# Colorado Future of Gas:

## Building Decarbonization – Literature Review

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# Abstract

Requested by the Colorado Future of Gas Steering Committee, this literature review examines a wide range of research on building emissions reductions. Under Colorado's Clean Heat Standard (Senate Bill 21-264), gas utilities will be required to develop clean heat plans that meet the state's goal of reducing greenhouse gas (GHG) emissions by 4% below 2015 levels by 2025, and 22% below 2015 levels by 2030. This literature review examines different emissions reduction strategies and provides an overview of the costs and emissions impacts associated with the eligible resources allowed under the Clean Heat Standard. The review also discusses how emissions reduction strategies could impact customers, disproportionately impacted communities, the workforce, existing infrastructure, and reliability.

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List of Acronyms

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**ACEEE** - American Council for an Energy-Efficient Economy

**AGF** - American Gas Foundation

**AQCC** - Air Quality Control Commission

**ASHP** - Air source heat pump

**BAU** – Business-as-usual

**Btu** - British thermal units

**ccASHP** - Cold climate air source heat pump

**CCS** - Carbon capture and sequestration

**CCUS** - Carbon capture, use, and storage

**CCEF** - Colorado Clean Energy Fund

**CEE** - Center for Energy and Environment

**CEO** – Colorado Energy Office

**CNEE** - Center for the New Energy Economy

**CO$_2$** - Carbon dioxide

**CO$_2$e** - Carbon dioxide equivalent

**CPACE** - Commercial Property Assessed Clean Energy

**CPUC** - California Public Utilities Commission

**DAC** - Direct air capture

**DSM** - Demand side management

**E3** - Energy and Environmental Economics, Inc.

**EERS** – Energy efficiency resource standard

**EIA** - Energy Information Administration

**EOR** – Enhanced Oil Recovery

**GDU** – Gas Distribution Utility

**HVAC** - Heating, Ventilation, and Air Conditioning

**IOU** - Investor-owned utility

**GHG** - Greenhouse gases

**GPI** - Great Plains Institute

**Gt** - Gigaton

**kg** – Kilogram

**kW** – Kilowatt

**kWh** – Kilowatt hour

**LCRI** - Low-Carbon Resources Initiative

**IIJA** - Infrastructure Investment and Jobs Act

**IRA** - Inflation Reduction Act

**Mcf** - Thousand cubic feet

**MMBtu** – Metric million British thermal units

**MMT** - Million metric tons

**MSW** – Municipal solid waste

**NREL** - National Renewable Energy Laboratory

**PUC** - Public Utilities Commission

**RENU** - Colorado Residential Energy Upgrade

**RNG** - Renewable natural gas

**RPACE** - Residential Property Assessed Clean Energy

**SNG** - Synthetic natural gas

**tCO$_2$** - Ton of carbon dioxide

# Colorado Future of Gas: Building Decarbonization – Literature Review

## Introduction

Enacted in 2021, Colorado's Senate Bill 21-264 (Clean Heat Standard) set clean heat targets for large gas distribution utilities (GDUs), requiring that GDUs serving more than 90,000 retail customers reduce greenhouse gas (GHG) emissions by 4% below 2015 levels by 2025, and 22% below 2015 levels by 2030. As part of compliance with the Clean Heat Standard, GDUs are first required to submit, for public utilities commission (PUC) review and approval, clean heat plans that will reduce carbon dioxide and methane emissions that meet the clean heat targets at the lowest reasonable cost.[1] The bill set a cost cap of 2.5% of annual gas bills for all full-service customers.

Eligible resources under the Clean Heat Standard include energy efficiency and demand-side management (DSM), recovered methane,[2] green hydrogen, beneficial electrification, pyrolysis of tires (if that pyrolysis meets a recovered methane protocol), and any other technology the PUC determines to be cost-effective and that reduces carbon emissions in customer end-uses or that meets a recovered methane protocol developed by the Air Quality Control Commission (AQCC).

The Steering Committee was created to inform Colorado's clean heat planning process. The Committee is comprised of representatives from several non-governmental organizations, state agencies, including the PUC and the Colorado Energy Office (CEO), and utilities. The Center for the New Energy Economy (CNEE) was selected to lead project facilitation and conduct a literature review. This literature review examines the findings of several studies on the role of gas and electricity in building decarbonization. This review aims to inform the Steering Committee by addressing the trade-offs of various approaches to meeting the Clean Heat Standard's emissions targets.

This literature review will focus on examining different emissions reduction scenarios. To do so, this review examines different technologies, their emissions impacts and costs, and potential impacts on customers, disadvantaged communities, and jobs. We begin by discussing areas for future research.

### Areas for Future Research

Our review of the literature found several areas for future research. The impacts of building decarbonization strategies on customer bills and electric and gas rates were difficult to find. Though some studies discussed customer impacts, these studies did not explore bill impacts in depth. Similarly, while several papers reviewed the potential impacts of different gas and electric rate designs, a study with data specific to Colorado or the region would be useful.

The costs, availability, infrastructure needs, and emissions reductions associated with different technologies also require additional study, especially within Colorado's context. While the studies and reports examined for this literature review were very rarely specific to Colorado, we highlight findings for states that share similarities with Colorado's energy market and climate.

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[1] Municipal utilities are required to submit their plans to the AQCC.

[2] Recovered methane is defined as the following resources, if they are located in Colorado and meet a recovered methane protocol established by the AQCC: biomethane, methane derived from municipal solid waste (MSW), pyrolysis of MSW, biomass pyrolysis, enzymatic biomass, or wastewater treatment; certain captured coal mine methane and methane leak repairs to gas distribution and service lines.

We especially found disagreement and a lack of information regarding the costs associated with emerging technologies. It was difficult to find precise cost estimates for synthetic natural gas (SNG), recovered methane, and electrification and energy efficiency technologies and retrofits. Some of this uncertainty stems from the fact that some of these resources are not currently in widespread use. Cost estimates are expected to become more abundant and accurate as technologies advance and become established. Additionally, the expected impact of recent federal legislation, including the Infrastructure Investment and Jobs Act (IIJA) and Inflation Reduction Act (IRA), was not addressed in several of the studies cited throughout this literature review. Where possible, the impacts of the IIJA and IRA are noted, but further research into the impacts of these laws, especially on customers and utilities in Colorado, is needed. It may be wise to use a range of costs where possible.

All clean heat plans are likely to benefit from reasonable estimations of the projected rate of customer adoption of technologies, another area where additional research is needed. This is especially true for heat pumps or dual fuel heating systems in all areas of Colorado. Researching likely customer adoption rates will be important for modeling gas and electricity demand under different clean heat plan scenarios for the state.[3] For example, when customer adoption of electrification is rapid, the gas supply will require less decarbonization. On the other hand, low rates of adoption will require increased decarbonization.[4]

As with all transitions, workers employed by the building and utilities sectors may face job conversions or losses. The rate of change is likely to vary by sector and by scenario. Little information on anticipated job impacts is currently available. Colorado would benefit from additional study of this. Considering how transitions under different scenarios might impact low-income, at-risk, or historically disadvantaged communities can allow for better planning and mitigation of potential harms. Evaluating likely impacts will require meaningful engagement and dialogue with these communities.

Analyzing current infrastructure and future infrastructure needed to support the development and use of alternative fuels will be particularly important in almost any scenario explored in plans to comply with the Clean Heat Standard. Specifically, data regarding retirement costs for natural gas plants was not readily available.

Research into different climate areas of Colorado regarding dependence on gas for heating and the ability of cold-climate heat pumps to operate in mountain regions is also needed. Additional analysis is also needed as it relates to the differences between utility service areas and different types of construction: mountain new construction; mountain existing construction; non-mountain new construction; and non-mountain existing construction.

Colorado's Clean Heat Standard could be amended in the future. For instance, the standard could be amended to include or exclude eligible resources as technological advancements occur and as the impacts of these resources on the environment and economy become better understood. The Clean Heat Standard's emissions reduction goals and timeline could also be adjusted. This is an area that will remain

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[3] NREL is currently researching customer adoption rates (among other things). Updates on this work is available here: https://www.nrel.gov/buildings/end-use-load-profiles.html

[4] Aas, Dan, John Stevens, John de Villier, Hadiza Felicien, Anthony Fratto. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios." E3. March 13, 2022. https://www.xcelenergy.com/staticfiles/xe-responsive/E3-Natural-Gas-Plan-Analysis.pdf

unexplored here, though future policy change is worth considering throughout any planning or modeling that may occur.[5]

## Modeling Future Scenarios

Models are imperfect predictors of the future. They are planning tools that outline potential outcomes based on modeling decisions, and the use of different assumptions and different goals creates variation. Here, we provide an overview of the models used by the studies we examined for this literature review.

At minimum, decarbonization models require assumptions about emissions reduction targets, availability of resources and technology, customer adoption rates, fuel and infrastructure costs, and rate impacts. Most of the studies examined for this literature review set an emissions reduction target of 100% by 2050, with some using 2030 as an interim target date. Most of the studies examined here developed scenarios that met emissions goals.

Most analyses examine a reference case (or a business-as-usual case), a mixed technology or hybrid scenario, and a high decarbonization scenario (electrification and/or decarbonized gas). Occasionally, other scenarios are included that fall in between these types of scenarios.

### Reference Cases

Reference cases are those in which current policies and technology trends continue, a business-as-usual (BAU) scenario modeled out to a specific end year, generally 2050. Reference case scenarios rarely meet emissions targets. However, because reference cases model emissions under BAU circumstances, they allow comparisons of emissions reductions, costs, and customer and community impacts associated with the other scenarios included in the analysis.[6] Including a reference case also allows predicted trends in such things as natural gas prices and demand to appear and inform the evaluation of other scenarios.

### Mixed Technology Scenarios

Mixed technology or hybrid scenarios often involve some combination of alternative fuels, existing gas, electrification, and energy efficiency. Because mixed technology scenarios allow multiple approaches to decarbonization, these scenarios vary widely and are often included in multiple forms in the same study. In some studies, mixed technology scenarios are created by manipulating available resources and technologies, and fuel costs.[7] Mixed or hybrid scenarios can also model the rates at which these technologies are likely to be adopted by customers, including industrial users.[8,9,10] In some cases, these

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[5] Several bills still pending in the Colorado General Assembly would impact implementation of Colorado's Clean Heat Standard (see Appendix A).

[6] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities." American Gas Association. February 2022. https://www.aga.org/wp-content/uploads/2022/02/aga-net-zero-emissions-opportunities-for-gas-utilities.pdf

[7] See: Low-Carbon Resources Initiative (LCRI). 2022. "Low-Carbon Resources Initiative, Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis." https://lcri-netzero.epri.com/

[8] See: Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."

[9] See: Schlag, Nick, Arne Olson, Gerrit De Moor, Charlie Duff, Vivian Li, and Oluwafemi Sawyerr. 2019. "Xcel Energy Low Carbon Scenario Analysis Decarbonizing the Generation Portfolio of Xcel Energy's Upper Midwest System." Energy and Environmental Economics (E3). July 2019. https://www.ethree.com/wp-content/uploads/2019/08/E3_Xcel_MN_IRP_Report_2019-07_FINAL.pdf

[10] See: Drake, Trevor and Audrey Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses." The Great Plains Institute and the Center for Energy and Environment. July 2021. https://e21initiative.org/wp-content/uploads/2021/07/Decarbonizing-NG-End-Uses-Stakeholder-Process-Summary.pdf

scenarios also incorporate a variety of retirement dates for existing generation assets such as coal and nuclear plants, which can aid in infrastructure planning.[11]

Mixed technology scenarios include hybrid gas-electric scenarios. This dual fuel approach can allow utilities to meet decarbonization goals through electrification while retaining natural gas as a backup source for extreme weather or peak energy demand.[12] Electrification with gas back up can also allow the gas mix to be more gradually transitioned to a zero- or low-emission renewable gas mix, which might mitigate some of the risks that emerge in scenarios that depend on singular approaches such as full electrification or full gas decarbonization.[13] These approaches might also allow increased customer choice and ensure affordability and reliability.[14,15]

High Decarbonization Scenarios

Most of the studies examined by this literature review include a 100% or high electrification by 2050 scenario. In general, these models examine scenarios under which new buildings would be required to meet certain electrification standards while existing buildings would undergo retrofits to increase energy efficiency and electrification (where possible). Generally, electrification of existing buildings in these scenarios focuses on the installation of heat pumps and the replacement of gas appliances with electric. Scenarios that incorporate the electrification of industry typically include an assumption that the most heat-intensive processes switch to alternative fuels (including hydrogen).

Some models broke out different building types, for instance new buildings, existing buildings, and industry. This is important because electrification of different types of buildings will likely need to be accomplished through different technologies and on different timelines. Establishing different timelines for new building electrification requirements and existing building retrofits can inform estimates of potential costs for customers, aid in forecasting demand, and enable load and infrastructure planning.[16]

There is disagreement over the likely costs and benefits associated with mixed technology and high electrification scenarios. While some studies find that mixed technology approaches will reduce costs, minimize negative customer impacts, maintain reliability, increase emissions reductions, improve resiliency, and create opportunities for emerging technologies,[17] others find that high electrification scenarios increase emissions reductions and are lower in cost and risk because they rely on existing technologies including energy efficiency and electric utilities have already demonstrated their ability to reduce emissions while maintaining reliability.[18,19,20] However, some argue that electric utilities may not

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[11] See: Schlag, et. al. 2019. "Xcel Energy Low Carbon Scenario Analysis -- Upper Midwest System."

[12] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."

[13] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[14] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[15] LCRI. 2022. "Net-Zero 2050."

[16] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[17] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[18] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."

[19] Aas, Dan, Amber Mahone, Zack Subin, Michael Mac Kinnon, Blake Lane, Snuller Price. 2020. "The Challenge of Retail Gas in California's Low-Carbon Future: Technology Options, Customer Costs, and Public Health Benefits of Reducing Natural Gas Use" California Energy Commission. April 2020. https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-055-F.pdf

[20] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

have the ability to meet the increased demand that will occur with electrification, necessitating additional regulatory, policy, and technological support.[21]

In some studies, a decarbonized gas scenario was used in addition to or as an alternative to a high electrification scenario. For instance, the 2021 Minnesota natural gas decarbonization study uses a high decarbonized gas scenario that examines a future where building heating continues to be fueled by natural gas, which is gradually replaced by low-carbon alternatives including biomethane, synthetic natural gas, and hydrogen. This scenario assumes high levels of building efficiency improvements and that industry will rely on green hydrogen.[22]

### General Conclusions and Key Considerations

As noted above, most studies agree that some amount of increased electrification and efficiency is likely to occur even under reference case scenarios with no new adoption of electrification or decarbonization policies. Nationwide, this could reduce GHG emissions to 45% below 2005 levels by 2050.[23] Generally, the studies reviewed here find that meeting net-zero targets will require the use of negative emissions tools like carbon capture and sequestration, direct air capture, and emissions offsets. The availability and costs of negative emissions technologies and carbon offsets are likely to impact gas utility portfolios.[24] Studies also find that emissions reductions from customer-side measures will comprise the majority of emissions reductions in most scenarios.[25,26] Predicted emissions reductions and the pace of those reductions will be impacted by modeling decisions including scope, customer adoption rates, technology availability, and costs.

Under every scenario examined by the studies reviewed here, the gas system changes. Most studies find that even in reference cases, there will be an overall decline in demand for gas by 2050. Xcel Energy's study found that under low rates of electrification, the gas system would need to rely on renewable natural gas and hydrogen and that emissions offsets and negative emissions technologies would be required to meet emissions goals in 2030 and 2050.[27] Given that natural gas can provide firm capacity generally and backup power in cold climates, it is likely to remain an important resource into the future, requiring increased use of renewable and low-emission gas to meet emissions targets.[28] Modeling should examine the extent to which alternative fuels (including renewable natural gas, biomethane, synthetic natural gas, and hydrogen) can be used in Colorado's gas system.

