy of any such information or any conclusions based thereon. Neither ICF nor AGA are responsible for typographical, pictorial or other editorial errors. The report is provided AS IS.

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ABSTRACT

In recognition of the need to address climate change, a growing number of jurisdictions and businesses are announcing goals to achieve deep decarbonization with an increasing focus on meeting net-zero emissions targets within the next three decades. The American Gas Association commissioned ICF to conduct an in-depth assessment of opportunities for gas utilities to support these ambitious goals. The analysis examined the greenhouse gas emissions associated with utility operations, gas production and transportation emissions, and utility customer emissions created by the direct use of natural gas in the residential, commercial, industrial, and transportation sectors.

This study finds that through the use of a variety of technologies and approaches, gas utilities can achieve net-zero emissions targets and contribute to economy-wide net-zero emissions goals. Further evaluation of these emission reduction opportunities and their ability to support tenets aligned with safety, affordability, reliability, resilience, and feasibility criteria will be an important part of developing and implementing decarbonization strategies. Community and customer benefits beyond greenhouse gas emissions reductions, such as reduction in air pollution, increased economic development, and consumer energy savings, may also be realized and are not reflected in this analysis. To be successful, any pathway to achieve net-zero emissions—including those not assessed in this study—will require the support of policymakers, regulators, and customers, along with investment into infrastructure and emerging technologies.

Given the importance of natural gas and gas infrastructure in the current U.S. economy, this analysis shows that gas utilities can play crucial and enduring roles in building economy-wide pathways to achieve a net-zero greenhouse gas emissions future. Pathways that utilize gas infrastructure offer opportunities to incorporate renewable and low-carbon gases, provide optionality for stakeholders, help minimize customer impacts, maintain high reliability, improve overall energy system resilience, and accelerate emissions reductions. The ability of gas infrastructure to store and transport large amounts of energy to meet seasonal and peak day energy use represents an important and valuable resource that needs to be considered when building pathways to achieve net-zero greenhouse gas emissions goals.

ICF analyzed various emission reduction technologies/options for gas utilities and worked with the AGA to develop several illustrative pathways that showcase how different combinations of these solutions can be designed to achieve net-zero emissions. The approaches examined include managing energy demand by expanding energy efficiency and promoting emerging technologies, supplying renewable and low-carbon fuels, reducing emissions from gas utility operations and pipelines, and utilizing negative emissions technologies. The study presents national-level results, dependent on a wide range of assumptions. The preferred mix of measures will ultimately vary by region and utility. Further analysis that accounts for highly localized considerations, including costs and impacts on consumers, communities, and the economy, will be needed to study these and other pathways for a given area or gas utility service territory.

The challenge of meeting net-zero emissions goals should not be understated. Reaching economy-wide net-zero emissions targets will require transformational changes in producing, transporting, storing, and consuming energy (gas, electricity, and other forms). All options should be on the table to ensure a cost-effective, reliable, resilient, and equitable transition to a net-zero emissions energy system, and gas and electric utilities both have roles to play to support this transition. Expanded research, development, and deployment support are vital to achieving these targets. Nonetheless, this study demonstrates the many opportunities and solutions for gas utilities to help their customers and communities address climate change and accelerate strategies to achieve net-zero emissions goals.

EXECUTIVE SUMMARY

Climate change is one of the defining challenges of our time. Addressing climate change will require fundamental changes in energy use and reducing greenhouse gas (GHG) emissions throughout the economy.

The Intergovernmental Panel on Climate Change has indicated that deep reductions in greenhouse gas emissions will be necessary to mitigate the largest risks of climate change, and that economy-wide net-zero emissions are needed by 2050 in order to limit global warming to 1.5°C (in line with the Paris Agreement).[1] As a result, municipalities, states, and the federal government have committed to clean energy or greenhouse gas reductions with an increasing focus on meeting net-zero emissions targets within the next three decades. In addition, many businesses—including natural gas utilities—have announced clean energy or emission reduction commitments. But clear pathways to these goals are still unknown. The starting point in any climate policy discussion should be the consideration of all potential greenhouse gas emission reduction tools.

As policymakers and businesses consider strategies to meet economy-wide net-zero emissions targets, many stakeholders have sought to mandate electrification of consumer end-uses. Often these approaches have been pursued without a robust evaluation of the associated challenges or risks, or considering and assessing the decarbonization opportunities across the natural gas value chain.

This report provides an in-depth assessment of four illustrative pathways that rely on gaseous fuels and gas infrastructure to achieve net-zero greenhouse gas emissions by 2050. Although the specific pathways differ significantly in approach, all encompass expanded energy efficiency initiatives, a shift to renewable and low-carbon fuel supplies, reduced emissions from gas operations and pipelines, carbon offsets, and negative emissions technologies.

This report is not intended to provide a precise roadmap for gas utilities to follow.

Instead, it illustrates the potential for gas technologies and infrastructure to support deep reductions in GHG emissions and highlights the need to consider these opportunities in all planning for net-zero pathways.

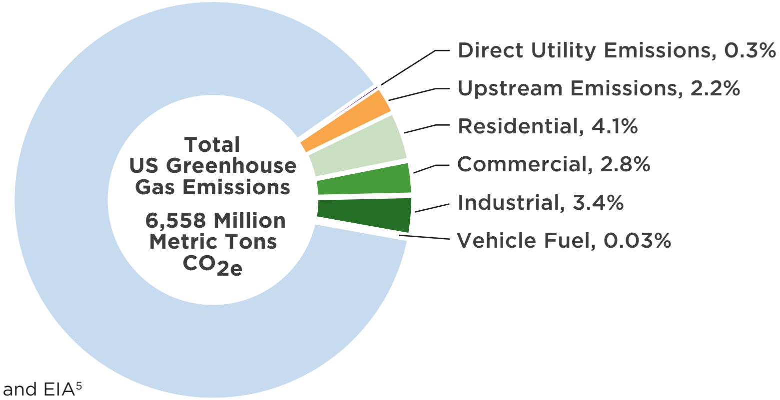
1 *Climate Change 2021: The Physical Science Basis*, the Intergovernmental Panel on Climate Change, 2021: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

Greenhouse gas emissions related to gas utilities can be considered in three separate categories[2]:

- **Direct gas utility emissions**
- **Customer emissions (residential, commercial, industrial, and vehicle fuel) from the onsite combustion of gas**
- **Upstream gas emissions from the production and transportation of gas purchased from utilities**

As shown in **Exhibit E.S. 1**, 2019 greenhouse gas emissions associated with gas utilities represented less than 13% of total US emissions.[3] Of those, customer emissions comprise the bulk of overall emissions linked to gas utilities. The ability of gas utilities to help their customers reduce these emissions will be critical to reaching economy-wide net-zero targets. Much of the analysis in this study focuses on pathways to reduce customer emissions, but separate opportunities and pathways are also presented for direct utility and upstream emissions categories.

Exhibit E.S. 1 – Total 2019 US Greenhouse Gas Emissions and GHG Emissions Categories Associated with Gas Utilities[3]



Source: EPA[4] and EIA[5]

To be successful, all pathways to achieve net-zero emissions will require the support of policymakers, regulators, and customers, along with significant investment into infrastructure and emerging technologies. Reaching net-zero emissions targets will require transformative changes to our energy systems and will have cost and other implications for consumers (a full consideration of which is outside the scope of this study). Nonetheless, this study suggests that there are crucial and enduring roles that gas utilities and gas infrastructure can play when building pathways to achieve a net-zero emissions future. In particular, decarbonization pathways that leverage both the gas and electric systems have a greater potential to help minimize negative customer impacts, maintain high reliability, accelerate carbon reductions, improve overall energy system resiliency, and create opportunities for emerging technologies (such as power-to-gas and hydrogen) to support the needs of both systems in a net-zero future.