Assumptions regarding the use and availability of resources and technologies varied. Some studies allowed unrestrained choice in technologies while others limited availability to those resources that met certain cost or emissions criteria or that were already widely available.[29,30,31] For instance, a Low-Carbon Resources Initiative (LCRI) study on decarbonizing the entire U.S. economy modeled one scenario that included all technology and resource options while two other scenarios limited the use of carbon capture technology

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[21] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[22] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[23] LCRI. 2022. "Net-Zero 2050."
[24] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[25] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[26] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."
[27] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[28] LCRI. 2022. "Net-Zero 2050."
[29] See: Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[30] See: Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[31] See: Massachusetts Commission on Clean Heat. 2022. "Final Report." Massachusetts Commission on Clean Heat. November 30, 2022. https://www.mass.gov/doc/massachusetts-commission-on-clean-heat-final-report-november-30-2022/download

and bioenergy, and assumed certain natural gas prices that differed from reference case prices.[32] Scenarios also differed in their use of negative emissions tools, including carbon offsets. Consideration of how and to what extent negative emissions technologies will be used will be an important factor in scenario development and analysis. The costs and emissions impacts of negative emission technologies are discussed later in this literature review.

While reliable systems provide predictable supply, resilient systems are those that can respond quickly to or withstand certain events. In addition to considering reliability, scenarios should also include measurable and observable resiliency metrics by integrating these into cost-benefit analyses that also consider the avoided direct and indirect costs to utilities, customers, and broader society.[33] The studies examined here agree that resource flexibility will be key to meeting emissions reductions goals while maintaining reliability and resiliency.[34]

There are two types of scenarios that require similar near-term actions, the mixed technology and high electrification scenarios. The Minnesota working group noted that these two scenario types "share complementary and overlapping strategies" that can provide "flexibility to move from one to the other at a later date if one becomes more attractive or more feasible." This flexibility may not exist between other scenario types. For instance, switching from a decarbonized gas scenario to a scenario with higher levels of building electrification would be possible, but it would likely be costly and difficult.[35] Optionality not only between resources but also between scenarios may be a factor for consideration.

Though building decarbonization is an important tool for emissions reduction, most building decarbonization modeling did not include seasonal fluctuations in energy use.[36] Nationally, seasonal building energy demand increases by 60%, compared to May's demand, during the January peak. It is important to include seasonal fluctuations in modeling because seasonal peaks have typically been met with fossil fuel resources. It is important to consider specific needs and characteristics when evaluating emission reduction strategies, as differences in climate, energy policies, energy prices and markets, composition of the building stock, existing commercial and industrial uses, and the capacity, age, and GHG intensity of existing energy supply infrastructure should inform decarbonization strategies.[37] In general, we found that state-specific studies were better able to account for these and other variables.

Building electrification is expected to expand particularly in scenarios where supply side decarbonization technologies such as alternative fuels are more expensive.[38] Increased load should be expected under any rate of electrification.[39] This will likely require the deployment of clean energy and storage technologies to meet emissions targets.[40]

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[32] LCRI. 2022. "Net-Zero 2050."

[33] Guidehouse. 2021. "Building a Resilient Energy Future, How the Gas System Contributes to US Energy System Resilience." American Gas Foundation. January 2021. https://gasfoundation.org/wp-content/uploads/2021/01/Building-a-Resilient-Energy-Future-Full-Report_FINAL_1.13.21.pdf

[34] See also: Von Wald, Gregory, Kaarthik Sundar, Evan Sherwin, Anatoly Zlotnik, Adam Brandt. 2022. "Optimal gas-electric energy system decarbonization planning." Advances in Applied Energy, Volume 6, 2022, 100086. ISSN 2666-7924. https://doi.org/10.1016/j.adapen.2022.100086

[35] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses." at 59.

[36] See: Buonocore, Jonathan J. et. al. 2022. "Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage." Nature Portfolio Scientific Reports. https://doi.org/10.1038/s41598-022-15628-2

[37] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[38] LCRI. 2022. "Net-Zero 2050."

[39] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[40] Buonocore, et. al. 2022. "Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage."

*Scenario Costs*

The costs associated with each scenario are uncertain and subject to several factors. These include technological improvement, access to feedstocks, supply chain issues, materials costs, customer adoption rates, infrastructure expansion and maintenance requirements, state and federal energy policies, including availability of state or federal funding and incentives, and more. Technology and energy costs will play an important role in scenario building, particularly if least-cost pathways are being sought.[41] Customer adoption rates should be included in modeling as they affect the costs and market penetration of technologies. Modeling assumptions should also address the numbers of customers using dual fuel, all-electric, or all gas systems, as this can impact energy costs. Most scenarios found that high electrification would likely result in high upfront costs for customers, though savings would emerge over time. Studies generally predict higher natural gas rates under nearly every scenario. This potential highlights the need for policies and programs that address affordability.[42]

There are many other factors that should be considered as scenarios are developed and analyzed, including available resources, emissions reductions, and cost and affordability. These will be explored in detail below.

## Technology

Technology is likely to be one of the determining factors of how gas utilities meet Colorado's Clean Heat Standard. Availability, cost, and innovation of existing and new technologies will influence which scenarios are more or less likely to be feasible. The discussion that follows provides an overview of the technologies and approaches most often addressed in plans to reduce emissions from the built environment.

### Natural Gas

One third of the primary energy consumed in the U.S. is natural gas.[43] In 2020, the combustion of gas, coal, and oil for electricity generation was responsible for 31% of total U.S. carbon dioxide ($CO_2$) emissions and "Natural gas and petroleum systems are the second largest source of [methane] emissions in the United States."[44] Colorado was the 8th largest producer of natural gas in 2021, and users in the state consumed approximately 550 trillion British thermal units (Btu) of gas in 2020. Approximately 70% of Colorado's homes use natural gas as their primary heating source, and the residential and electric power sectors each account for about one-third of the state's natural gas demand.[45]

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[41] In November 2022, the PUC adopted rules to implement the Clean Heat Standard. In its decision, the Commission outlined six quantitative factors the PUC will consider when evaluating "lowest reasonable cost," including: "(1) fuel costs; (2) non-fuel direct investment associated with the clean heat plans; (3) gas infrastructure costs; (4) gas system operations costs; (5) a cost test that includes both the social cost of carbon and the social cost of methane; and (6) any other costs and benefits, as determined by the Commission" (CPUC Decision C22-0760 at 144).

[42] Ong, Alison, Michael Mastrandea, and Michael Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers: Identifying Cost Effective Paths to a Zero Carbon Building Fleet." Stanford Woods Institute for the Environment. June 2021. https://woodsinstitute.stanford.edu/system/files/publications/Building_Decarbonization_Policy_CA_Natural_Gas_Ratepayers_Whitepaper.pdf

[43] National Grid and RMI. 2022. "Collaborating for Gas Utility Decarbonization." National Grid and RMI. https://www.nationalgridus.com/media/pdfs/our-company/collaborating-for-gas-utility-decarbonization-report.pdf

[44] EPA. 2022. "Overview of Greenhouse Gases." U.S. Environmental Protection Agency. May 16, 2022. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

[45] EIA. 2022. "Colorado State Energy Profile." U.S. Energy Information Administration. April 21, 2022. https://www.eia.gov/state/print.php?sid=CO

Generally, studies agree that gas use will decline due to increased electrification and energy efficiency, and higher natural gas prices. However, gas is likely to remain an important energy resource. Natural gas can be blended with other gases with a similar make up, which can reduce emissions and take advantage of existing infrastructure.[46,47,48] Gas can also be paired with other technologies and resources. For instance, heat pumps paired with gas backups have been found to be particularly effective in colder climates.[49]

Currently, the peak energy demand met by natural gas is higher than the demand met by electricity. This is due to regional reliance on heating, which could mean that colder states will need to continue to rely on gas for a longer time than states with warmer climates.[50, 51] In New England, a recent report found that eliminating combustion resources and replacing them with renewable electricity resources and storage would require "substantial resource overbuilds" creating "disproportionally high system costs." Cost impacts might be mitigated by continuing to use the gas system in a mixed technology strategy that uses gas, renewable fuels, and targeted electrification.[52]

Renewable Natural Gas and Other Low Emissions Fuels

The fuel mix under most scenarios reviewed here examined how alternative or low emissions fuels could be incorporated to reduce gas system emissions. Generally, the degree of reliance on alternative fuels depended on the rate at which electrification and increased energy efficiency were assumed to occur – scenarios with low customer uptake of electrification and energy efficiency had higher remaining gas demands. Studies tend to agree that renewable natural gas (RNG) and other low-carbon gases will likely continue to be used, even under high electrification scenarios.

RNG is "pipeline compatible gaseous fuel derived from biogenic or other renewable sources that has lower life cycle carbon dioxide equivalent ($CO_2e$) emissions than geological natural gas."[53] These fuels can include biomethane,[54] climate neutral hydrogen, and synthetic natural gas produced from climate-neutral sources.[55] Mixing RNG with natural gas can reduce emissions while maintaining system reliability for peak demand and heating.[56] While RNG may be an effective emissions reduction strategy to allow continued

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[46] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."
[47] Billimoria, Sherri and Mike Henchen. 2020. "Regulatory Solutions for Building Decarbonization: Tools for Commissions and Other Government Agencies." RMI. 2020. https://rmi.org/insight/regulatory-solutions-for-building-decarbonization/
[48] See also: Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[49] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[50] O'Neill, Brian. et al. 2021. "Natural Gas Use in the U.S. Building Sector in Global Low Carbon Pathways." Xcel Energy. 2021. https://www.xcelenergy.com/staticfiles/xe-responsive/Archive/Natural-Gas-Use-in-Buildings-in-Low-Carbon-Pathways.pdf
[51] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities.
[52] E3 and ScottMadden. 2022. "MA DPU Docket 20-80 - The Role of Gas Distribution Companies in Achieving the Commonwealth's Climate Goals." Energy and Environmental Economics and ScottMadden Management Consultants. March 18, 2022. https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/14633269 at 61.
[53] ICF. 2019. "Renewable Sources of Natural Gas, Supply and Emissions Reduction Assessment." American Gas Foundation. December 2019. https://gasfoundation.org/2019/12/18/renewable-sources-of-natural-gas/
[54] Senate Bill 21-264 defines biomethane as a mixture of $CO_2$ and hydrocarbons released from biological decomposition of organic material that is primarily methane and provides a net reduction in GHG emissions. The similar structure of biomethane allows it to be mixed directly into natural gas pipelines as long as the new supply meets natural gas pipeline quality standards (E3 and ScottMadden. 2022. "MA DPU Docket 20-80.").
[55] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[56] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

gas use, there remain concerns about future costs and availability, which will be influenced by policy, market conditions, and technological development.[57,58,59,60]

While exact costs are unknown, cost estimates for RNG and other alternative fuels suggest that they may exceed the current costs of natural gas.[61] For instance, a California rate study finds that in a scenario where RNG use increases by 2% annually through 2035 (ultimately reaching a 30% RNG mix), there would be a 40% gas rate increase for customers over the base case scenario.[62] Future availability of RNG and other alternative fuels is also unknown. While some studies find potentially inadequate supplies,[63] ICF found that in a low resource scenario, 1,660 trillion Btu of RNG could be produced and added to natural gas pipelines each year by 2040, compared to a high resource scenario which estimated 3,780 trillion Btu could be produced each year by 2040.[64] In a more recent study, however, ICF found it would likely be possible to develop higher levels of RNG than in previous estimates.[65]

When burned, hydrogen emits only water, however creating hydrogen can be energy intensive and, depending on the type of energy used, emissions intensive.[66] SB 21-264 defines green hydrogen as hydrogen developed from a clean energy resource that uses water as the source of hydrogen. Hydrogen can be used to produce carbon-free electricity on demand, by using renewable energy to generate hydrogen from water and then transporting or storing the hydrogen until needed.[67] Hydrogen is expected to be an important resource for replacing traditional fuel uses particularly in the industrial, manufacturing, and transportation sectors.[68] A 20% blend of hydrogen could reduce Colorado's natural gas consumption by 7.3%.[69]

The low density of hydrogen makes it harder to store than traditional fuels.[70] At current efficiencies, energy losses for end-users are likely to occur. This is due to conversion losses and lower efficiency in appliances, as compared to electric appliances.[71] This should be considered when evaluating the cost of hydrogen. Other concerns regarding hydrogen focus on impacts to infrastructure, both on the distribution and customer sides. The percentage of hydrogen that can be blended with natural gas is limited – higher percentages require modification of both distribution system and customer infrastructure.[72] For instance,

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[57] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[58] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[59] ICF. 2019. "Renewable Sources of Natural Gas."
[60] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[61] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[62] Ong, Mastrandea, and Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers."
[63] See: Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[64] ICF. 2019. "Renewable Sources of Natural Gas."
[65] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."
[66] Chugh, Abhinav and Emanuele Taibi. 2021. "What is Green Hydrogen and Why Do We Need It? An Expert Explains." World Resources Institute. December 21, 2021. https://www.weforum.org/agenda/2021/12/what-is-green-hydrogen-expert-explains-benefits/
[67] BloombergNEF. 2020. "Hydrogen Economy Outlook." Bloomberg Finance. March 30, 2020. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
[68] BloombergNEF. 2020. "Hydrogen Economy Outlook."
[69] Loiter, Jeff and Lorance Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure - Applications Specific to Colorado's SB 21-264, A Report for the Colorado Public Utilities Commission." National Regulatory Research Institute. October 12, 2022. (Available on Request)
[70] BloombergNEF. 2020. "Hydrogen Economy Outlook."
[71] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."
[72] E3 and ScottMadden. 2022. "MA DPU Docket 20-80."

one study found that concerns for end-use consumers and infrastructure emerge at a 5% system-wide standard for hydrogen blending.[73] Commercial and industrial compatibility with hydrogen mixing is a significant challenge that could limit its use.[74] Xcel found that some gas system conversions would be necessary "to serve dedicated hydrogen to a limited number of large customers."[75] An important concern about hydrogen is that producing green hydrogen through electrolysis requires large amounts of water, a concern that will be increasingly important in Colorado.[76]

Recovered Methane

Under SB 21-264, recovered methane includes biomethane, methane derived from municipal solid waste (MSW) including pyrolysis of MSW; biomass pyrolysis or enzymatic biomass; or wastewater treatment. It also includes coal mine methane reductions not currently required by law, and methane that would have leaked without repairs to infrastructure, all of which must occur in Colorado and be approved by the AQCC. The Clean Heat Standard establishes tradeable recovered methane credits that reflect a real, measurable, and quantifiable permanent reduction or removal of one metric ton of carbon dioxide equivalent that is not otherwise required by law. Oversight of recovered methane projects will be accomplished through the Colorado Recovered Methane Protocols and Crediting and Tracking System.

Beneficial Electrification

Enacted in 2021, Colorado's Senate Bill 21-246 directed the PUC to establish energy savings targets for and review and approve beneficial electrification plans submitted by electric investor-owned utilities (IOUs). The new policy, to be modeled on the state's existing DSM programs, aims to incentivize voluntary adoption of beneficial electrification measures by residential, commercial, and industrial customers. Utility plans must include programs targeted at low-income and disproportionately impacted communities (with at least 20% of funding allocated to these households). This includes offering incentives for multifamily buildings.[77]

The Clean Heat Standard uses Senate Bill 21-246's definition of beneficial electrification, "converting the energy source of a customer's end use from a nonelectric fuel source to a high-efficiency electric source, or avoiding the use of nonelectric fuel sources in new construction or industrial applications if the result of the conversion or avoidance is to: (1) reduce net greenhouse gas emissions over the lifetime of the conversion or avoidance; and (2) reduce societal costs or provide for more efficient utilization of grid resources."