The following sections discuss each of these topics in more detail.

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2 The World Resources Institute and World Business Council for Sustainable Development (WRI/WBCSD) have established widely adopted GHG measurement and tracking protocols. These protocols separate corporate emissions for reporting companies into three categories or "Scopes." This report avoids the scope terminology in an attempt to make the content easier to comprehend by a broad audience. However, the three gas utility GHG emissions categories discussed here do generally fall into the scope categories as well. Direct natural gas utility emissions are Scope 1 emissions. For gas utilities, customer emissions from the onsite combustion of gas sold by the company are Scope 3 emissions. Customer emissions from combustion of gas delivered but not sold by utilities are not included in Scope 3 but are sometimes included in this analysis. For gas utilities, upstream emissions from the production and transportation of gas they sell are also Scope 3 emissions. Scope 2 emissions related to electricity consumed by the gas utility are not included here but are typically negligible relative to the Scope 1 or 3 emissions, and would be mitigated as electricity generation shifts to net-zero.

3 The GHG emissions associated with gas utilities shown here do not include any combustion or upstream emissions for natural gas use by the electricity generation sector, or for natural gas that is not delivered by gas distribution companies (e.g., not all industrial natural gas demand is delivered by gas utilities). Total US GHG emissions are from EPA's latest ***Inventory of U.S. Greenhouse Gas Emissions and Sinks*** covering emissions in 2019. Customer emissions are calculated based on LDC delivered volumes share of national gas consumption in 2019 based on EIA-176 reporting. Direct utility emissions include methane and CO2 emissions, based on the EPA inventory and methane GWP of 25. Upstream emissions are calculated based on volumes delivered to customers captured here and an average emissions factor of 11.3 kg CO2e/Mcf.

4 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019 – Main Text - Corrected Per Corrigenda, Updated 05/2021 (epa.gov)

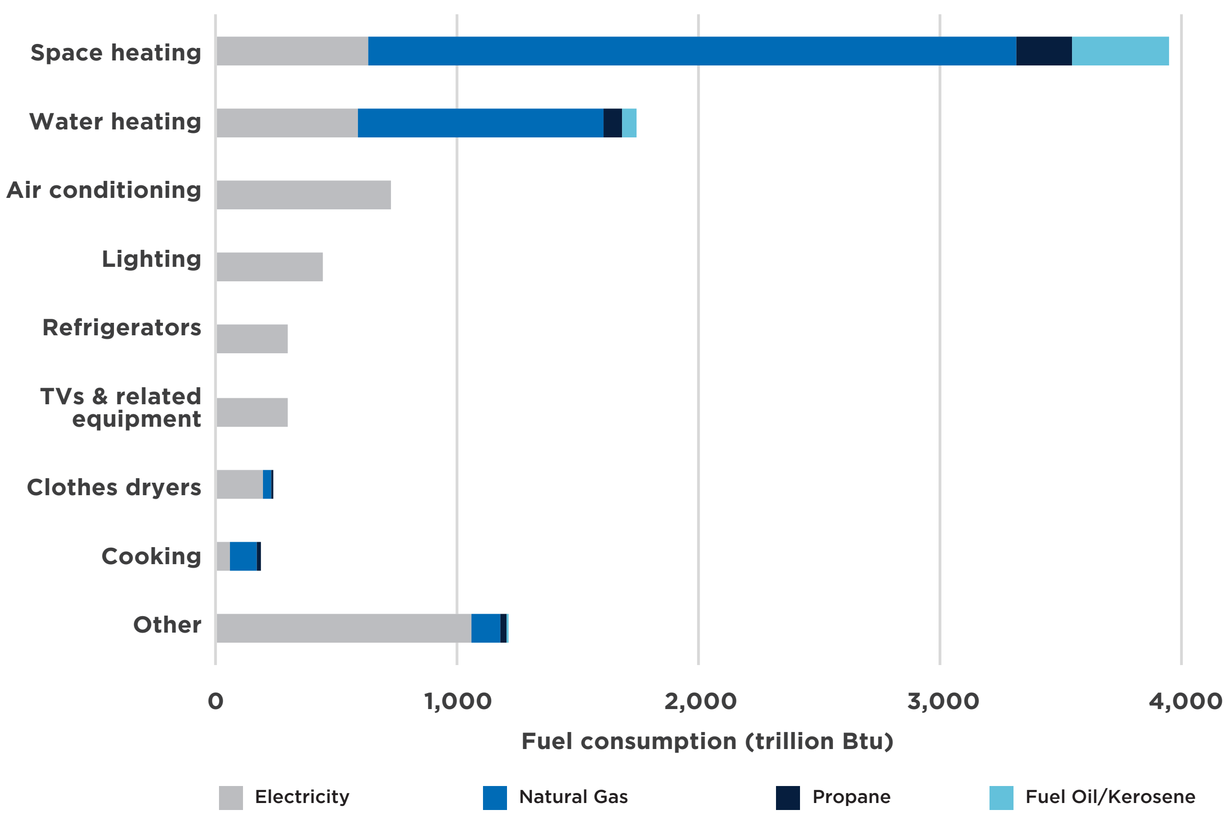
5 https://www.eia.gov/dnav/ng/ng_cons_sum_a_EPG0_vgt_mmcf_a.htm

Gas utilities and gas infrastructure can play crucial and enduring roles when building pathways to achieve a net-zero emissions future

Natural gas is a core component of the U.S. energy system, and customers and policymakers value it for its affordability, flexibility, reliability, and resiliency. **More than fifty percent of American households currently use natural gas as a heating fuel, and reliance on gas is even higher in many colder regions.** Natural gas dominates space and water heating consumption in residential households, as shown in **Exhibit E.S. 2**, and it is also widely used in commercial and industrial facilities. The scale of the U.S. economy's dependence on natural gas highlights the crucial role for gas infrastructure on any pathway to net-zero greenhouse gas emissions by 2050, and the need to address associated carbon dioxide and methane emissions. Additionally, the ability of gas infrastructure to store and transport large amounts of energy to meet seasonal and peak day energy use represents an important and valuable resource that should not be ignored when building pathways to achieve net-zero greenhouse gas emissions goals.

Based on the analysis presented in this report, there is a range of pathways to net-zero greenhouse gas emissions utilizing the gas system. An integrated approach to decarbonization that leverages the advantages of the gas distribution system is likely to support a more effective, reliable, and resilient transition to a net-zero energy system that minimizes negative impacts for customers.

Exhibit E.S. 2 – U.S. Household End-use Energy Consumption by Fuel (trillion Btu)



Source: EIA 2015 Residential Energy Consumption Survey

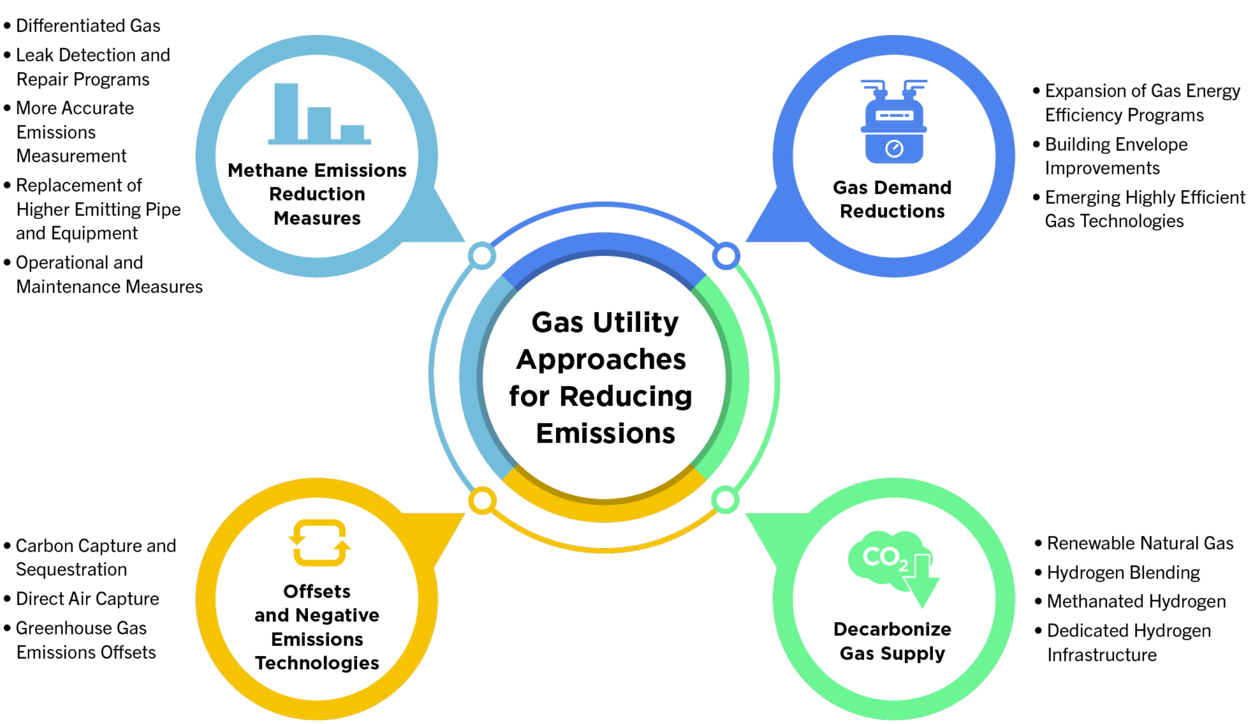
Using a range of different approaches and technologies, gas utilities can meet net-zero GHG emissions targets, and the appropriate mix of measures will vary by region and utility

For this report, ICF worked with AGA to develop illustrative pathways to net-zero emissions combining different technologies and approaches to emission reductions. In particular, ICF and AGA focused on opportunities to reduce greenhouse gas emissions within gas utilities' purview, including utility operations, gas production and transportation, and the direct use of natural gas by utility customers across the residential, commercial, industrial, and transportation sectors. This study finds that through the use of a variety of technologies and approaches, gas utilities can achieve net-zero emissions targets and contribute to economy-wide net-zero emissions goals.

At a high level, the emission reduction strategies for gas utilities included in this report can be separated into four general categories, shown in **Exhibit E.S. 3**. The first approach is to reduce gas demand; the second is to decarbonize the gas supply required to meet the remaining demand; the third is to reduce utility system and upstream emissions from methane leaks; and the fourth is to use negative emissions technologies to offset remaining GHG emissions. These strategies can largely be employed simultaneously, and the relative priority of individual approaches will vary by region and utility.

A wide range of existing and emerging energy efficiency and gas equipment and supply options have potential to contribute to decarbonization goals.

Exhibit E.S. 3 - Examples of Gas Utility Approaches to Reducing Emissions

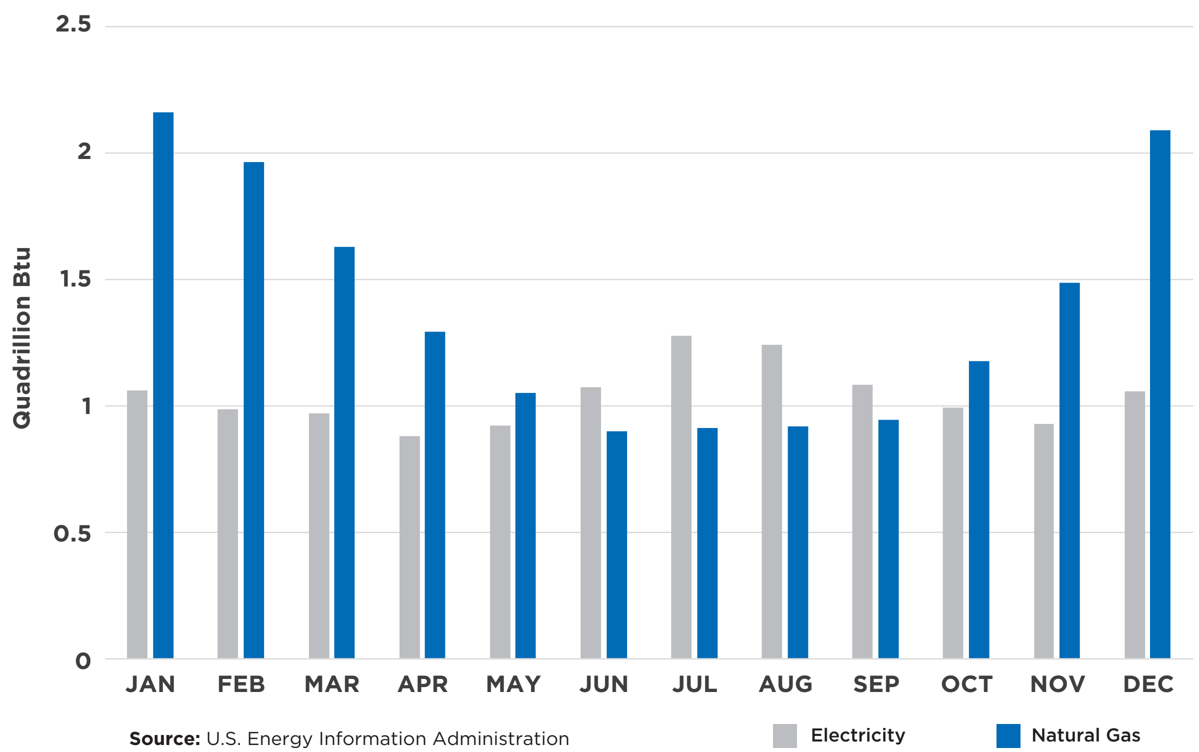


The ability of gas infrastructure to store and transport large amounts of energy to meet seasonal and peak day energy use represents an important and valuable resource that needs to be considered when building pathways to achieve net-zero greenhouse gas emissions goals

Many of the discussions and analyses looking at net-zero emissions targets begin from the assumption that mandated electrification of all fossil fuel uses, including all uses of natural gas, will be required (along with a shift to a net-zero emissions electric system), and that most, if not all, of the existing natural gas distribution infrastructure will need to be phased out. However, because a relatively limited amount of robust and comprehensive decarbonization scenario analysis that includes natural gas decarbonization strategies has been completed to date, policymakers and other key stakeholders should conduct more analysis that considers the value of natural gas decarbonization strategies or the potential risks of a limited decarbonization approach that focuses exclusively on electrification of all sectors of the economy.