Decarbonization is likely to require electrification of several sectors including space and water heating and transportation.[78] A 2022 study found that building electrification will increase the amount of energy required to meet demand. The study notes that to meet decarbonization goals, existing renewable energy infrastructure will need to be expanded, though the rate of expansion necessary can be reduced through

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[73] Arun S.K. Raju, Alfredo Martinez-Morales, and Oren Lever. 2022. "Hydrogen Blending Impacts Study: Final Report." California Public Utilities Commission. July 18, 2022. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF

[74] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[75] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios." at 12.

[76] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[77] CNEE. 2022. "State Brief: Colorado." Center for the New Energy Economy. https://cnee.colostate.edu/wp-content/uploads/2022/10/State-Brief_CO_September_2022.pdf

[78] Schlag, et. al. 2019. "Xcel Energy Low Carbon Scenario Analysis -- Upper Midwest System."

the use of highly energy efficient electrification strategies.[79] Seasonal peak demand is very likely to shift from summer to winter under most electrification scenarios.[80,81]

Electrification can be accomplished through retrofits of existing buildings and by requiring new buildings to meet certain electrification standards. Electrification technologies include heat pumps, water heater heat pumps, electric clothes dryers, and other electric appliances.[82]

Heat pump technology takes heat from a source, generally surrounding air, the ground, or geothermal energy, and then transfers the heat inside. Many heat pumps can also provide cooling in warm weather by moving heat out of a building. Heat pumps are increasingly more efficient than conventional heating technologies like boilers or electric heaters, and they can reduce energy costs.[83] The Energy Systems Integration Group found that switching to an air source heat pump (ASHP) reduced annual gas use by 60 to 100%, with an average reduction of 83% for customers in a study group of 80.[84] Because some types of heat pumps lose efficiency in extreme cold, they may not be suitable for all regions. However, cold climate air source heat pumps (ccASHPs), designed to heat buildings "at or below 5°F," while still providing cooling in warmer months, are improving.[85]

While heat pumps can often save customers money in the long term, consumers will confront significant upfront costs and potential disruption as building retrofits are completed.[86] Even with federal and state rebates, costs for heat pumps reach thousands of dollars with additional costs for installation and/or building retrofits.[87] In some cases, energy use costs might increase. For instance, Home Innovation Research Labs found that customers in Denver could face both higher upfront and higher operating costs.[88] While heat pumps are associated with reduced efficiency in colder climates,[89] new technology such as high-efficiency variable speed heat pumps have been found to produce annual energy savings of 22% to 35% in cold-climates in several building types.[90] Electric resistance heating can also be used as a supplement to heat pumps in cold regions, though this has been associated with increased electric peak demand and can require new electric infrastructure.[91]

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[79] Buonocore, et. al. 2022. "Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage."

[80] Buonocore, et. al. 2022. "Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage."

[81] Schlag, et. al. 2019. "Xcel Energy Low Carbon Scenario Analysis -- Upper Midwest System."

[82] Home Innovation Labs. 2021. "Cost and Other Implications of Electrification on Residential Construction." National Association of Home Builders. https://www.nahb.org/-/media/NAHB/nahb-community/docs/committees/construction-codes-and-standards-committee/home-innovation-electrification-report-2021.pdf.

[83] IEA. 2022. "The Future of Heat Pumps: How A Heat Pump Works." International Energy Agency. 2022. https://www.iea.org/reports/the-future-of-heat-pumps/how-a-heat-pump-works

[84] Sergici, Sanem, Akhilesh Ramakrishnan, Goksin Kavlak, Adam Bigelow, and Megan Diehl. 2022. "Heat Pump-Friendly Cost-Based Rate Designs." Energy Systems Integration Group. https://www.esig.energy/heat-pump-friendly-rate-designs/

[85] Desai, Jal and Kevin Wu. 2022. "Cold Climate Air Source Heat Pumps (ccASHPs) Technology." NREL. July 2022. https://www.nrel.gov/docs/fy22osti/83290.pdf; see also: Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[86] Desai and Wu. 2022. "Cold Climate Air Source Heat Pumps Technology."

[87] Sergici, et. al. 2022. "Heat Pump-Friendly Cost-Based Rate Designs."

[88] Home Innovation Labs. 2021. "Cost and Other Implications of Electrification on Residential Construction."

[89] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[90] Shoukas, Gregory, Eric Kozubal, Eric Bonnema, Ramin Faramarzi, and Steven LaBarge. 2022. "High Efficiency Heat Pumps Can Pave the Path for Building Decarbonization in Cold Climates." NREL. August 2022. https://www.nrel.gov/docs/fy22osti/82346.pdf

[91] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

### Dual Fuel Technologies

Hybrid, or dual fuel, technologies combine electric technologies with gas or RNG. This is common in heat pump infrastructure where customers with existing gas maintain it to serve as a backup to their heat pump on extreme temperature days when heat pump efficiency drops significantly. This could be particularly useful in colder climates and in areas where gas infrastructure already exists. A hybrid gas-electric heating system can reduce emissions and stabilize energy costs. However, these systems could create operational and cost challenges for gas utilities, because they are unlikely to impact peak demand while average annual demand will decline.[92]

Customer adoption rates will play an important role in the future technology and resource mix. For instance, an Xcel Energy report's estimates of customer adoption of dual fuel, all electric, and gas heating technologies under three scenarios finds that varying customer adoption rates create differences in the market penetrations of different technologies (see Figure 1).[93]

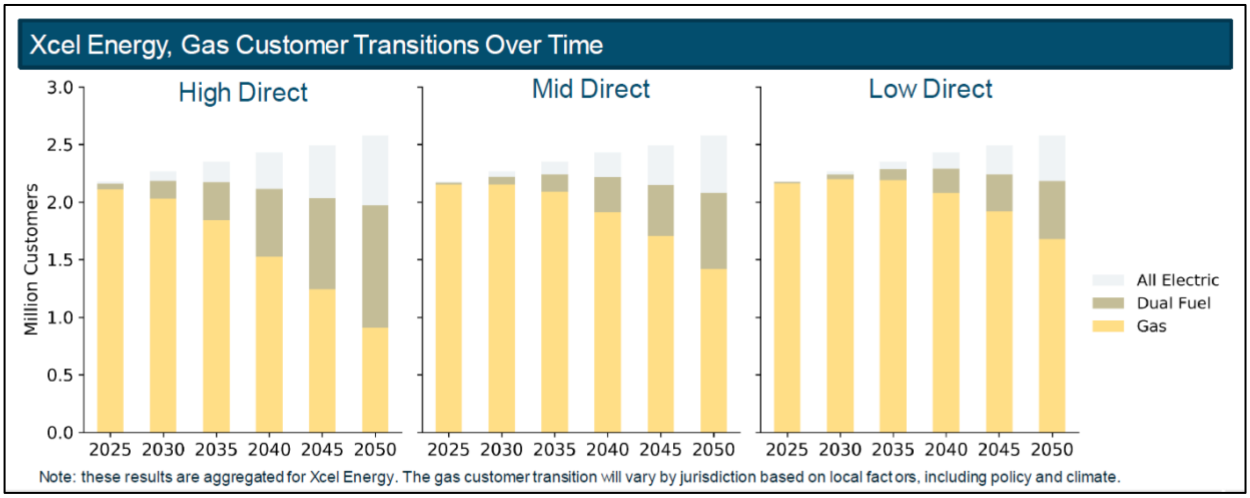

*Figure 1 - Projected Xcel Energy customer adoption rates of all electric, dual fuel, and gas heating technologies under three scenarios. Source:* E3 2022

### Energy Efficiency and Demand Side Management

Energy efficiency is a low risk and cost-effective strategy that can be the first tool used to reduce energy-related emissions.[94] Energy efficiency programs and technologies allow customers to reduce their overall energy consumption. DSM programs, including demand response programs, aim to reduce energy demand particularly during peak demand or during emergencies by encouraging customers to modify their pattern of energy use.[95,96]

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[92] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."
[93] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."
[94] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."
[95] Aniti, Lori. 2019. "Demand-side Management Programs Save Energy and Reduce Peak Demand." U.S. Energy Information Administration. March 29, 2019. https://www.eia.gov/todayinenergy/detail.php?id=38872
[96] EIA. n.d. "Electric Utility Demand Side Management - Archive." U.S. Energy Information Administration. Accessed March 15, 2023. https://www.eia.gov/electricity/data/eia861/dsm/

DSM programs offer several benefits, the most notable of which is reducing energy demand, which can mitigate the impacts associated with high rates of building electrification.[97,98] Reducing demand will be an important consideration in any strategy to reduce emissions – in nearly every scenario examined in this literature review, there was an increased demand for energy whether under a reference case, high electrification, or decarbonized gas scenario. This can be attributed to growing populations, economic growth, and increased energy availability. DSM can ease the attendant pressure on the grid.[99] DSM can also lead to avoided costs associated with new generation stations, transmission lines, and other infrastructure that may no longer be needed due to reduced energy demand.[100]

Utilities often offer energy efficiency and DSM incentives or programs, sometimes at the behest of state policies. Utility DSM programs are typically focused on residential and commercial customers.[101] DSM includes a range of programs including rate design, financing for end users, behavior change incentives, and incentives for manufacturers. Regulators may want to differentiate between DSM and electrification programs to highlight differences in cost effectiveness.[102]

While DSM offers several benefits, there are concerns that should be taken into consideration. Energy efficiency and DSM programs can introduce equity concerns for low- and middle-income customers who may not be able to take full advantage of these programs. While many utilities offer programs specifically for low- and middle-income customers, these programs may not offer the same level of benefits. Energy efficiency and DSM programs can be structured to direct benefits to customers who most need assistance managing their energy burden.[103] While DSM and energy efficiency programs can reduce emissions, states rarely require utilities to measure the GHG reductions achieved by these programs. Success of these programs is often measured by direct energy savings rather than in GHG reductions, which can lead to utilities missing opportunities, in terms of both the timing and location of projects, for greater impact.[104]

Colorado's House Bill 22-1362 created several new provisions related to building energy codes. The bill creates an energy code board tasked with developing a model electric ready and solar ready code before June 1, 2023, and a model low energy and carbon code before July 1, 2025. The bill also tasks the Colorado Energy Office with developing a model green code for adoption by local governments and state agencies. The bill also sets timelines for the adoption of new codes by local governments and state agencies, provides certain exemptions for rural counties, creates new grant programs for the purchase and installation of high efficiency equipment and appliances, and provides for training related to the implementation of the new codes.[105]

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[97] Aniti. 2019. "Demand-side Management Programs Save Energy and Reduce Peak Demand."

[98] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[99] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[100] Aniti. 2019. "Demand-side Management Programs Save Energy and Reduce Peak Demand."

[101] Aniti. 2019. "Demand-side Management Programs Save Energy and Reduce Peak Demand."

[102] Xcel Energy. 2020. "Transitioning Natural Gas for a Low-Carbon Future." Xcel Energy. 2020. https://s25.q4cdn.com/680186029/files/doc_downloads/irw/Gas/Natural-Gas-Strategy-Report.pdf

[103] Walton, Robert. 2022. "Integrating Efficiency into Demand-Side Management Portfolios May Introduce Equity Risks: Analysts." Utility Dive. February 17, 2022. https://www.utilitydive.com/news/integrating-efficiency-into-demand-side-management-portfolios-may-introduce/618930/

[104] Gold, Rachel and Gennelle Wilson. 2022. "Rewarding What Matters in Energy Efficiency - Shifting Utility Performance to Focus on Climate." RMI. September 16, 2022. https://rmi.org/rewarding-what-matters-in-energy-efficiency/

[105] CNEE. 2022. "State Brief: Colorado."

## Emissions

As of 2022, the U.S. derived 84% of its primary energy from fossil fuels. Some estimates find that fossil fuels will supply between 9% and 53% of U.S. energy by 2050. This range is dependent on the availability and deployment of negative emissions technologies, which could allow continued use of fossil fuel resources. End uses are expected to shift to more efficient and low carbon energy as the use of hydrogen and electrification increases. Electricity use could increase from 21% of final energy today to up to 59% in 2050, and low-carbon fuel use could increase from 5% today to up to 36% in 2050 in net-zero scenarios.[106] The mix of energy resources and technologies deployed throughout the energy system will have a direct impact on the amount, type, and intensity of emissions. Below we explore the emissions impacts associated with the technologies reviewed above.

### Natural Gas Emissions

Natural gas emissions are included in scenario analyses to varying degrees. It is important for scenarios to accurately include the climate impact of natural gas emissions. This is particularly important for methane emissions, which are often underestimated in scenario analyses and GHG inventories.[107] While the combustion of natural gas is less carbon intensive than that of coal or oil and emits fewer pollutants for the energy delivered, "methane is a shorter-lived gas than [$CO_2$] but is nevertheless 86 to 34 times more potent than [$CO_2$] on 20 and 100 year timescales, respectively."[108,109] Consumption of natural gas in the U.S. has increased by approximately 41% since 2005, with the electric power and industrial sectors accounting for 90% of that increase.[110] In 2021, U.S. $CO_2$ emissions from natural gas combustion were responsible for up to 34% of all U.S. energy sector $CO_2$ emissions.[111] While emissions related to natural gas combustion are almost 43% higher today than they were in 2005, the replacement of coal with natural gas has led to a decrease in electric sector GHG emissions in recent years.[112]

Emissions associated with natural gas also occur through flaring at well heads, and from leaks in oil and gas wells, storage tanks, pipelines and other distribution infrastructure, and at gas plants.[113] Low estimates regarding emissions from natural gas leakage find that approximately 133 million metric tons (MMT) of $CO_2$e emissions are added to the atmosphere annually.[114] Methane emissions must be reduced by 45% by 2030 to meet the Paris Climate Agreement's 1.5℃ goal, and a 30% reduction could be achieved by targeted methane recovery measures, including leak detection and gas infrastructure repair and replacement

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[106] LCRI. 2022. "Net-Zero 2050."

[107] Kemfert, Claudia, Fabian Präger, Isabell Braunger, Franzisk M. Hoffart and Hanna Brauers. 2022. "The Expansion of Natural Gas Infrastructure Puts Energy Transitions at Risk." *Nature Energy* 7, 582–587 https://doi.org/10.1038/s41560-022-01060-3

[108] Lebel, Eric D., Colin J. Finnegan, Zutao Ouyang, and Robert B. Jackson. 2022. "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes." *Environmental Science & Technology 56* (4), 2529-2539. DOI: 10.1021/acs.est.1c04707. https://pubs.acs.org/doi/10.1021/acs.est.1c04707

[109] C2ES. n.d. "Natural Gas." Center for Climate and Energy Solutions. Accessed March 29, 2023. https://www.c2es.org/content/natural-gas/

[110] C2ES. n.d. "Natural Gas."

[111] EIA. 2022. "Natural Gas and the Environment." U.S. Energy Information Administration. November 7, 2022. https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php

[112] C2ES. n.d. "Natural Gas."

[113] EIA. 2022. "Natural Gas and the Environment."

[114] Billimoria and Henchen. 2020. "Regulatory Solutions for Building Decarbonization."

programs undertaken throughout the natural gas supply chain and in other applications including landfill gas and anaerobic digestion.[115,116,117,118,119]

Natural gas is used in several sectors for heating, generally using boilers or furnaces. Natural gas-fired boilers and furnaces emit nitrogen oxides, carbon monoxide, carbon dioxide, methane, nitrous oxide, volatile organic compounds, traces of sulfur dioxide, and particulate matter. Emissions levels will depend on the type, size, operating conditions, and efficiency of the boiler or furnace being used. While post-combustion technologies can be applied to natural gas-fired boilers to reduce nitrogen oxide emissions,[120] natural gas heat can reduce indoor air quality and damage human health.[121] In addition to space and water heating, natural gas is also used in residential and commercial settings for such applications as cooking and clothes drying, with similar implications for indoor air quality.