One important factor to consider in any comprehensive decarbonization scenario analysis is that the peak energy demand currently served by natural gas is significantly higher than that of the electrical system in most regions. The primary reason is that most locations in the US have higher heating loads than cooling loads, as measured through heating or cooling degree days.[6] The existing gas energy storage and delivery infrastructure was designed to reliably serve customers through spikes in consumption driven by space heating during cold winter periods, while the electric infrastructure was generally designed for lower levels of peak demand (driven mainly by summer air conditioning loads). **Exhibit E.S. 4** compares total monthly electricity and gas demand in the U.S. The demand differential between gas and electricity is even more pronounced when looking at the peak day or the peak hour instead of monthly averages

Exhibit E.S. 4 – 2020 US Electric and Natural Gas Consumption Across all Customer Sectors



Source: U.S. Energy Information Administration

6 *November 2021 Monthly Energy Review*, US Energy Information Administration, 2021: https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

As a result of this differential in peak demand between gas and electricity, it's likely that a large-scale shift to electric heating—even using highly-efficient technology such as air-source heat pumps—would drive significant increases in peak electric loads, shift the electric grid from summer peaking to winter peaking in many locations, and increase the challenges associated with decarbonizing electric generation using intermittent renewable sources. While careful analysis is required to understand the full extent of any challenges in a specific region, electrification could spur additional infrastructure costs if it necessitates an increase in available generating capacity and electricity grid upgrades to meet a new peak electricity demand. As demonstrated by the 2021 cold snap in Texas, energy infrastructure needs to be built to accommodate such peaks—even if very cold periods are infrequent.

Leveraging renewable and low carbon gas for heating and other uses can help bolster decarbonization while maintaining high levels of energy system reliability with regards to building heating needs. More broadly, continued utilization of gas infrastructure can bring flexibility to future energy systems and could make net-zero pathways more feasible for the electric grid. One possible example is hybrid gas-electric heating systems, which provide space heating through the use of an electric air-source heat pump paired with a natural gas furnace and utilize integrated controls that optimize the energy consumption, emissions and cost of the system throughout the year. Hybrid heating can help provide many of the decarbonization benefits of all-electric heat pumps (or even offer additional flexibility benefits on days with low renewable generation by switching to gas heating) while reducing high winter electric peaks, maintaining heat reliability for customers, and helping to maintain lower energy bills during cold periods. It should be noted that the hybrid heating opportunity would also create operational and cost challenges for gas utilities (accommodating similar peak demand while annual demand declines), and may require a much different regulatory paradigm. Leveraging gas and electricity in decarbonization plans could also help alleviate other challenges associated with an electrification-only approach, particularly the logistical and cost issues that utilities and others face in comprehensively retrofitting existing buildings (across all sectors). Emerging strategies such as hydrogen and power-to-gas may also help enable natural gas infrastructure to be used for renewable energy storage, providing a potentially compelling long-duration energy storage solution for variable renewable energy and helping the power sector add more renewables.

Some regional factors may pose challenges for wide-scale building electrification, particularly if gas isn't included as part of the overall decarbonization plan. These include:

- Limits on the region's existing electric supply capacity and the outlook for new capacity coming online. New renewable energy resources combined with energy storage baseload capacity offer a viable path to serve increased demand from electrification while reducing carbon emissions. Although renewable electricity resources like solar and wind have become relatively inexpensive, storing power from those intermittent resources remains expensive. While declining battery storage prices support shifting renewable power to different hours of the day, replacing dispatchable fossil fuel generation and storage capacity is particularly challenging for long duration seasonal or reliability requirements (for example, having multiple days of stored electricity to cover periods of low renewable generation).

- The region's adoption rate of electric vehicles (EVs), how much (and how quickly) that will shift energy demand from gasoline to electricity, and whether there are policies and incentives in place to sufficiently shift EV charging out of peak demand periods. Both vehicle and building electrification can stress the distribution grid—and create peakier, less-predictable power demand—so measures should be taken to avoid these increases in electric load occurring at the same time and in the same places when possible, and add new infrastructure to manage them as needed.

- The efficiency of the building stock in a region. The cost of all forms of energy is likely to go up in pursuit of net-zero emissions targets. Energy efficiency is often the most cost-effective emissions-reduction strategy and in many cases should be the first action taken. As a result, it may make sense to prioritize and incentivize energy efficiency upgrades, such as building envelope upgrades, before pursuing building electrification. Older, less efficient buildings may also pose additional hurdles to electrification due to increase costs, complexity of retrofits, and need for upgraded electrical service.

The challenges and opportunities for electrification will also depend on the scale, speed, and sectors being electrified. Not all forms of electrification will have the same costs or impacts, and some gas end uses like space heating are likely to pose a particular challenge to electrify. Pathways that leverage decarbonization strategies across both the gas and electric system may have potential to better maintain low energy costs, improve system reliability, create opportunities for emerging technologies (such as power-to-gas and hydrogen) to support the needs of both systems, accelerate carbon reductions, and improve overall energy system resiliency.

Planning for a net-zero future should not necessitate a choice between one energy system or another energy system (gas, electricity, or other forms). Leveraging the gas and electricity systems for their relative strengths should allow for a lower-risk pathway to reducing emissions.

Continued utilization of gas infrastructure can increase the likelihood of successfully reaching net-zero targets while minimizing customer impacts

Any pathway to net-zero emissions will require transformative changes to multiple energy systems and the economy as a whole, and will face a number of significant emergent challenges (both expected and unexpected). However, some decarbonization pathways are likely to be more feasible to implement, appealing to customers, and have a higher chance of success. All of the emissions reduction options need to be considered and, where viable, deployed in net-zero emissions pathways in order to maintain flexibility, decrease the chances of energy systems failing, maintain or increase existing public support for aggressive climate action, and increase the chances of reaching net-zero targets. Pre-selecting 'winning' technologies for 2050 or making decisions to shut down some energy systems that customers across all sectors currently rely on will reduce the role that innovation can play in supporting emissions reductions, and may make it more difficult and expensive to achieve net-zero emissions goals.

The table in **Exhibit E.S. 5** outlines the four pathways included in this analysis and highlights the primary emission reduction measures in each pathway. These pathways are meant to be illustrative of the kinds of combinations of emission reduction strategies that could be pursued and they are not intended to be prescriptive. Many other pathways combining emission reduction strategies differently could also be possible, and this study does not attempt to establish an 'optimized' pathway. Particularly given the diverse array of measures available, the optimal pathways for a specific region and utility will vary based on highly localized factors, such as climate/temperatures, energy prices, the composition of the housing stock, and commercial and industrial base, as well as the capacity, age and GHG intensity of existing electricity generation, transmission, and distribution infrastructure. The other decarbonization pathways adopted in a given area, including for sectors outside the scope of this work (e.g., power generation[7] and transportation), as well as the speed of change, will also impact the optimal pathway for a given region.

Each of the four pathways studied reaches net-zero emissions for the gas utility and gas utility customers by 2050. The pathways discussed in this report combine a number of different measures to reach net-zero emissions targets, and **Exhibit E.S. 6** summarizes how each of these pathways leads to gas utility customer emission reductions. The color bands represent the emission reductions achieved relative to a baseline 'Business as Usual' (BAU) case, showing the diversity of strategies included in each pathway to net-zero emissions. The relative portion of 2050 savings between reductions in gas demand, renewable and low carbon gas supply, renewable and low carbon gas supply, and negative emissions technologies are indicated to the right.