While gas utilities can meet emissions reduction targets through a variety of means, these are likely to rely on four types of action: decarbonizing the gas supply, reducing emissions from methane leaks, reducing gas demand, and using negative emissions tools, all of which are discussed below. While these strategies can be undertaken simultaneously, individual regions may need to prioritize different actions.[122]

### Renewable Natural Gas, Hydrogen, and Recovered Methane Emissions

Decarbonizing the gas supply is likely to rely on low emissions fuels including biogas, synthetic gas, and green hydrogen.[123] An ICF study found that deploying RNG could reduce GHG emissions by 101 to 235 MMT by 2040.[124] One study found that in a medium growth trajectory starting at a biogas adoption rate of 0.29% of generation, 6.02 gigatons (Gt) $CO_2$e would be saved between 2020 and 2050.[125]

Biogas and synthetic gas emissions impacts should be carefully considered because the source of the gas will determine its impact. For instance, biogas is sometimes thought of as a net-zero carbon fuel source because the organic matter used has stored carbon that would have been released it when it decomposed anyway. However, biogas produces methane emissions and the type of energy used to create the biogas must also be considered. Leaks during the production and transportation of the gas must also be accounted for when biogas emissions are calculated. Any policy scenario in which RNG is used must

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[115] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[116] Climate & Clean Air Coalition. n.d. "Benefits and Costs of Mitigating Methane Emissions." Climate & Clean Air Coalition. Accessed March 30, 2023. https://www.ccacoalition.org/en/content/benefits-and-costs-mitigating-methane-emissions

[117] CDPHE. n.d. "Recovered Methane Protocols and Crediting and Tracking System." Colorado Department of Public Health and Environment. Accessed March 20, 2023. https://cdphe.colorado.gov/air-pollution/recovered-methane

[118] See: Colorado SB 21- 264 https://leg.colorado.gov/bills/sb21-264

[119] Under Senate Bill 21-264, recovered methane projects are ineligible if the emissions reductions are required by federal or state law.

[120] EPA. 2020. "Natural Gas Combustion." U.S. Environmental Protection Agency. September 2020. https://www.epa.gov/sites/default/files/2020-09/documents/1.4_natural_gas_combustion.pdf

[121] Lebel, et. al. 2022. "Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens."

[122] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[123] NRDC. 2020. "A Pipe Dream or Climate Solution? The Opportunities and Limits of Biogas and Synthetic Gas to Replace Fossil Gas." Natural Resources Defense Council. June 2020. https://www.nrdc.org/sites/default/files/pipe-dream-climate-solution-bio-synthetic-gas-ib.pdf

[124] ICF. 2019. "Renewable Sources of Natural Gas."

[125] Project Drawdown. N.d. "Methane Digesters." Project Drawdown. Accessed March 30, 2023. https://drawdown.org/solutions/methane-digesters

consider how it will establish and enforce emissions standards, monitoring, and reporting in order to account for the short- and long-term climate impacts of the gas.[126]

A study requested by the Colorado PUC found that a hydrogen blend of 20% could lead to a 11.6% reduction in emissions.[127] Yet, to fully understand the emissions reduction potential, further examination into the comprehensive impacts of hydrogen emissions is needed. While hydrogen is not currently defined by state or federal policy as a GHG, it can act as an indirect GHG by extending the lifetime of other pollutants in the atmosphere.[128, 129] "Leaked hydrogen can also impact ozone concentrations, potentially harming air quality and the recovery of the ozone layer, and it can create water vapor in the atmosphere, enhancing the greenhouse gas effect."[130] Hydrogen leaks are a concern. Because hydrogen has a lower energy content than natural gas, a greater volume of hydrogen would be needed to create the same amount of energy.[131, 132] Therefore, higher pressures may need to be applied to pipelines with hydrogen-methane blends. Hydrogen is also a much smaller molecule than methane. These two factors may result in higher rates of leakage. Hydrogen leakage can occur in two areas, leaks at joints and leaks through the material of pipelines. A Gas Technology Institute (GTI) study found that pure Hydrogen leaks from pipeline joints occur at a higher rate (3.8 to 4.6 times higher) than that for natural gas. Another factor to consider, polyethylene pipelines are permeable for hydrogen.[133]

While the use of green hydrogen, or hydrogen produced by renewable energy and that uses water as its source, as contemplated by Colorado's Clean Heat Standard**,** will likely result in both reduced use of natural gas and decreased GHG emissions, this process requires large amounts of water, a concern that will be increasingly important in Colorado.[134]

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[126] NRDC. 2020. "A Pipe Dream or Climate Solution?"

[127] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[128] Koch Blank, Thomas, Raghav Muralidharan, Kaitlyn Ramirez, Alexandra Wall, and Tessa Weiss. 2022. "Hydrogen Reality Check #1: Hydrogen Is Not a Significant Warming Risk." RMI. May 9, 2022. https://rmi.org/hydrogen-reality-check-1-hydrogen-is-not-a-significant-warming-risk/

[129] See also: Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[130] Koch Blank, et al. 2022. "Hydrogen Reality Check #1."

[131] Arun S.K. Raju, et al. 2022. "Hydrogen Blending Impacts Study: Final Report."

[132] See also: Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[133] Arun S.K. Raju, et al. 2022. "Hydrogen Blending Impacts Study: Final Report."

[134] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

Beneficial Electrification and Emissions

In the U.S., buildings emit 600 MMT of $CO_2$ emissions annually. The majority of this is associated with gas space and water heating. While emissions from the U.S. electricity sector have been declining over the past decade, emissions from buildings have remained stable, if not increasing (see Figure 2).[135]

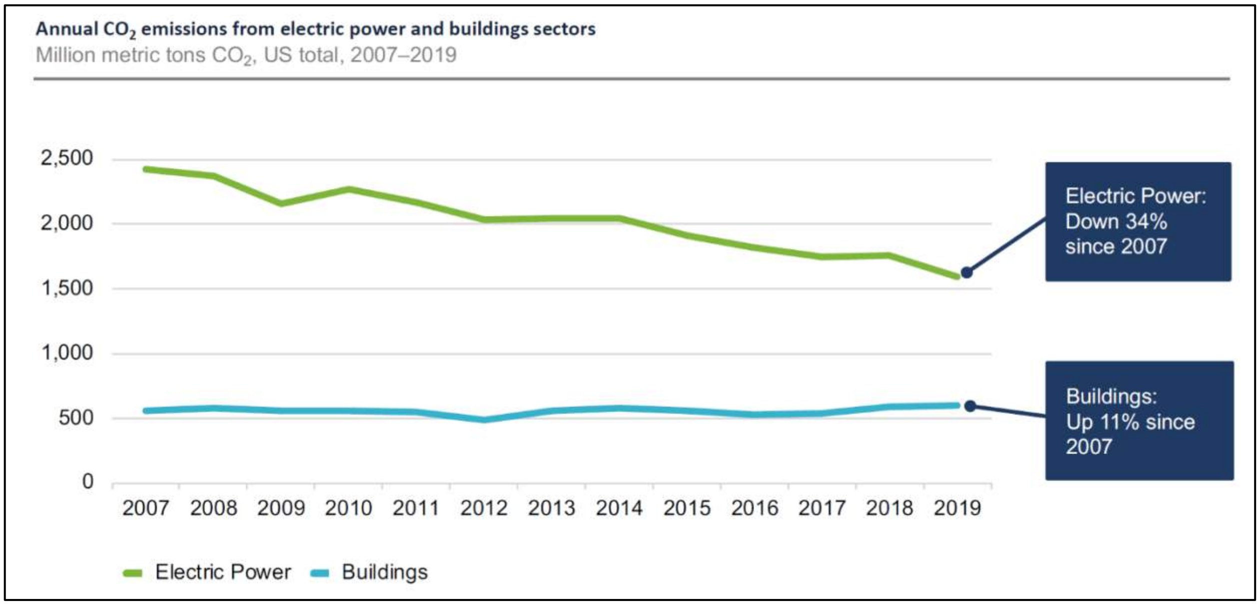

*Figure 2 - Annual emissions from the electric power sector (green) and the building sector (blue) from 2007 to 2019. Source: RMI 2020*

Electrification of both existing and new buildings is likely to yield greater emissions reductions than if only new buildings are required to be electrified.[136] In addition, electrification, in buildings and in other sectors, is likely to improve air quality and public health.[137] In a scenario that limits warming to 1.5° to 2°C where residential and commercial building emissions are reduced primarily by replacing gas with electricity, emissions reductions could range from 0% to 30% in 2030 and 30% to 85% by 2050.[138] The emissions reductions associated with heat pumps are well established (see Figure 3). A single switch to a heat pump could reduce emissions by 1 to 7 metric tons of carbon per year.[139] At an adoption rate of 2.9 (today) increasing linearly to 3.5 in 2060, high efficiency heat pumps could result in a reduction of 4.04 Gt of $CO_2e$ emissions by 2050. While an adoption rate of 2.9 (today) increasing linearly to 4.3 in 2060 would lead to a reduction of 9.05 Gt of $CO_2e$ emissions by 2050.[140] However, there are other GHG emissions to consider. Particularly, from fluorinated gas leakage, or if the heat pump is run on emissions intensive electricity. However, the IEA notes emissions would still be 20% lower than those of a gas boiler.[141]

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[135] Billimoria and Henchen. 2020. "Regulatory Solutions for Building Decarbonization."

[136] Ong, Mastrandea, and Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers."

[137] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[138] O'Neill, et. al. 2021. "Natural Gas Use in the U.S. Building Sector in Global Low Carbon Pathways."

[139] Thomas, Michael. n.d. "How Much Money Do Heat Pumps Save?" Carbon Switch. Accessed March 15, 2023. https://carbonswitch.com/heat-pump-savings/

[140] Project Drawdown. n.d. "High-Efficiency Heat Pumps." Project Drawdown. Accessed March 30, 2023. https://drawdown.org/solutions/high-efficiency-heat-pumps

[141] IEA. 2022. "The Future of Heat Pumps."

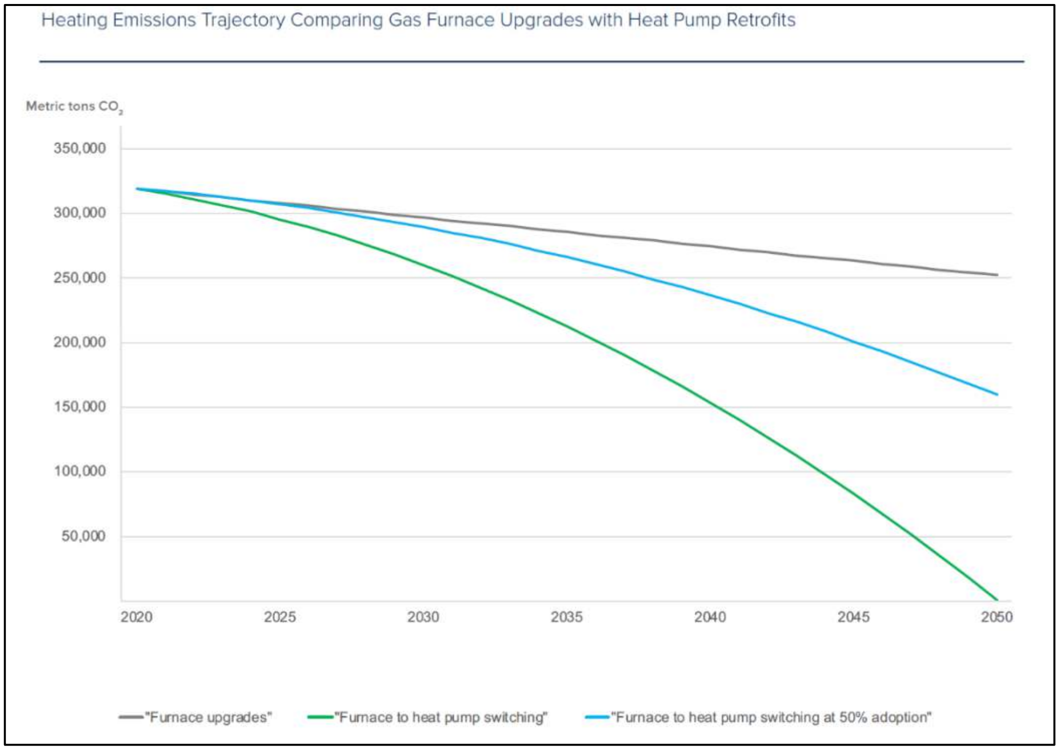

*Figure 3 - Rate at which heating related emissions decline under three scenarios (1) furnace upgrades (gray); (2) switching from a gas furnace to a heat pump (green); and (3) 50% gas to heat pump switching (blue).*
*Source: [RMI 2020]*

### *Dual Fuel Heating System Emissions*

"A dual-fuel approach captures the advantages of electrification while retaining the capacity of the gas system to provide heating on cold winter days."[142] Dual fuel heat pump systems can reduce emissions by reducing the amount of time a gas furnace operates annually.[143] Additionally, by using gas back-up, the electric heat pump does not have to operate during cold weather when it is at its lowest efficiency, which can also reduce emissions.[144] However, while these systems can reduce overall demand on the gas system, peaks on high demand days may increase well beyond average.[145]

There are conflicting findings regarding dual fuel systems. While a 2022 study found that dual fuel heat pumps were an effective and necessary emissions reduction strategy,[141] a 2020 study of different heat pump types in 48 states found varying levels of emissions reductions. Specifically, a single-speed dual fuel heat pump was found to reduce emissions in nine states while a variable speed dual fuel heat pump reduced emissions in 15 states. The single speed dual fuel heat pump had lower annual $CO_2$ emissions in 15 states (where more than 15% of electricity was generated by coal) than the variable speed electric heat

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[142] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios." at 4
[143] Dichter, Nelson. and Aref Aboud. 2020. "Analysis of Greenhouse Gas Emissions from Residential Heating Technologies in the USA." UC Davis Western Cooling Efficiency Center. September 15, 2020. https://wcec.ucdavis.edu/wp-content/uploads/GHG-Emissions-from-Residential-Heating-Technologies-091520.pdf
[144] Dichter and Aboud. 2020. "Analysis of GHG Emissions from Residential Heating Technologies in the USA."
[145] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

pump. When studied specifically in Colorado, emissions from all four heat pump types were predicted to increase compared to similar buildings with a gas furnace (see Figure 4).[146]

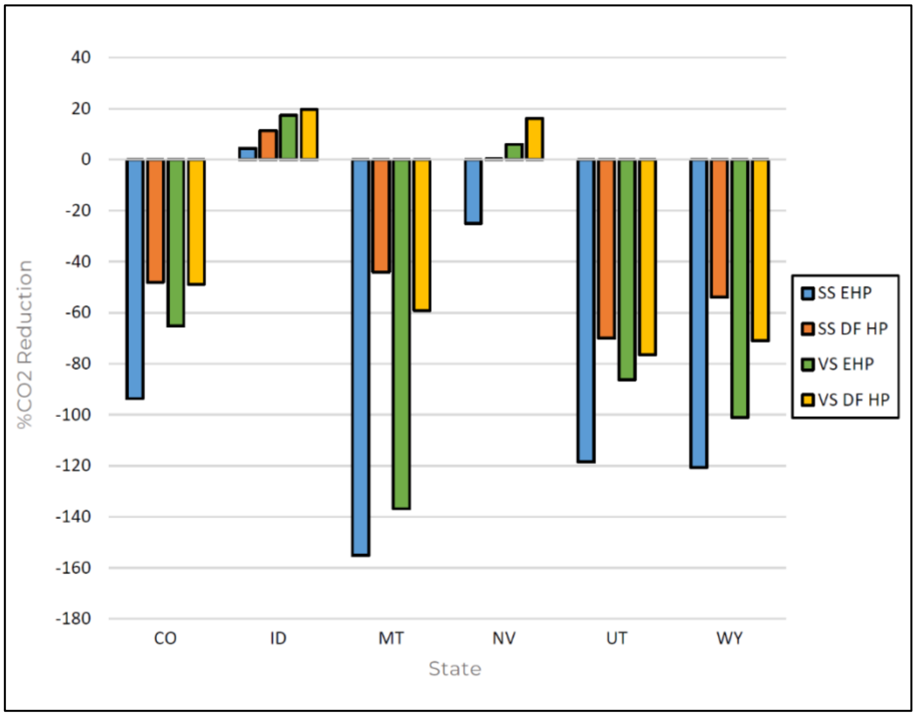

*Figure 4 - Average $CO_2$ reduction for electric heat pumps (EHP) and dual fuel heat pumps (DF HP) for the Rocky Mountain states. (SS - Single Speed and VS - Variable Speed).*
*Source:* UC Davis Western Cooling Efficiency Center 2020

Energy Efficiency, DSM, and Emissions

Emissions related to on-site combustion of gas account for the majority of emissions attributed to natural gas use.[147,148] These emissions can be addressed through efficiency programs and technologies including building envelope improvements and the adoption of efficient HVAC systems, lighting, and appliances.[149,150] Emissions reductions can also be achieved through DSM technologies and programs. Potential emissions reductions from net-zero buildings, or buildings that are highly energy efficient and use renewable energy, could range from 5 to 32 Gt $CO_2e$, depending on adoption rate. For instance, if 9.7% of new buildings are net-zero by 2050, the emissions reduction could be approximately 7.1 Gt of $CO_2e$.[151]

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[146] The findings of this report come with caveats: First, the authors do not specify whether they studied cold climate heat pumps. Second, the report does not appear to account for potential emissions reductions from a heat pump used for cooling (as compared to a central air conditioner). Third, the 2020 report also does not appear to incorporate emission reductions associated with reductions in grid carbon intensity.

[147] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[148] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."

[149] ICF. 2022. "Net-Zero Emissions Opportunities for Gas Utilities."

[150] Project Drawdown. n.d. "Building Retrofitting." Project Drawdown. Accessed March 30, 2023. https://drawdown.org/solutions/building-retrofitting

[151] Project Drawdown. 2023. "Net Zero Buildings." Project Drawdown. https://drawdown.org/solutions/net-zero-buildings

Modeling the emissions impacts of energy efficiency retrofits is difficult due to the large number of variables that impact emission reductions.[152]

Negative Emissions Tools

While emissions removal tools are likely to be essential for addressing GHGs, emission reduction tools, which allow emissions to be mitigated at the source, should be prioritized. This will ensure that less carbon removal is necessary to meet climate and emissions targets.[153]

Carbon capture and sequestration (CCS) allows power plants to capture up to 90% of their $CO_2$ emissions directly from the stacks of the plant before it is released into the atmosphere.[154,155] The $CO_2$ can then be transported and injected into geological formations deep underground where it is then stored.[156,157] Captured $CO_2$ can be used in other industries (carbon capture, use, and storage (CCUS)). In modeling for the Intergovernmental Panel on Climate Change's Fifth Assessment Report, CCS was required to meet a 2°C warming target in half of the models. Without CCS, costs of emissions reductions increased 138%. There are currently 26 commercial-scale CCS projects globally, including natural gas processing and coal-fired generation CCS projects, with others under development.[158] U.S. and state regulations govern where carbon storage is allowed.[159]

Direct air capture (DAC) technologies remove $CO_2$ from the air. The captured $CO_2$ is then stored in geological formations or can be used in industrial and commercial processes. While the process is similar to CCS, it is far more energy intensive, and costly, to capture $CO_2$ from the air than it is at the source. Technological advancements could allow DAC technologies to be powered by renewable or low-carbon energy sources.[160] This can increase the net capture efficiency of DAC by ensuring that more carbon is removed than is added by the energy required to power the plant.[161] There is relative flexibility in siting DAC. Currently, DAC plants operate in many climates and can be located near power stations for easy access to energy.[162] DAC plants can also be sited near geological sequestration sites, minimizing the need for $CO_2$ pipelines.[163] However, questions remain about DAC facilities' abilities to operate in extreme temperatures, high humidity, or in high pollution areas.[164] DAC technology is currently being tested at large-scale facilities, however it is not yet available for commercial deployment. One concern with DAC is

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[152] Project Drawdown. 2023. "Building Retrofitting."
[153] Lebling, Katie, Haley Leslie-Bole, Zach Byrum, and Liz Bridgwater. 2022. "6 Things to Know About Direct Air Capture." World Resources Institute. May 2, 2022. https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal
[154] EPA. 2023. "Overview of Greenhouse Gases."
[155] C2ES. n.d. "Carbon Capture." Center for Climate and Energy Solutions. Accessed March 15, 2023. https://www.c2es.org/content/carbon-capture/
[156] EPA. 2023. "Overview of Greenhouse Gases."
[157] EPA. 2022. "Class VI - Wells Used for Geological Sequestration of Carbon Dioxide." U.S Environmental Protection Agency. Accessed March 15, 2023. https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide
[158] C2ES. n.d. "Carbon Capture."
[159] EPA. 2022. "Class VI Wells for Carbon Sequestration."
[160] IEA. 2022. "Direct Air Capture - Technology Deep Dive." International Energy Agency. September 2022. https://www.iea.org/reports/direct-air-capture
[161] Lebling, et. al. 2022. "6 Things to Know About Direct Air Capture."
[162] IEA. 2022. "Direct Air Capture - Technology Deep Dive."
[163] Lebling, et. al. 2022. "6 Things to Know About Direct Air Capture."
[164] IEA. 2022. "Direct Air Capture - Technology Deep Dive."

that there is no real market for carbon removal, and what does exist is minimal. Therefore, DAC may require significant public funding.[165]

In the case of both CCS and DAC, use of the captured carbon in industrial or commercial settings is possible, though how it is used can reduce the impact of its removal from the atmosphere. For instance, using captured carbon as carbonization for drinks is not a long term or effective emissions reduction strategy while use of captured carbon in plastics or concrete can be a longer-term solution. Expansion of the renewable or low-emissions energy system is also necessary to ensure that CCS and DAC are removing more carbon than is produced by powering the plants.[166] This should be considered in scenario planning as decarbonization strategies will require the significant deployment of renewable or clean energy infrastructure.

Carbon offsets are another technique that can be considered for reducing emissions. Polluting companies buy offsets, which reflect negative emissions elsewhere, to compensate for GHG emissions.[167] Typically, each offset reflects one ton of $CO_2$ (or equivalent) reduction or removal. Once a credit purchased, it cannot be traded again.[168] These transactions often take place within carbon markets which can be developed voluntarily by an industry or by government.[169, 170] LCRI estimated carbon prices for each of its economy-wide net-zero scenarios. These ranged from $165 per ton of $CO_2$ ($tCO_2$) to $1,200/$tCO_2$.[171] Xcel's 2022 study on GHG reductions for gas found that the need for negative emissions measures is likely to shift from emissions offsets in 2030 to DAC in 2050.[172]

## Technology Costs

### Natural Gas

In 2023, the average cost of a new gas furnace is between $3,000 and $10,000.[173] For 2022, the average residential natural gas price in Colorado was $12.74 per thousand cubic feet (Mcf), a 40% increase from 2021, when it was $9.10/Mcf.[174] In January 2023, the Colorado price of gas delivered to customers was $13.27/Mcf, a 4% increase over the 2022 average.[175] The Energy Information Administration (EIA)

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[165] Lebling, et. al. 2022. "6 Things to Know About Direct Air Capture."

[166] Lebling, et. al. 2022. "6 Things to Know About Direct Air Capture."

[167] Pomeroy, Robin. 2022. "Carbon Offsets - How Do They Work, and Who Sets the Rules." World Economic Forum. September 2, 2022. https://www.weforum.org/agenda/2022/09/carbon-offsets-radio-davos/

[168] Favasuli, Silvia and Vandana Sebastian. 2021. "Voluntary Carbon Markets: How They Work, How They're Priced and Who's Involved." S&P Global. June 10, 2021. https://www.spglobal.com/commodityinsights/en/market-insights/blogs/energy-transition/061021-voluntary-carbon-markets-pricing-participants-trading-corsia-credits

[169] Hewitt, Edward. 2022. "How the Voluntary Carbon Market Could Help Us Get to Net Zero." World Economic Forum. March 23, 2022. https://www.weforum.org/agenda/2022/03/voluntary-carbon-market-net-zero

[170] Favasuli and Sebastian. 2021. "Voluntary Carbon Markets."

[171] LCRI. 2022. "Net-Zero 2050."

[172] Aas, et al. 2022. "Xcel Energy Gas Business GHG Reduction Scenarios."

[173] Zito, Barbara and Lowe Saddler. 2023. "How Much Does a New Furnace Cost?" Forbes Home. March 29, 2023. https://www.forbes.com/home-improvement/hvac/new-furnace-cost/

[174] EIA. 2023. "Natural Gas Prices." U.S. Energy Information Administration. March 31, 2023. https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm

[175] EIA. 2023. "Colorado Price of Natural Gas Delivered to Residential Consumers." U.S. Energy Information Administration. March 31, 2023. https://www.eia.gov/dnav/ng/hist/n3010co3m.htm

projected that during the 2022-2023 winter (October to March), residential consumers would likely see heating costs of $862 to $1,096 ($143.67 to $182.67 per month) for natural gas.[176]

When considering natural gas costs, it is also important to note the cost of natural gas plants and transportation infrastructure costs. This literature review examines building electrification scenarios including electrification scenarios under which electricity demand and peak demand is expected to increase. As gas is a lower emissions fuel source, compared to other fossil fuels, its use might expand under some scenarios, which is what an Xcel Energy study found in 2019. To summarize these results, "investment in new natural gas resources to meet capacity needs enables a low-cost pathway to decarbonize electricity and to facilitate levels of electrification needed to meet economy-wide carbon reduction goals."[177] In 2020, the average cost of constructing a new natural gas power plant was $1,116 per kilowatt (kW). The total construction costs for new natural gas power plants built in the U.S. in 2020 was over $6 billion.[178]

Almost 50% of the U.S. natural gas transportation system was built in the 1950s and 1960s.[179] This aging infrastructure will likely need to be updated or retrofitted to accommodate increases in gas demand. Cost expenditures for U.S. gas distribution systems have risen dramatically since 2007.[180] Infrastructure may also need to be expanded further or updated to support increased use of RNG or hydrogen. For instance, a study requested by the Colorado PUC notes that "To the extent that [existing] systems may be required to transport higher blends or even pure hydrogen at some point in the future, a different assessment of the construction practices and materials, with their attendant cost impacts, may be warranted."[181] According to the most recent information available, updating existing gas infrastructure with new pipes throughout the U.S. will cost an estimated $341.5 billion.[182,183] While this expenditure estimate is nationwide and pertains to the entire distribution system, continued use of any portion of the existing system to transport new fuels (RNG, hydrogen) will encounter issues of existing system updating/retrofitting needs and associated expenses.

Typically, homebuilders and gas companies split the cost to extend pipelines into new neighborhoods and developments. Utilities then recover these expenses from their existing customers. However, this practice has garnered opposition as states move to decarbonize. Opponents argue that ratepayers should not finance infrastructure that will extend the use of fossil fuels that is counterproductive to climate goals.[184]

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[176] EIA. 2022. "Winter Fuels Outlook." U.S. Energy Information Administration. October 2022. https://www.eia.gov/outlooks/steo/special/winter/2022_Winter_Fuels.pdf

[177] Schlag, et. al. 2019. "Xcel Energy Low Carbon Scenario Analysis -- Upper Midwest System." at 98.

[178] EIA. 2022. "Construction Cost Data for Electric Generators Installed in 2020." U.S. Energy Information Administration. August 23, 2022. https://www.eia.gov/electricity/generatorcosts/

[179] EIA. 2022. "Natural Gas Explained - Natural Gas Pipelines." U.S. Energy Information Administration. November 18, 2022. https://www.eia.gov/energyexplained/natural-gas/natural-gas-pipelines.php

[180] Billimoria and Henchen. 2020. "Regulatory Solutions for Building Decarbonization."

[181] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[182] Parfomak, Paul W. 2023. "DOT's Federal Pipeline Safety Program: Background and Issues for Congress." Congressional Research Service. March 31, 2023. https://sgp.fas.org/crs/misc/R44201.pdf

[183] Parformak (2023) provides this cost in 2015 dollars, 2023 dollars were calculated using the Bureau of Labor Statistics' CPI Inflation Calculator, available here: https://www.bls.gov/data/inflation_calculator.htm

[184] Brasch, Sam. 2022. "Regulators Set Heavy Restrictions for New Natural Gas Lines, but Stop Short of Eliminating Subsidies" Colorado Public Radio. December 8, 2022. https://www.cpr.org/2022/12/08/colorado-natural-gas-restrictions-home-construction/

In September 2022, California became the first state in the nation to eliminate ratepayer subsidies for new gas connections.[185] Colorado was expected to follow suit. However, in late 2022, the Colorado PUC issued Decision C22-0760, which resulted from PUC Proceeding 21R-0449G, "Amendments to Gas Rules Implementing SB 21-264 & HB 21-1238." Ultimately, the decision did not eliminate subsidies, but instead created a new metric for determining the size of ratepayer subsidies in the future, which are likely to shrink over time.[186] The Decision indicates that new natural gas customers will now assume the cost of natural gas hookups, including costs associated with increases in design-day peak demand, which is "the highest hourly natural gas flow rate projected for a utility system, or a portion thereof, based on the relevant design day coldest temperature, i.e., the 1-in-30-year low temperature data." The PUC's decision notes that the gas infrastructure planning rules are a "first step in developing a 'nonpipeline alternatives' analysis framework for specific project investment."[187]

Renewable Natural Gas, Low Emission Fuels, and Recovered Methane

The costs and availability of RNG and low emission gas will be influenced by policy, market conditions, and technological development.[188] While exact costs are unknown, because these fuels are not yet deployed at scale, cost estimates for RNG and other alternative fuels suggest that they are likely to exceed the current costs of natural gas.[189,190]

In a scenario examining biomethane and methane digesters, a medium growth trajectory with an initial adoption rate of 0.29% of generation would have a net upfront cost of $138.13 billion with a lifetime operational savings of $45.54 billion between 2020 and 2050.[191] In 2020, the American Gas Foundation (AGF) projected that biogas and synthetic natural gas will cost between $7 to $45 per million Btu – costs that are three to eight times higher than 2020 natural gas prices. A California study projects biogas will cost $8 to $40 per million Btu and synthetic methane will cost between $37 to nearly $90 per million Btu at scale in 2050.[192] A different California study projects that SNG produced from a new plant with 100% direct air capture will have a commodity cost of $86 per metric million Btus (MMBtu) by 2050 under a conservative cost scenario; this is compared to a forecasted cost of $5/MMBtu for natural gas. The same study projects SNG with DAC could cost $41/MMBtu under an optimistic cost scenario. That study also notes that if RNG were used to power a furnace, the monthly operating costs would fall between $160 and $262.[193,194]

A new synthetic gas technology out of the Pacific Northwest National Laboratory, which allows for carbon capture and the conversion of carbon to methane, promises lower costs compared to traditional synthetic

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[185] CPUC. 2022. "CPUC Decision Makes California First State in Country to Eliminate Natural Gas Subsidies." *C*alifornia Public Utilities Commission. September 15, 2022. https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-decision-makes-ca-first-state-in-country-to-eliminate-natural-gas-subsidies#:~:text=The%20California%20Public%20Utilities%20Commission,lower%20utility%20bills%20for%20consumers

[186] Brasch. 2022. "Regulators Set Heavy Restrictions for New Natural Gas Lines."

[187] Details of Decision C22-0760. December 1, 2022. DORA. https://www.dora.state.co.us/pls/efi/EFI_Search_UI.Show_Decision?p_session_id=&p_dec=29605 at 74.

[188] ICF. 2019. "Renewable Sources of Natural Gas."