7 While gas demand in the power sector was not included in this analysis, the study assumed that greenhouse gas emissions from electricity generation would be net-zero by 2050; this is a critical assumption that drives the logic for several of the measures explored in the different pathways.

Exhibit E.S. 5 – Illustrative Gas Customer Decarbonization Pathways

Pathway		Description	Key Strategies
1	**Gas Energy Efficiency Focus**	This pathway is designed to help maintain customer fuel choice by leveraging existing infrastructure, demand-side management programs, and regulatory structures. It drives emission reductions primarily through the significant expansion of utility energy efficiency programs, promotion of gas heat pump technology, building shell retrofits, more stringent fuel-neutral building energy codes, and considerable volumes of renewable and low carbon gases.	• Gas heat pumps • Aggressive fuel-neutral building energy codes • Major building shell retrofits • High-efficiency gas appliances • Other energy efficiency (E.E.) measures • RNG & hydrogen blending • Negative emissions technologies
2	**Hybrid Gas-Electric Heating Focus**	This pathway focuses on coordinated gas and electric infrastructure planning and optimization through widespread adoption of hybrid gas-electric integrated heating systems, as well as selective electrification of certain end uses (with the goal of avoiding additional stress on the electric grid where possible), in conjunction with a large push for more gas energy efficiency. Greater coordination, and hybrid heating systems specifically, will require new regulatory structures to accommodate, but may also offer the potential to achieve a more optimized energy system (eg. controlling hybrid systems to respond to real-time signals like low levels of wind or solar generation).	• Hybrid gas-electric heating • Improved fuel-neutral building energy codes • Building energy efficiency retrofits • High-efficiency gas appliances • Electric appliances • Other E.E. measures • RNG & hydrogen blending • Negative emissions technologies
3	**Mixed Technology Approach**	This pathway represents an "all of the above" scenario with fuel-neutral policy where customers choose from a range of applications. Rather than focusing primarily on a single technology or a single energy system, this pathway illustrates a wide range of technologies to reach emission reduction targets such adoption of gas heat pumps, a ramp-up in utility efficiency programs, hybrid heating technologies, and some electric applications.	• Hybrid gas-electric heating • Gas heat pumps • Electric air-source heat pumps • Improved fuel-neutral building energy codes • Building energy efficiency retrofits • High-efficiency gas appliances • Electric appliances • Other E.E. measures • RNG & hydrogen blending • Negative emissions technologies
4	**Renewable and Low Carbon Gas Focus**	This pathway prioritizes the decarbonization of the energy supply in order to limit the need for customers to make major changes in energy equipment and infrastructure. It relies heavily on existing and emerging renewable and low carbon fuels and less on aggressive retrofits of the building stock. This pathway still includes significant levels of gas energy efficiency improvements.	• Improved fuel-neutral building energy codes • Building energy efficiency retrofits • High-efficiency gas appliances • Gas heat pumps • Other E.E. measures • RNG & hydrogen blending • Dedicated hydrogen infrastructure • Negative emissions technologies

As with any complex forward-looking projection incorporating a wide array of data inputs, these pathways depend on a range of assumptions. First, the analysis in this study shows the possibility to develop more RNG than previous estimates developed by ICF for the 2019 American Gas Foundation study on RNG. This study relied on the same resource potential as the 2019 study but reflected a 10 year longer timeline, as well as changes in expectations regarding the achievable share of the resource potential (see **Section 4.4.1** for further details). Second, all the pathways studied in this analysis are built off a range of key assumptions from the U.S. Energy Information Administration's (EIA) 2020 Annual Energy Outlook (AEO) reference case forecast, which assumes roughly 25% natural gas customer growth between 2020 and 2050. This built-in expectation of customer growth shows how, under the right conditions, gas utilities can continue to be critical parts of future energy mixes while still enabling and supporting a shift to a net-zero economy. Because more emphasis was placed on developing pathways showcasing a diversity of options to meet 2050 targets—rather than optimizing all technologies included in a given scenario or trying to reach interim milestones—this study does not attempt to predict what is most likely to happen by 2050. Finally, the results of this study are presented at the national level; further analysis accounting for highly localized considerations (including costs) will be needed to study these and other pathways for a given region.

The gas utility customer GHG emissions for each of the four pathways are shown in **Exhibit E.S. 6**. The customer emissions shown in this exhibit represent more than 80% of overall gas utility-related GHG emissions. Pathways to reduce the remaining roughly 20% of emissions, reducing the direct utility and upstream GHG emissions to net-zero levels, are also covered in the full report.

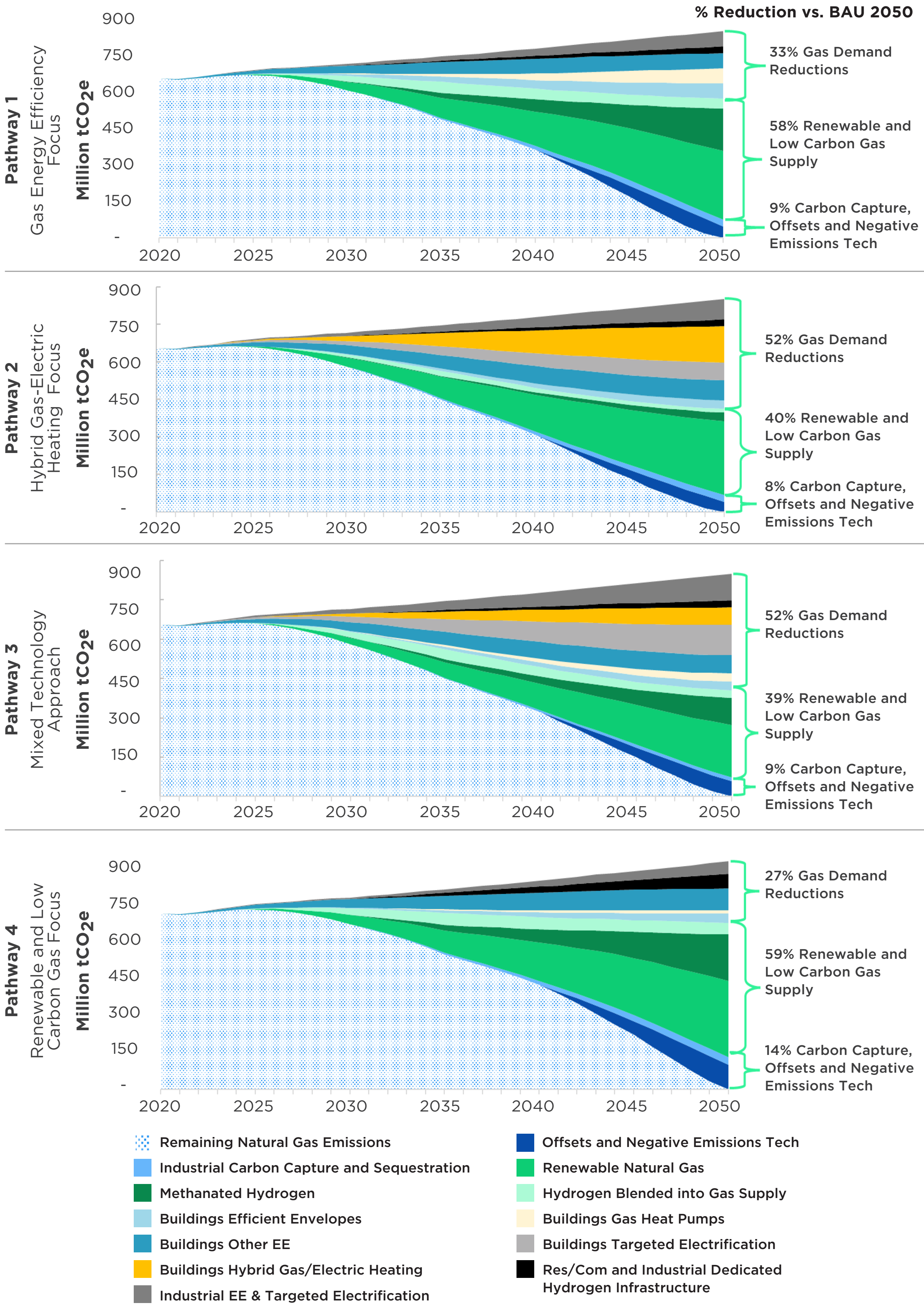
Gas utilities can achieve significant emission reductions by pursuing immediate actions like expanded energy efficiency, renewable fuels, and methane emissions mitigation