[189] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[190] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[191] Project Drawdown. 2023. "Methane Digesters."

[192] NRDC. 2020. "A Pipe Dream or Climate Solution?"

[193] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[194] As noted above, the EIA projected that average monthly natural gas heating costs would range from $143. 67 to $182.67 between October 2022 and March 2023.

natural gas. The new process would have an upfront investment cost that is 32% less, operation and maintenance costs that are lower by 35%, and would bring down the cost of synthetic natural gas by 12%.[195] This, however, is dependent on the in practice results and the adoption rates of the new technology.

A report examining decarbonization of Minnesota's natural gas end uses notes that green hydrogen is an emerging fuel that is not yet deployed at scale, which makes it difficult to accurately determine costs, fuel availability, and reliability.[196] For green hydrogen to be viable, it would need to be cost competitive with other RNGs in terms of costs of production, storage, transportation, and utilization.[197] Some cost estimates put electrolyzer produced hydrogen at twice the current price of natural gas in the next 10 to 20 years.[198] However, BloombergNEF projects that green hydrogen prices will decrease in upcoming years as renewable energy prices continue to fall, energy efficiency increases, and technological improvements are made to electrolyzers. Bloomberg estimates that green hydrogen could be produced for $0.7 to $1.6 per kilogram before 2050. These prices would be equivalent to natural gas prices between $6 to $12 per MMBtu.[199]

If CCS is added to the hydrogen production process, the price increases to $1 to $2 per kilogram (kg), while using renewable energy in production leads to prices ranging from $3 to $8/kg.[200] Other estimates place the cost of hydrogen with DAC from a new plant at $20/MMBtu by 2050 in a low cost scenario.[201] Low-carbon hydrogen produced from natural gas ranges in price from $0.5 to $1.7/kg, the variation depending on local natural gas prices.[202,203]

The IEA's Net Zero Emissions by 2050 Scenario report estimates that prices for green hydrogen could fall to $1.3 to $3.5/kg by 2030, particularly in regions with high renewable energy potential. Longer term projections find that renewable hydrogen prices could fall as low as $1/kg making it cost competitive with natural gas hydrogen combined with CCS technology.[204] Increased interest from utilities and investments by the federal government, including $8 billion in federal money from the IIJA to support regional hydrogen hubs and the IRA's new clean hydrogen tax credits of up to $3/kg of clean hydrogen produced, may lead to technological advancements, economies of scale, and cost reductions.[205,206] In addition, the U.S. Department of Energy's Hydrogen Shot program, launched in 2021, has the goal of reducing the price of

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[195] Bane, Brendan. 2021. "Making Methane from CO2: Carbon Capture Grows More Affordable." Pacific Northwest National Laboratory. September 2, 2021. https://www.pnnl.gov/news-media/making-methane-co2-carbon-capture-grows-more-affordable

[196] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[197] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[198] Baldwin, Sara, Dan Espisito, and Hadley Tallackson. 2022. "Assessing the Viability of Hydrogen Proposals: Considerations for State and Utility Regulators and Policy Makers." Energy Innovation and Policy Technology Inc. https://energyinnovation.org/publication/assessing-the-viability-of-hydrogen-proposals-considerations-for-state-utility-regulators-and-policymakers/

[199] BloombergNEF. 2020. "Hydrogen Economy Outlook."

[200] IEA. 2021. "Global Hydrogen Review 2021." International Energy Agency. October 2021. https://www.iea.org/reports/global-hydrogen-review-2021/executive-summary

[201] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[202] IEA. 2021. "Global Hydrogen Review 2021."

[203] Not currently an eligible resource under Colorado's Clean Heat Standard.

[204] IEA. 2021. "Global Hydrogen Review 2021."

[205] Loiter and Hanna. 2022. "Green Hydrogen for Pipeline Injection in LDC Infrastructure."

[206] Baldwin, et al. 2022. "Assessing the Viability of Hydrogen Proposals."

clean hydrogen to $1 /kg in one decade.[207] In a study examining decarbonization scenarios for Minnesota, the Great Plains Institute (GPI) and the Center for Energy and Environment (CEE) found that dedicated hydrogen, produced by renewable electricity, would be a more affordable option for industry than using decarbonized gaseous fuels in the existing gas system.[208]

The Climate and Clean Air Coalition estimates that in the waste, coal, and oil and gas sectors, emissions reductions could be accomplished at a price of $600 per ton of methane saved. Methane reductions in the oil and gas sector could cost around $520 per ton of methane. Costs of methane reduction in other sectors range from $190 to $3,240 per ton.[209] In a model examining methane capture from landfills, installation costs of the technology were assumed to be $1,921/kW with a fixed operation and maintenance cost of $237.20/kW. These costs could increase depending on region and the technology used, particularly if gas-to-electricity technology is used.[210]

Beneficial Electrification

While requiring the electrification of both existing and new buildings could result in higher rates for gas ratepayers, it also generally leads to higher emissions reductions. Rate impacts can be mitigated through cost management and proactive planning.[211] Studies across a variety of geographies have found that building electrification is a least-cost pathway to decarbonization.[212] However, increased building electrification is very likely to require an unprecedented build out of renewable and clean energy generation and transmission infrastructure, including energy storage.[213] The costs associated with this should be included in decarbonization modeling.

In 2018, the National Renewable Energy Laboratory (NREL) projected that prices for ASHPs would decline by 20 to 38% by 2050.[214] Costs for heat pumps are impacted by several factors including the size of the home, its energy efficiency, the current heat source used in the home, and regional climate.[215] A 2021 Home Innovation Labs report compared electrification costs between climate regions, including Denver as a "cold climate" region and finding that in colder climates customers will likely be faced with both higher upfront installation costs and higher operating costs throughout the life of the equipment. Ultimately, buying a heat pump in Denver could cost between $8,259 to $9,088 depending on the type of heat pump selected. For houses that rely on natural gas, there could be additional costs for retrofitting or updating electrical infrastructure.[216,217] A 2022 NREL study on cold climate heat pumps found that equipment costs

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[207] DOE. n.d. "Hydrogen Shot." U.S. Department of Energy - Hydrogen and Fuel Cell Technologies Office. Accessed March 30. https://www.energy.gov/eere/fuelcells/hydrogen-shot

[208] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[209] Climate & Clean Air Coalition. n.d. "Benefits and Costs of Mitigating Methane Emissions."

[210] Project Drawdown. n.d. "Landfill Methane Capture." Project Drawdown. Accessed March 30, 2023. https://drawdown.org/solutions/landfill-methane-capture

[211] Ong, Mastrandea, and Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers."

[212] Billimoria and Henchen. 2020. "Regulatory Solutions for Building Decarbonization."

[213] Buonocore, et. al. 2022. "Inefficient Building Electrification Will Require Massive Buildout of Renewable Energy and Seasonal Energy Storage."

[214] Billimoria, Sherri, Leia Guccione, Mike Henchen, Leah Louis-Prescott. 2018. "The Economics of Electrifying Buildings - How Electric Space and Water Heating Supports Decarbonization of Residential Buildings." RMI. https://rmi.org/insight/the-economics-of-electrifying-buildings/

[215] Thomas. n.d. "How Much Money Do Heat Pumps Save?"

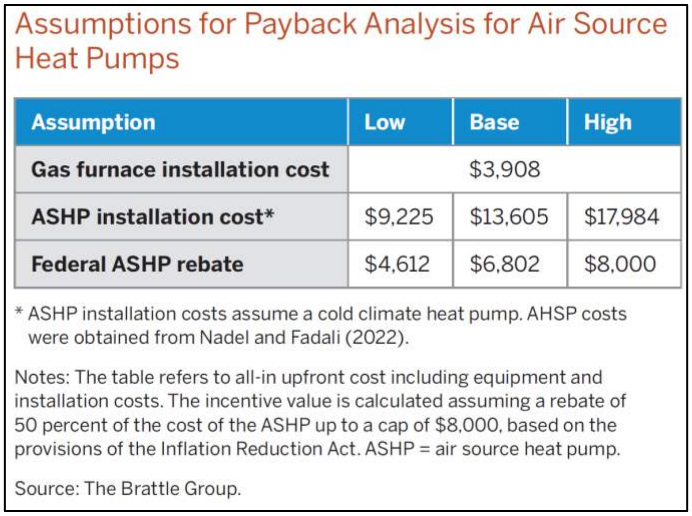
[216] Home Innovation Labs. 2021. "Cost and Other Implications of Electrification on Residential Construction."

[217] This study used price data for heat pumps appropriate for Denver's climate zone.

range from $4,000 to $8,000 with additional labor costs of $2,000 to $4,000. Overall, the study found that between equipment, labor, and home upgrades or retrofits, the total costs for a heat pump range between $7,000 and $20,000.[218]

High efficiency heat pumps, or heat pumps with at least a 3.5 seasonal coefficient of performance and at least a 5.9 seasonal energy efficiency ratio, were found to have high upfront costs but save trillions in lifetime costs. High efficiency heat pumps at an adoption rate of 2.9 (today) increasing linearly to 3.5 in 2060 would result in upfront costs of $76.10 billion with lifetime savings in operating costs of $1.05 trillion between 2020 and 2050. While an adoption rate of 2.9 (today) increasing linearly to a rate of 4.3 in 2060 would lead to upfront costs of $118.34 billion and lifetime savings of $2.43 trillion between 2020 and 2050.[219]

An Energy Systems Integration Group study also examined how electrification through the installation of ASHPs impacts customer costs. While this study notes the high upfront costs for ASHPs (see Figure 5), it also finds that customers could save $453 to $1,212 annually on their electric bill after installing an ASHP.[220] A 2020 California study estimated the operating cost of a heat pump would be between $34 to $53 per month.[221] Savings on electric bills after installing an ASHP will be highly dependent on rate design.[222] The cost of a heat pump will also be dependent on the availability of state and federal tax credits and rebates. State, federal, and utility financial incentives will be discussed below.



Assumptions for Payback Analysis for Air Source Heat Pumps

| Assumption | Low | Base | High |
|---|---|---|---|
| **Gas furnace installation cost** | | $3,908 | |
| **ASHP installation cost*** | $9,225 | $13,605 | $17,984 |
| **Federal ASHP rebate** | $4,612 | $6,802 | $8,000 |

* ASHP installation costs assume a cold climate heat pump. AHSP costs were obtained from Nadel and Fadali (2022).

Notes: The table refers to all-in upfront cost including equipment and installation costs. The incentive value is calculated assuming a rebate of 50 percent of the cost of the ASHP up to a cap of $8,000, based on the provisions of the Inflation Reduction Act. ASHP = air source heat pump.

Source: The Brattle Group.

*Figure 5 - Cost assumptions for payback used in ESIG analysis.*
*Includes federal rebates from the Inflation Reduction Act.*
*Source: ESIG 2022*

Dual Fuel Technologies and Approaches

Dual fuel heat pumps, heat pumps that are powered by electricity with natural gas or gas alternative furnaces as a backup, can provide reassurance to the customer that their heat will not be interrupted by extreme cold or electricity failures. In a CEE model, customer bills were kept low through use of a dual fuel system that uses an economic balance to determine when each part of the system is used. An economic

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[218] Desai and Wu. 2022. "Cold Climate Air Source Heat Pumps Technology."

[219] Project Drawdown. 2023. "High-Efficiency Heat Pumps."

[220] Sergici, et. al. 2022. "Heat Pump-Friendly Cost-Based Rate Designs."

[221] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[222] Sergici, et. al. 2022. "Heat Pump-Friendly Cost-Based Rate Designs."

balance point occurs when it costs the same for either the furnace or the heat pump to operate due to the temperature outside, generally falling between 25°F and 45°F. The switchover point between heat pump and furnace can be changed depending on gas or electric rate changes. Dual fuel systems can also be used with low-cost heat pump systems, and customers can choose standard efficiency heat-pumps which are often more affordable over high-efficiency heat pumps if they use a dual fuel system.[223] The most readily available cost estimates for dual fuel heat pumps ranged between $2,500 to $10,000.[224]

The 2021 Decarbonizing Minnesota study found the most affordable option for residential and commercial customers to be the electrification with gas backup scenario. This was found to be true regardless of whether decarbonized gaseous fuels were more or less expensive, as in this scenario, there is a more cost-effective balance between infrastructure investments and fuel costs compared to the others examined in the study.[225]

### Energy Efficiency and DSM

Energy efficiency and DSM programs reduce energy demand, therefore reducing pressure and wear on existing generation stations, transmission lines, and other infrastructure, which may reduce the need for new energy infrastructure. The avoided costs associated with DSM and energy efficiency programs should be factored in when considering the costs and benefits of these programs.[226]

Energy efficiency is considered a low-risk and least cost resource that should be the first building block in any decarbonization strategy (see Figure 6).[227] Additionally, DSM and energy efficiency programs can save consumers money on their energy bills.[228] Because modeling the results of energy efficiency retrofits is difficult due to the large number of variables that impact costs, cost estimates are difficult to obtain.[229] However, using the energy efficiency program portfolios of 48 large IOUs, American Council for an Energy-Efficient Economy (ACEEE) found that the levelized cost of energy saved was $0.024 / kWh in 2018. As compared to supply-side resources, the cost of energy efficiency is “comparable to the least-cost

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[223] Otalora-Fadner, Arbor. 2022. “How a Dual Fuel Heat Pump System with Natural Gas Backup Balances Emissions Reduction with Savings.” Air Source Heat Pump Collaborative. June 30, 2022. https://www.mnashp.org/blog/dual-fuel-heat-pump-with-natural-gas-backup

[224] Home Advisor. n.d. “How Much Does a Heat Pump Cost?” Angi’s List. Accessed March 22, 2023. https://www.homeadvisor.com/cost/heating-and-cooling/install-a-heat-pump/

[225] Drake and Partridge. 2021. “Decarbonizing Minnesota’s Natural Gas End Uses.”

[226] Aniti. 2019. “Demand-side Management Programs Save Energy and Reduce Peak Demand.”

[227] ICF. 2022. “Net-Zero Emissions Opportunities for Gas Utilities.”

[228] Office of Energy Efficiency and Renewable Energy. n.d. “Energy Efficiency.” U.S. Department of Energy - Office of Energy Efficiency and Renewable Energy. Accessed March 12, 2023. https://www.energy.gov/eere/energy-efficiency

[229] Project Drawdown. 2023. “Building Retrofitting.”

generation resources available on the grid today, and it is cheaper than the least expensive fossil fuel option" (see Figure 6).[230]

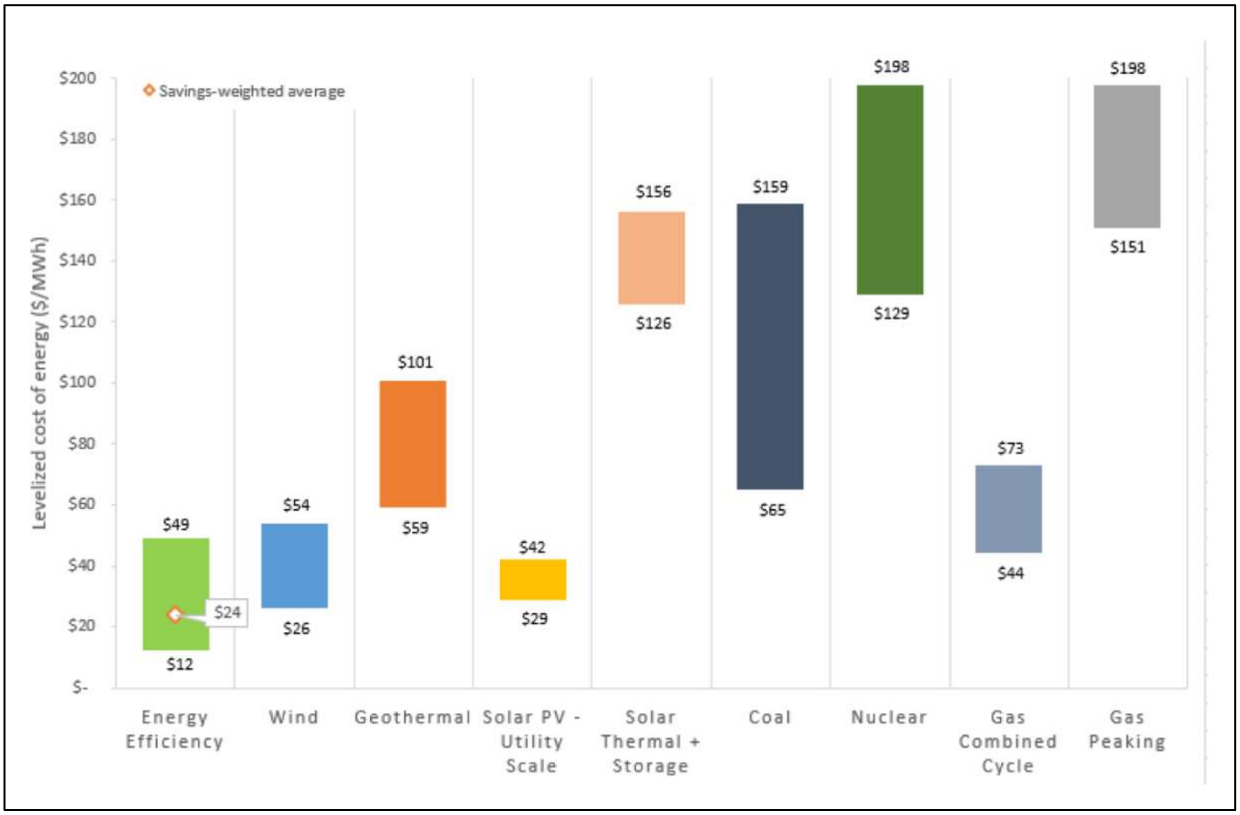

*Figure 6 – Levelized cost of energy efficiency, as compared with unsubsidized supply-side resources*

*Source: Cohn 2021*

Negative Emissions Tools

A 2020 study on carbon capture and storage in Colorado found that the state has the "potential to store over 123 billion tons of $CO_2$ in geological saline formations and at least 163 MMT of $CO_2$ in enhanced oil recovery (EOR) fields." At existing facilities with the potential to use CCS technology, carbon capture costs ranged from $15 to $57 per ton.[231] IEA estimates from 2019 put the levelized cost of carbon capture from natural gas processing at $15 to $25 per ton and at $50 to $100 per ton for electricity generation. For alternative fuels such as hydrogen, levelized carbon capture costs range from $50 to $80 per ton, and between $25 to $35 per ton for bioethanol.[232]

DAC technology costs currently range from $250 to $600 per metric ton of carbon removed, and estimations of future costs put DAC between $150 to $200 per metric ton in the next five to 10 years.

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[230] Cohn, Charlotte. 2021. "The Cost of Saving Electricity for the Largest U.S. Utilities: Ratepayer-Funded Efficiency Programs in 2018." American Council for an Energy-Efficient Economy. https://www.aceee.org/topic-brief/2021/06/cost-saving-electricity-largest-us-utilities-ratepayer-funded-efficiency

[231] Regional Carbon Capture Deployment Initiative. 2020. "Colorado Implementing Carbon Capture and Storage Technology." Regional Carbon Capture Deployment Initiative and the Great Plains Institute. August 2020. https://carboncaptureready.betterenergy.org/wp-content/uploads/2020/09/CO_8_26_2020.pdf at 1.

[232] IEA. 2022. "Levelised cost of CO2 capture by sector and initial CO2 concentration, 2019." International Energy Agency. October 26, 2022. https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019

DOE's Carbon Negative Shot initiative is working to reduce carbon removal costs and to ensure that carbon removal technologies reach gigaton scale at $100 per ton in the next 10 years.[233] In 2021, the Pacific Northwest National Laboratory developed a new carbon capture technology that reduces costs by 19% compared to current commercial technology, which costs $400 to $500 million per unit and captures carbon at a rate of $58.30 per metric ton removed. The new technology could capture carbon at a rate of $47.10 per metric ton.[234]

The cost of carbon offsets varies widely, as it depends on the type of offset and the market in which it was purchased. Projections for the future costs of carbon offsets depend on market growth. As of 2021, the price of a single carbon offset (1 ton of $CO_2e$ removed or reduced) can range between several cents to $15. For credits from more expensive projects like reforestation or CCS, costs can range from $100 to $300 tons/$CO_2e$.[235] Some future estimates put the cost of carbon offsets as high as $224 per ton by 2029 before falling to $120 per ton in 2050.[236]

## Customer Impacts

Senate Bill 21-264 set a cost cap of 2.5% of annual gas bills for all full-service customers. Accordingly, for Colorado, the information related to customer impacts, discussed below, is subject to this cost cap. In addition, the bill excludes transportation gas service customers, or customers transporting customer-owned gas through the gas pipeline system, from the emissions targets.

### Rate Impacts

The average residential natural gas price in Colorado was $12.74 per Mcf in 2022. For commercial customers, that price was $11.32, and for industrial customers, the average price was $10.13 per Mcf in 2022.[237] In January 2023, the average price of electricity for the residential sector was 14.20¢/kWh, for commercial customers, that price was 11.05¢/kWh, while industrial customers paid 8.67¢/kWh.[238] Estimates of the likely rate impacts of decarbonization are difficult to find, and the estimates that do exist disagree, and are not specific to Colorado, creating an area in need of additional research. While some find that building electrification could drive energy rates down for all customers under certain conditions,[239] others find that rates increase in all scenarios.[240]

Typically, the average retail rate paid by residential, commercial, and industrial customers includes commodity and delivery charges. Both of these charges may increase under both high and low building electrification scenarios.[241] In scenarios where a low rate of building electrification occurs, this is due to

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[233] Lebling, et. al. 2022. "6 Things to Know About Direct Air Capture."

[234] Bane, Brendan. 2021. "Cheaper Carbon Capture is on the Way." Pacific Northwest National Laboratory. March 11, 2021. https://www.pnnl.gov/news-media/cheaper-carbon-capture-way

[235] Favasuli and Sebastian. 2021. "Voluntary Carbon Markets."

[236] Bloomberg. 2022. "Carbon Offsets Price May Rise 3,000% by 2029 Under Tighter Rules." Bloomberg Professional Services. March 2, 2022. https://www.bloomberg.com/professional/blog/carbon-offsets-price-may-rise-3000-by-2029-under-tighter-rules/

[237] EIA. 2023. "Natural Gas Prices."

[238] EIA. 2023. "Rankings: Average Retail Price of Electricity to Residential Sector, January 2023 (cents/kWh)." U.S. Energy Information Administration. https://www.eia.gov/state/data.php?sid=CO

[239] See: CAL Advocates. 2022. "Building Electrification Memo (Draft)." Available on request.

[240] See: Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[241] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

the increased use of low carbon fuels, which is likely to increase commodity costs.[242,243] In scenarios where high rates of building electrification are modeled, delivery charges increase as users exit the gas system.[244] Accordingly, residential and industrial customers are affected differently depending on the scenario.

Residential and small commercial customers are likely to bear most of the costs associated with operating and maintaining the gas distribution system (delivery). This is because large gas users, typically large industrial customers, do not receive distribution-level service.[245] As customers exit gas service, delivery costs, likely to remain stable or to increase over time, will be divided among fewer and fewer customers, which could result in higher rates for those customers who continue to receive gas service (see figure 7).[246,247] This can disproportionately impact renters and low-income customers who are less able to electrify.[248] One study found that while long-term cost reductions under a full electrification scenario were likely, "unsustainable increases in gas rates and customer energy bills could [occur in California] after 2030," which requires the development of strategies to address gas rates.[249]

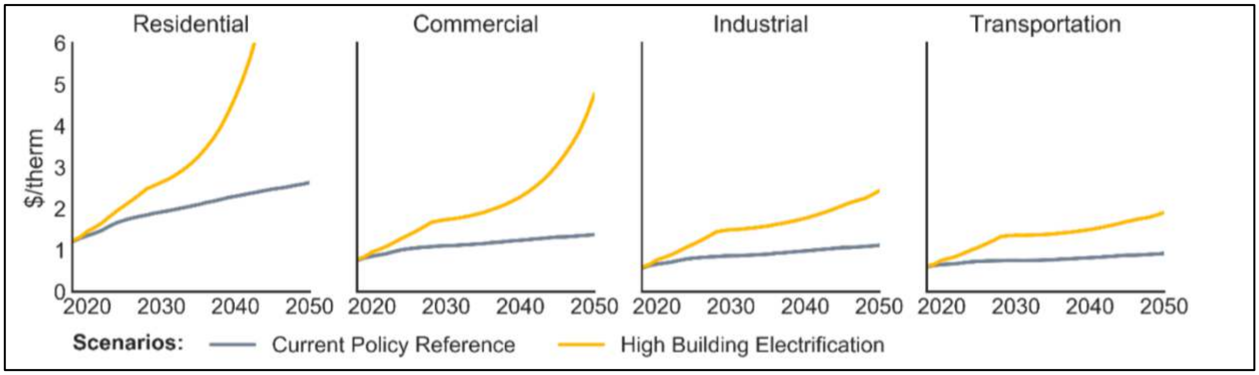

*Figure 7– Gas rates by sector in a high electrification scenario. Source: CEC 2020*

Bill impacts for mixed fuel customers (using both gas and electricity) may be less substantial, at least in the short-term, but this is likely to vary with market, building, and climate conditions.[250] This is because existing customers remain on the gas system, allowing costs to be evenly distributed. However, as noted above, the costs of low carbon fuels, including biomethane, synthetic methane, and hydrogen are expected to remain much higher than the current costs of natural gas, which will impact customer fuel charges.[251] One study found that the lowest gas rate impacts coupled with the highest emissions reductions emerged from a scenario under which strategic gas retirements were paired with targeted electrification. This "branch pruning" scenario allowed strategic gas retirements to keep the gas system scaled to meet customer needs. However, this scenario creates equity concerns because residents must

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[242] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[243] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[244] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[245] Colorado's Clean Heat Standard excludes transportation gas service customers from the emissions targets.
[246] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[247] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[248] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[249] Note that this study was specific to California, which typically has milder winters than Colorado, allowing heat pumps to perform at higher efficiency, which can make it less expensive to heat homes in the state using electricity than with gas.
[250] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[251] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

invest in electric appliances and electric retrofits as neighborhoods are converted. These concerns could be mitigated through incentives and electrification financing mechanisms.[252]

An additional consideration, under a high electrification scenario, increased electrical load can create higher electrical system costs, particularly for infrastructure updates needed to meet peak demand. Pairing air source heat pumps with gas backup can significantly reduce these costs by reducing the amount of infrastructure updates and generation and storage resources needed to meet daily and seasonal peaks.[253]

Because commodity charges are a large portion of industrial customers' rates, industrial rates may increase more in the no or low building electrification scenario, however, modeling suggests rates are likely to increase across all customer types (see Figure 8).[254] Industrial rate impacts could be mitigated by dedicated hydrogen supply. [255]

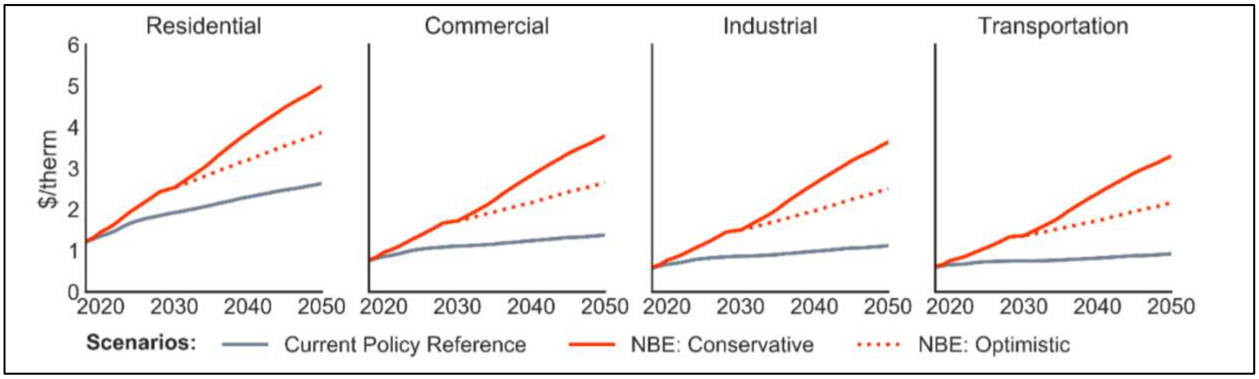

*Figure 8 – Gas rates by sector in a low electrification scenario. Source: CEC 2020*

Our review suggested a handful of additional options for mitigating rate impacts. Energy efficiency programs could be amended to include fuel switching and load management technologies.[256] Rate design is likely to be a key consideration. Utilities can encourage customers to use energy when it costs the least to produce it through time of use rates.[257,258] In Maine, policymakers determined that utility rates for heat pump customers did not accurately reflect grid operation and maintenance costs. Legislation adopted in 2021 directed utilities to create a new opt-in rate that would impose a higher monthly service fee, but a lower fee for each kilowatt hour consumed, to more accurately reflect the costs that heat pump users impose on the grid.[259] Cal Advocates suggests that rate designs that are not dependent on consumption may encourage building electrification by making it more affordable.[260]

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[252] Ong, Mastrandea, and Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers."

[253] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[254] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."

[255] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[256] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[257] CAL Advocates. 2022. "Building Electrification Memo (Draft)."

[258] See also: Billimoria, et al. 2018. "The Economics of Electrifying Buildings."

[259] Ogrysko, Nicole. 2022. "How New Electric Rates for Mainers Using Heat Pumps or Electric Vehicles Will Work." October 13, 2022. Maine Public. https://www.mainepublic.org/environment-and-outdoors/2022-10-13/how-new-electric-rates-for-mainers-using-heat-pumps-or-electric-vehicles-will-work

[260] See CAL Advocates. 2022. "Building Electrification Memo (Draft)."

Incentive Programs

Incentive programs offered by utilities or by local, state, and federal government agencies can mitigate cost impacts on customers.

*Utility-Run Incentive Programs*

Colorado requires that regulated gas utilities manage energy efficiency programs that also provide rebates and incentives to enable customers to undertake energy efficiency improvements. The state's energy efficiency resource standard (EERS) requires that gas IOUs set spending targets of more than 0.5% of the previous years' annual revenues from customers. Energy efficiency savings targets are then set by the PUC relative to spending targets.[261]

In 2021, Colorado's Greenhouse Gas Pollution Reduction Roadmap found that gas utility investments and savings under the EERS "have been very modest compared to the level of efficiency improvements that are achieved by leading utility programs."[262] Accordingly, the Roadmap urged increased utility investment in energy efficiency. Later that year, the Colorado General Assembly adopted several changes to EERS requirements for gas IOUs. Under House Bill 21-1238 gas utilities are required to set savings targets every four years and the PUC will set DSM savings targets for natural gas utilities that reflect "maximum cost-effective and achievable" savings potential. The bill also requires that 25% of residential programs target low-income households and amended cost-effectiveness tests for natural gas utility DSM programs to include avoided costs to ratepayers related to reduced natural gas consumption using a calculation that includes a social cost of carbon of $68 per short ton and a social cost of methane of $1,756 per short ton.[263,264]

In Colorado, both Black Hills Energy and Xcel Energy provide incentives for customers to reduce their emissions and energy use. Black Hills offer rebates for its residential and business customers to install energy efficient appliances.[265] Xcel offers rebates for its customers for smart thermostats, LED light bulbs, energy efficiency home upgrades, heat pumps and heat pump water heaters, and insulation. The utility also offers income-qualified weatherization programs and provides incentives for its customers to use renewable energy and battery storage.[266,267]

*State Incentives*

Colorado's incentives encourage residential, commercial, and industrial customers to invest in electrification, energy efficiency, and low carbon distributed energy resources. Colorado's Residential Energy Upgrade (RENU) Loan provides low-interest financing to residential homeowners for energy efficiency and renewable energy improvements, including "insulation, air sealing, energy-efficient windows, efficient space conditioning and water heating equipment, heat pump water heaters, and solar PV systems." RENU offers extended loan terms and loans for borrowers with lower credit scores. In

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[261] ACEEE. 2022. "Colorado: Utilities – Energy Efficiency Resource Standards." American Council for an Energy-Efficient Economy. April. https://database.aceee.org/state/colorado

[262] CEO. 2021. "GHG Pollution Reduction Roadmap." Colorado Energy Office. January 2021. https://energyoffice.colorado.gov/climate-energy/ghg-pollution-reduction-roadmap at 73.