Improvements in energy efficiency are typically the lowest-cost approach to reducing emissions and can have a significant impact while also offering a range of benefits to customers (from reduced bills to increased comfort). According to 2020 AGA research, natural gas utilities helped customers save 259 trillion Btu of energy and offset 13.7 million metric tons of carbon dioxide emissions from 2012 through 2018 in the US.[8] In a different 2020 report from Lawrence Berkeley National Laboratory, researchers found an average overall levelized program cost of saved natural gas of $0.40/therm across nearly 37 different utilities/program administrators in 12 states over six years.[9] That level of cost-effectiveness is difficult to match through non-efficiency approaches to gas demand reduction, and it underscores the importance of energy efficiency in any successful decarbonization plan. Many of the energy efficiency measures that gas utilities can promote, such as smart thermostats or building insulation retrofits, also promote customer choice since they can support decarbonization pathways using both electric and gas end uses.

8 *Natural Gas Efficiency Programs Report 2018 Program Year*, American Gas Association, 2020: https://www.aga.org/globalassets/aga-ngefficiency-report-py2018-5-2021.pdf

9 *Cost of Saving Natural Gas through Efficiency Programs Funded by Utility Customers: 2012–2017*, Lawrence Berkeley National Laboratory, 2020: https://escholarship.org/uc/item/0164134n

Exhibit E.S. 6 – U.S. Gas Utility Customer Emission Reduction Pathways

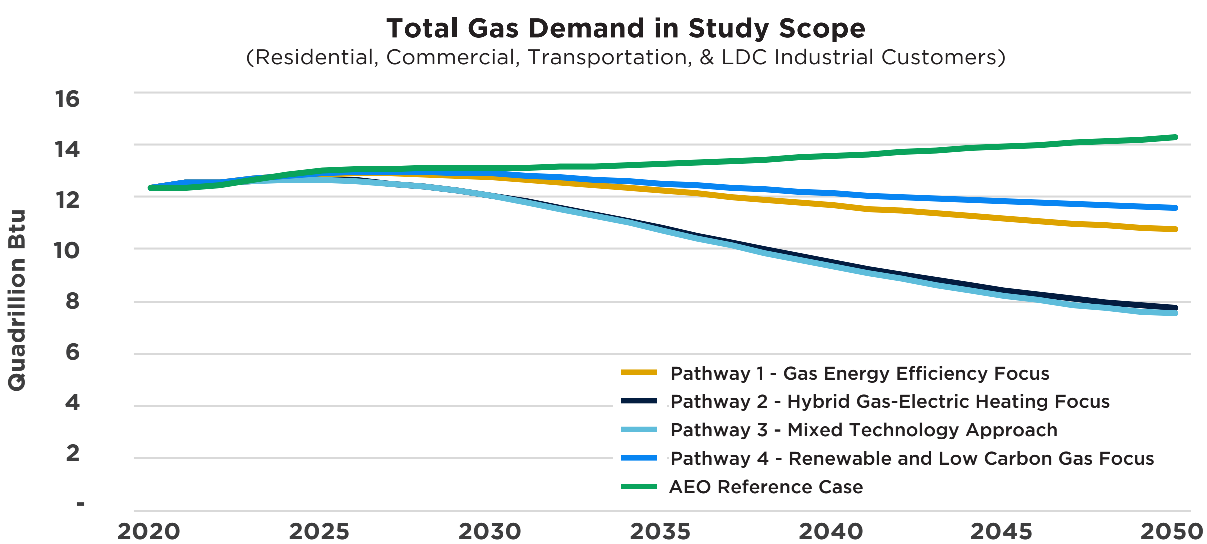


Any pathway to net-zero emissions will also require significant increases in renewable and low carbon gas, and all of the production that can be brought on-line will likely be needed. Gas utilities could help aggressively develop these resources in the coming years (taking a parallel approach to electric utilities that are working to develop emissions-free electricity quickly). Finally, more accurate quantification and reduction of methane leaks is also a key strategy for reducing GHG emissions. However, more precise and company-specific methane emissions factors will likely be needed to capture direct utility emissions more accurately and help utilities prioritize and track leak reductions.

While all pathways show an overall decline in customer gas demand by 2050, the degree of gas demand decline depends upon the unique set of emission reduction solutions deployed in each pathway. The line graph in **Exhibit E.S. 7** shows the changes in gas demand over time modeled in each of the four pathways studied in this report. The table in the exhibit shows the percent change in gas demand from 2020 in 2050, split by the different utility customer sectors. Overall, the pathways studied here would reduce utility customer gas demand by between 6% and 39% from 2020 levels, or between 22% and 55% from 2050 AEO Reference Case levels. The smallest reductions in gas demand come from pathways that rely more heavily on renewable gases.

The pathways studied in this analysis are built on key assumptions from the U.S. EIA AEO reference case forecast, which assumes natural gas customer growth of roughly 25% between 2020 and 2050. As a result, the demand reductions shown below would be significantly larger without the growth in the customer base predicted by the AEO Reference Case, and less renewable and low carbon fuel would be needed to meet customer needs in a lower demand scenario.

Exhibit E.S. 7 – Total Gas Demand for U.S. Gas Utility Customers[10] in Each Pathway



2050 VS 2020 % Change

	Total	Res	Com	Ind	Transp
AEO Reference Case	+16%	-3%	+13%	+32%	+413%
P4 - Renewable & Low Carbon	-6%	-9%	-5%	-13%	+413%

2050 VS 2020 % Change

	Total	Res	Com	Ind	Transp
P1. Gas EE Focus	-13%	-23%	-11%	-11%	+413%
P2 - Hybrid Heating	-37%	-54%	-46%	-19%	+413%
P3 - Mixed Approach	-39%	-52%	-44%	-29%	+413%

10 Utility customer gas demand only. Utility industrial demand assumed to represent half of total industrial gas use, while this chart also does not capture natural gas for power generation.

Large amounts of renewable and low-carbon electricity and gases, and negative emissions technologies, will be required to meet an economy-wide 2050 net-zero target

As in the power sector, rapid and widespread adoption of renewable, low-carbon, and negative emissions resources will be essential to the gas sector achieving net-zero emissions. All pathways included in this study incorporate a significant expansion of renewable natural gas (RNG) and hydrogen production and consumption.

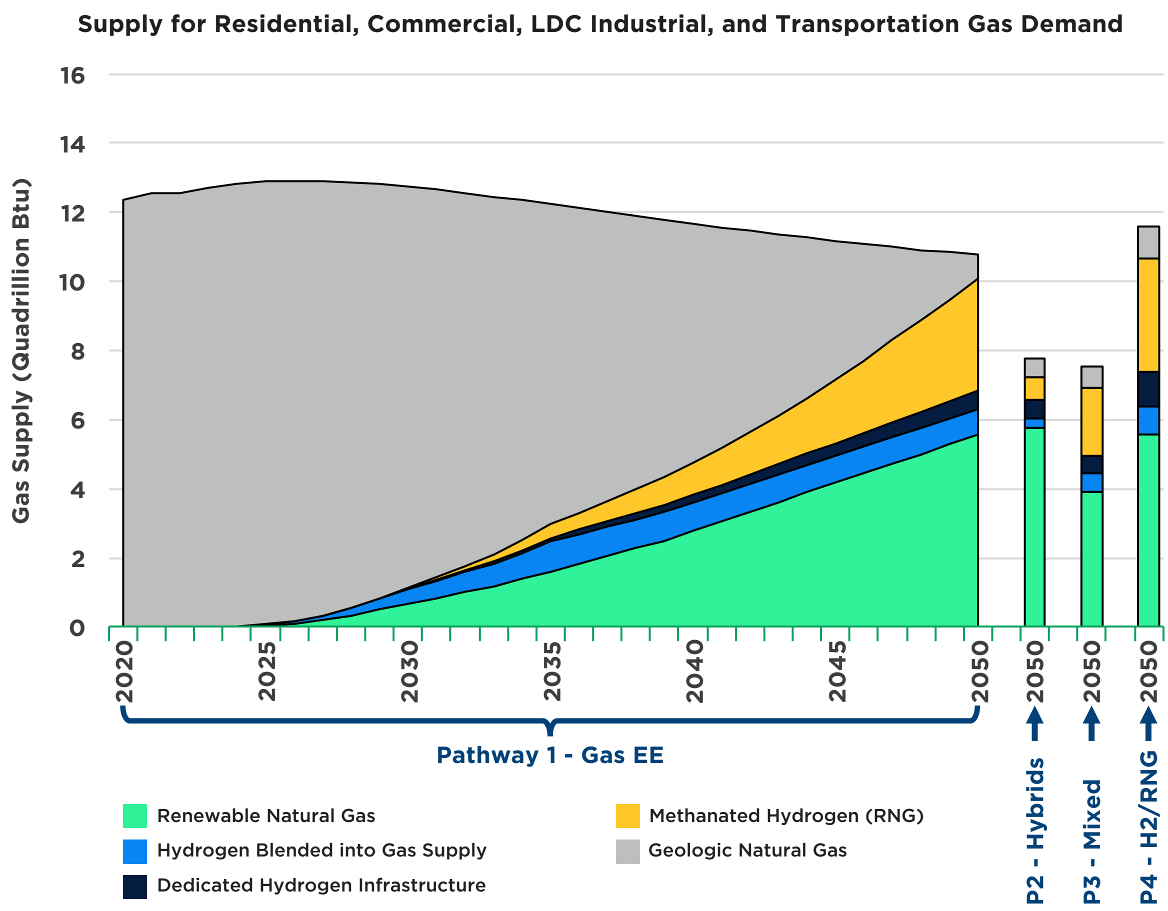
RNG has a clear role in helping different sectors to decarbonize. Uncertainties remain regarding the pace of technology advancements, competition from other sectors for this renewable energy, and policy approaches that will impact how quickly production levels can be ramped up, costs, and what total volumes might be achievable. Nonetheless, given its large potential to significantly reduce emissions, efforts should be taken to support the development and deployment of RNG and hydrogen projects as these issues are being studied and addressed. In order for the economy to reach net-zero targets, there will likely be a use for all of the renewable gas that can be produced. Although the availability of renewable gas is relatively limited at present in most regions, low-carbon fuel producers have shown the ability to ramp up production relatively quickly when a market is developed for the RNG. For example, a 2019 study performed on behalf of Argonne National Laboratory estimated that 157 RNG production facilities would be operating in the U.S. at the end of 2020 (up 78% from 2019), 76 projects under construction (up 100%), and an additional 79 projects in the planning process.[11]

11 https://energy-vision.org/wp-content/uploads/2020/12/EV-Argonne-2020-RNG-Release.pdf

Exhibit E.S. 8 shows the RNG and hydrogen gas supply assumptions included in each of the four pathways. Overall gas demand corresponds with **Exhibit E.S. 7** and is represented by the total height of the bars or bands. The graph shows the full 30-year evolution of the gas supply mix for the first pathway, and the final 2050 gas mixes for the other three pathways. Lower bars for pathways 2 and 3 represent larger reductions in gas demand. It is important to note that different combinations of the available renewable and low-carbon gas supply options could have been used in each of the pathways shown below. None of the supply mixes are 'optimized' in conjunction with the demand reductions for a given pathway. Instead, they illustrate a range of different possibilities for the gas supply. For example, Pathway 2 was used to demonstrate a possible gas supply mix if hydrogen was less abundant.

While pipeline infrastructure will still be leveraged for RNG and hydrogen in the pathways shown above, all of the pathways represent a major reduction in the consumption of geologic natural gas. However, it is important to note that this analysis and the chart above focus on utility customers and do not cover all U.S. gas demand or transportation. This chart does not include gas for power generation, transmission-connected industrial customers, or LNG exports which may continue to rely on geologic gas. The gas supply mix does not include potential hydrogen and RNG volumes used in the transportation or power generation sectors.

Exhibit E.S. 8 – Utility Customer Gas Supply Mix



To reach net-zero emissions reduction targets with some consumption of geologic natural gas remaining, a portion of the emissions associated with gas combustion would be captured using carbon capture and storage technologies in the industrial sector. We anticipate other negative emissions strategies, offsets, other emerging technologies, or more renewable and low carbon fuels to be used to close any final gaps towards net-zero emissions. These pathways are meant to illustrate potential opportunities and were not optimized, do not account for local considerations, and do not represent the full range of potential or possible gas solutions. It is difficult to predict how technology will develop over the next 30 years. A breakthrough in hydrogen production, carbon capture, or other high-impact areas could lead to the emergence of different pathway options or different mixes of measures.

There are a number of emerging strategies that can directly reduce GHG emissions or extract CO_2 from the atmosphere and sequester it. There is significant uncertainty on when different options are likely to mature and their ultimate cost-effectiveness. The advancement of such technologies could significantly alter the kinds of pathways discussed in this report and potentially allow for higher levels of geologic natural gas to continue to be used in the gas system while enabling gas utilities to achieve net-zero emissions.

With increased RD&D and coordination with the electric sector, there are greater opportunities to unlock more decarbonization measures that leverage the gas system

The net-zero pathways in this study include a balance of existing technologies in the market today, early-stage commercial technologies just beginning to reach the market, and emerging technologies at different stages of research, development, and demonstration (RD&D). RD&D funding offers a critical opportunity to support major new emissions reductions solutions, some of which may be envisioned here, while others may not yet have been conceptualized. Given the scale of the challenge in reaching net-zero greenhouse gas emissions across the economy and the inherent uncertainty in possible pathways to achieving net-zero emissions in other parts of the economy, companies and the government should continue to increase investment in gas system RD&D opportunities. Investments to unlock longer-term opportunities do not mean avoiding taking action now, particularly on the immediate actions, but parallel efforts to develop new and improved solutions can help make achieving these targets more likely and cost-effective. While RD&D needs are by no means exclusive to gas technologies, there are a number of promising areas to support, including gas heat pumps, hydrogen blending, and thermal gasification.

There may also be opportunities to take a more collaborative approach to decarbonization across both the electricity and gas systems. The current natural gas and electric systems have evolved together to meet customer energy needs with a high degree of reliability, at a relatively low cost, by effectively leveraging the relative benefits of both energy systems. Responding to the need for deep greenhouse gas emissions reductions will create fundamental challenges to both systems, particularly due to the need to shift from conventional gas supply and power generation sources to emerging renewable and low-carbon power and gas sources. Supporting a system where gas and electric utilities can continue to work together to reduce emissions could help minimize negative customer impacts, maintain high reliability, and create opportunities for emerging technologies (such as power-to-gas and hydrogen) to support the needs of both systems, accelerate carbon reductions, and improve overall energy system resiliency. All options should be on the table to ensure a cost-effective, reliable, resilient, and equitable transition to a net-zero emissions energy system, and gas and electric utilities both have roles to play to support this transition.

Supportive policy and regulatory approval will be essential for gas utilities to achieve net-zero emissions

Reaching net-zero emissions targets will require transformative changes to our energy systems and economy, and the analysis in this report lays out a series of illustrative pathways demonstrating the kinds of ways in which gas utilities can support this transition. However, gas utilities cannot implement decarbonization pathways on their own. Gas utilities operate under strict regulations by state and federal regulators and must adhere to many rules and processes. There are set parameters on the rates they charge customers to recover costs for investments and operating expenses, including the gas supply acquisitions. Natural gas utility regulations have historically focused on providing safe, reliable, and affordable service to consumers. There would be benefits to integrating environmental considerations into gas utility regulatory constructs. Environmental and climate policy must be aligned with gas utility regulatory constructs for gas utilities to continue to invest in gas infrastructure while advancing cost-effective emissions reduction opportunities.

While policy considerations and opportunities will depend on regional and state factors, some specific **regulatory actions** that could support the gas GHG emission reduction initiatives studied in this report include:

- Supporting expanded utility energy efficiency programs (e.g. through increased funding, changes to cost-effectiveness tests, etc.) to support the broader deployment of gas savings measures that are cost-effective relative to other options for reducing GHG emissions
- Developing policies that incentivize market demand for low carbon gas and advanced gas technologies in the residential, commercial, and industrial sectors
- Coordinating gas and electric system planning to understand the full range of decarbonization implications and pathway alternatives, as well as to determine the lowest cost and least-impact pathways for customers while meeting reliability requirements
- Considering updates to utility rate mechanisms and cost-recovery processes to ensure all parties are incented to support GHG emission reductions
- Developing structures to address consumer equity issues related to the distribution of decarbonization measures and impacts across all customers
- Considering methods to compensate gas customers for cost savings they achieve for electric customers through services such as energy storage, load flexibility, and peak shaving that are provided via the gas system (across a range of different measures and technologies)

Some additional **technology-focused opportunities** include:

- Supporting company-specific methane emissions factors to more accurately capture direct utility emissions and better understand the emissions reductions utilities are able to achieve
- Increasing research, development, demonstration, and deployment (RDD&D) funding for low-carbon gas and negative emissions technologies
- Promoting system modernization programs to maintain and upgrade gas infrastructure
- Improving building codes that reduce heating load while maintaining fuel choice in order to make new buildings more efficient and prioritize energy efficiency when buildings undergo major renovations
- Supporting hydrogen production and deployment through incentives, RD&D support, pilot programs, blending agreements, and codes and standards development.

Ultimately, the ability of both gas and electric utilities to successfully implement effective and tailored decarbonization strategies in their territories will be highly dependent upon support and approval from policymakers, regulators, customers, and other stakeholders. However, the extensive and complex transformations being envisioned to reach net-zero emissions targets have yet to be thoroughly examined in most regions. As a result, it's critically important that utilities, regulators, and other stakeholders perform careful and objective analyses to find the most effective, equitable, achievable, and least-cost path to net-zero—across both the electric and gas systems—that is in the best interest of customers in their service territories and jurisdictions.

The pathways in this study are illustrative of the types of approaches that could lead gas utilities to net-zero emissions by 2050. However, the optimal pathway will vary by utility and region and depends on many factors. **Exhibit E.S. 9** shows a sample of the kinds of measures and screening criteria that utilities, regulators, and policymakers could consider when developing gas emission reduction plans tailored to their region. It should be noted that thoroughly evaluating these local screening criteria requires an intensive analytical effort, and that plans will need to be re-visited periodically and evolve over time as conditions change.

Exhibit E.S. 9 – Example of Gas Utility Emissions Reduction Plan Options and Screening Criteria

Emission Reduction Options

Natural Gas Demand Reductions	Building shell upgrades (and/or code improvements focused on improving efficiency)
	High-efficiency space heating
	High-efficiency water heating
	Smart thermostats and building control upgrades
	More-efficient appliances and process equipment
	Building commissioning/ retrocommissioning
	Combined heat and power (CHP)
	District heating
	Home energy reports (behavioral efficiency)
	Low-flow hot water fixtures
	Gas heat pumps
	Electric appliances, and space and water heating equipment
	Hybrid space heating (e.g. electric heat pump paired with a gas furnace)
Renewable and Low-Carbon Gas Supply	Renewable natural gas
	Methanated hydrogen
	Hydrogen blended into gas supply
	Dedicated hydrogen infrastructure (including adoption of new end uses)
Methane Emission Reduction Measures	Differentiated gas
	Leak detection and repair programs
	More accurate emissions measurement
	Replacement of higher emitting pipe and equipment
	Operational and maintenance measures
Negative Emissions Technologies	Carbon capture and sequestration
	Direct air carbon capture
	GHG emissions offsets

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Screening Criteria

Local Considerations	Local, state, and regional emission reduction targets and climate policy
	Regulatory environment (including cost-effectiveness tests, etc.)
	Climate (particularly heating degree days and extreme temperatures) and impact on measure efficacy
	Composition and age of existing building and appliance stock
	Commercial and industrial base
	Current and projected economic growth
	Current energy prices (gas and electricity)
	Composition and age of existing natural gas and electric utility infrastructure
	Existing/planned electricity generation, transmission, and distribution infrastructure (capacity, age, GHG intensity, etc.)
	Regional renewable resource potential
	Utility type (gas or dual fuel, investor-owned, municipal, co-op, etc.)
	Local/regional plans for non-gas decarbonization, and potential competitive impacts from surrounding regions
	System hydrogen conversion feasibility
Local Evaluation Criteria	Safety
	Costs and affordability
	Impacts to energy system (resiliency, peak demand impacts, reliability, etc.)
	Impacts to customers (energy prices, reliability, non-energy impacts, etc.)
	Customer equity
	Consumer preferences
	Feasibility and ability to scale
	Renewable and low-carbon supply considerations
	Implementation support required (traditional DSM program, market transformation effort, etc.)
	Technological readiness
	Expected future technology improvements (performance, costs, etc.)
	Current and projected natural gas utility rate base

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Prioritized Utility Plan

Gas Utility Emissions Reduction Plan