[263] ACEEE. 2022. "Colorado: Utilities –EERS."

[264] CNEE. 2022. "State Brief: Colorado."

[265] Black Hills Energy. 2023. "Efficiency and Savings." Black Hills Energy. https://www.blackhillsenergy.com/efficiency-and-savings

[266] Xcel Energy. 2023. "Home Rebates." Xcel Energy. https://co.my.xcelenergy.com/s/residential/home-rebates

[267] Xcel Energy. 2023. "Renewable Energy." Xcel Energy. https://co.my.xcelenergy.com/s/renewable

addition, Colorado's Clean Energy Fund (CCEF) provides loans to low- and moderate-income households for energy efficiency retrofits and commercial property assessed clean energy (CPACE) loans for small businesses in just transition communities and rural areas.[268]

Through CPACE programs, local governments are authorized to offer financing for up to 100% of the costs of energy efficiency and renewable energy projects for owners of eligible commercial and industrial buildings. While the state has not yet authorized residential PACE (RPACE), such a program could provide incentives for homeowners' adoption of energy efficiency and clean energy technologies. Enacted in 2023, House Bill 23-1005 adds resiliency projects as eligible projects under the state's CPACE program. Resiliency projects include those that are designed to improve a property's indoor air quality and those that improve the property owners' ability to mitigate the effects of extreme temperatures.

Enacted in March 2023, House Bill 23-1134 will require that all home warranties sold in the state that cover appliance replacements include terms allowing homeowners to replace gas-fueled appliances with electric equivalents. In certain instances, warranty contracts may require that homeowners pay additional costs associated with replacement. Replacement appliances must meet state energy efficiency standards.

On March 30, 2023, legislators introduced House Bill 23-1272, "Tax Policy That Advances Decarbonization." As proposed, the bill would build upon the IRA by extending and creating several tax incentives. Among these, the bill would amend and create tax credits for heat pump systems and thermal energy networks; create a tax credit for owners of industrial facilities that conduct studies of or implement GHG emissions reduction improvements; and create tax credits, including a production tax credit, for in-state geothermal energy projects undertaken by individuals, businesses, or local governments.

*Federal Incentives*

States are poised to receive unprecedented federal funding for clean energy initiatives. Because this funding is so new, the studies included in this literature review do not include estimates regarding the like impacts on such things as customer adoption rates, technology costs, or bill impacts of the IIJA or the IRA. However, these federal Acts are likely to promote the adoption of the technologies discussed above, and their potential impacts should be considered during planning. For instance, the IRA provides several significant incentive programs, including rebates and tax credits for energy efficiency upgrades and the adoption of electric technologies, including the replacement of gas appliances.[269] Considerable funding is allocated specifically to support the adoption of heat pumps.[270] The IRA also allocates $4.5 billion for direct rebates to support electrification by low- and moderate-income households, $3 billion to support decarbonization efforts in environmental justice communities, $1 billion for energy efficiency ad electrification projects in affordable housing developments, and $145 million to help tribal communities transition to zero-emission energy systems.[271] The IIJA allocated $8 billion to support regional hydrogen

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[268] CEO. 2021. "GHG Pollution Reduction Roadmap." at 143.

[269] Lewis, Michelle. 2022. "Here's How the US Climate Act Will Lower Household Energy Bills." Electrek. August 8, 2022. https://electrek.co/2022/08/08/climate-act-energy-bills/

[270] Rewiring America. n.d. "What the IRA Means for Heat Pump Manufacturers." Rewiring America. https://assets.ctfassets.net/v4qx5q5o44nj/E5eXsBxtn4IyCYpKqt6nJ/f4a0d89a8bf6bff9f385d51b6f15e0a9/IRA_OEMs_Fact_Sheet.pdf; see also, CEE. 2022. "What does the Inflation Reduction Act mean for air source heat pump adoption?" November 9, 2022. Center for Energy and Environment. https://www.mncee.org/what-does-inflation-reduction-act-mean-air-source-heat-pump-adoption

[271] Rewiring America. 2022 "The Electric Explainer: Key Programs in the Inflation Reduction Act and What They Mean for Americans." Rewiring America. July 29, 2022. https://www.rewiringamerica.org/policy/inflation-reduction-act

hubs with at least two of those hubs exploring hydrogen's potential for heating and power generation end-uses.[272]

## Disproportionately Impacted Communities

Evaluating impacts on disproportionately impacted communities requires the meaningful involvement of and dialogue with these communities during planning and implementation processes. Part of this might include a study, using community input, on the specific concerns communities have related to decarbonization.[273] This study might also incorporate community suggestions on methods to address these concerns. Here we provide only a brief overview of potential impacts related to decarbonization on disproportionately impacted communities which can and should be informed through a rigorous engagement process.

As noted above, residential and small commercial customers are likely to bear most of the costs associated with operating and maintaining the gas distribution system. As customers exit gas service, costs will be divided among fewer and fewer customers, which could result in higher rates for those customers who continue to receive gas service.[274,275,276,277] Increasing costs could cause a feedback loop in which electrification and increasing gas costs lead to lower gas demand, therefore encouraging additional gas customers to exit, which leads to even fewer customers to share system costs, again increasing energy burden for remaining customers, which could push still more customers to leave the system. This feedback loop is ultimately most detrimental to those least able to leave the gas system or adopt electric appliances to mitigate against cost increases, specifically renters or low-income customers (see figure 9).[278,279]

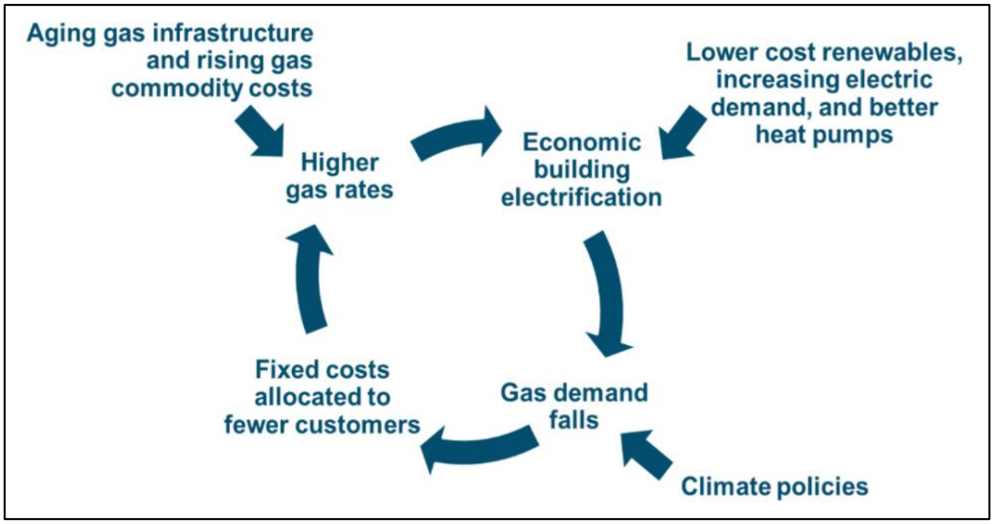

*Figure 9 – The feedback loop that could drive costs higher.*
*Source: CEC 2020*

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[272] Baldwin, et al. 2022. "Assessing the Viability of Hydrogen Proposals."
[273] Gridworks. 2019. "California's Gas System in Transition." Gridworks. 2019. https://gridworks.org/wp-content/uploads/2019/09/CA_Gas_System_in_Transition.pdf
[274] Aas, et al. 2020. "Challenge of Retail Gas in California's Low-Carbon Future."
[275] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[276] Ong, Mastrandea, and Wara. 2021. "The Cost of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers."
[277] Gridworks. 2019. "California's Gas System in Transition."
[278] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."
[279] Gridworks. 2019. "California's Gas System in Transition."

Historically disadvantaged communities have been disproportionately impacted by air and water pollutants associated with industry and the combustion of fossil fuels. While electrification is likely to lead to improvements in indoor and outdoor air quality, which will improve human health in all communities, disproportionately impacted communities should not bear the burden of a new age of infrastructure development. To ensure equity objectives are met, communities should be engaged in policy design, evaluation, and implementation and in infrastructure siting and economic development decisions that are attendant to the transition to a low emissions gas system.

To better ensure the equitable distribution of burden and benefit, programs can be developed to ensure that members of disproportionately impacted communities are "first in line" for cleaner technologies and building improvements; that outcomes are evaluated in terms of equity metrics, including, at minimum, energy burden and health impacts; and that job creation prioritizes businesses located in and members of these communities.[280,281,282, 283]

## Jobs and Workforce Impacts

As with all transitions, workers employed by the building and utilities sectors may face job conversion or loss. The rate of change is likely to vary by sector and by scenario, which will require careful consideration of workforce development priorities. For instance, scenarios under which customer adoption of heat pumps occurs rapidly have more immediate implications for the state's HVAC workforce (which may have little to no experience with the newer equipment) than for pipeline operation and maintenance jobs, which will be required for continued system upkeep and which may be key for pipeline decommissioning in the future.[284,285] In other scenarios, including rapid electrification, employees at single-fuel utilities are likely to be hardest hit, as there may not be another area of the company to which an employee can move. This creates an additional problem when an employee, who is left with no choice but to move to another company, may lose their pension, seniority, and other benefits.[286]

Opportunities for workforce development exist – the electrification workforce will be made up of many trades, and electrification can create jobs.[287] An important first step in determining jobs and workforce impacts is a workforce needs assessment, which includes input from labor and other affected parties, to determine existing capacity and current and future gaps.[288,289] Enacted in March 2023, Senate Bill 23-051 codifies Colorado's Office of Future Work in statute and expands its duties to include identifying

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[280] Massachusetts Commission on Clean Heat. 2022. "Final Report."

[281] See also: Hopkins, Asa S., Alice Napoleon, and Kenji Takahashi. 2021. "A Framework for Long-Term Gas Utility Planning in Colorado." Synapse Energy Economics, Inc. October 23, 2021. https://www.synapse-energy.com/long-term-gas-utility-planning-colorado

[282] See also: Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

[283] See also: National Grid and RMI. 2022. "Collaborating for Gas Utility Decarbonization."

[284] See: Hopkins, et al. 2021. "A Framework for Long-Term Gas Utility Planning in Colorado."

[285] Velez, Kiki. 2021. "California's Building Transition: Recommendations for Gas Transition Regulatory Proceedings at the California Public Utilities Commission." Building Decarbonization Coalition. January. https://buildingdecarb.org/wp-content/uploads/recommendations_for_gas_transition_regulatory_proceedings_at_the_cpuc.pdf

[286] Gridworks. 2019. "California's Gas System in Transition."

[287] Harwood, Meghan, Sean Newlin, Kiki Velez, and Michelle Vigen Ralston. n.d. "The Flipside Report: A White Paper on Targeted Geographic Electrification in California's Gas Transition." Building Decarbonization Coalition and Common Spark Consulting, Inc. https://buildingdecarb.org/wp-content/uploads/the_flipside_report_-_targeted_electrification_for_gas_transition.pdf

[288] Massachusetts Commission on Clean Heat. 2022. "Final Report."

[289] Drake and Partridge. 2021. "Decarbonizing Minnesota's Natural Gas End Uses."

opportunities for communities to transition to emerging industries through a variety of actions that include workforce development programs. Utilities can also adopt programs, including targeted or preferential within company transfers, training and upskilling programs, wage replacement, and early retirement benefits to protect potentially dislocated workers.[290] It might be prudent to include the costs of such programs in scenario models.

## Policy Considerations

Several bills still pending at the Colorado General Assembly as of the date of this writing (April 27, 2023), would likely impact the implementation of the Clean Heat Standard and have implications for Colorado's larger GHG emissions reduction goals (see Appendix A). Recently enacted state legislation that impacts implementation of the Clean Heat Standard has been discussed throughout this review, where appropriate.

As noted above, Colorado's Clean Heat Standard could be amended in the future. For instance, the standard could be amended to include or exclude eligible resources, or to adjust cost caps, as technological advancements occur and as the impacts of these resources on the environment and economy become better understood. The Clean Heat Standard's emissions reduction goals and timeline could also be adjusted. Potential policy change is worth considering throughout any planning or modeling that may occur.

Colorado should examine how federal funding can be leveraged to support the attainment of emissions reduction goals. Also discussed above, the IIJA and the IRA include several programs, including incentive programs, relevant to planning under the Clean Heat Standard. These programs could also be amended in the future to increase or decrease incentive amounts, or add or remove eligible technologies or industries, among other things. Again, potential policy change is worth considering, perhaps necessitating the inclusion of both best case and conservative estimates of such things as resource costs and availability and customer adoption rates.

## Conclusion

There are multiple options available for meeting Colorado's Clean Heat Standard. Our review suggests several important considerations for modeling these options.

Increased demand should be expected under any scenario. This may require significant and rapid deployment of clean energy and storage technologies to meet emissions targets. Models should account for these costs. In addition, because emissions reductions from customer-side measures will be key to meeting emissions targets, estimating likely customer adoption rates is important.[291] Generally, studies find that meeting net-zero targets will require the use of negative emissions tools like carbon capture and sequestration, DAC, and emissions offsets. The availability and costs of negative emissions technologies and carbon offsets will impact gas utility portfolios. Consideration of how and to what extent different

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[290] Velez, Kiki. 2021. "California's Building Transition."

[291] NREL is currently researching customer adoption rates (among other things). Updates on this work is available here: https://www.nrel.gov/buildings/end-use-load-profiles.html

negative emissions technologies will and can be used will be an important factor in scenario development and analysis.

Most building decarbonization modeling did not include seasonal fluctuations in energy use. Modeling that accounts for seasonal fluctuations and different climate areas of Colorado will be particularly important. Additional analysis is also needed as it relates to the differences between utility service areas and different types of construction in both new and existing buildings.

Studies agree that resource flexibility will be key to meeting emissions reductions goals while maintaining reliability and resiliency. Flexibility among scenarios may also be an important consideration. The Steering Committee might consider how scenarios can be developed to allow flexibility to move from one option to another if it becomes necessary. One study suggests that this might be accomplished by developing scenarios that share "complementary and overlapping strategies."

Technology and energy costs will play an important role in scenario building, particularly if least-cost pathways are being sought.[292] The costs associated with different scenarios are highly uncertain and are subject to several factors. These include technological improvement, access to feedstocks, supply chain issues, materials costs, customer adoption rates, infrastructure expansion and maintenance requirements, state and federal energy policies, including availability of state or federal funding and incentives, and more. The number of factors impacting costs and the potential for policy change is worth considering, perhaps necessitating the inclusion of best case and conservative estimates of costs, availability, and customer adoption rates.

Considering how transitions under different scenarios might impact low-income, at-risk, or historically disadvantaged communities can allow for the development of strategies to mitigate potential harms. Evaluating likely impacts will require meaningful engagement and dialogue with these communities. As with all transitions, workers employed by the building and utilities sectors may face job conversion or loss. The rate of change is likely to vary by sector and by scenario, which will require careful consideration of workforce development.

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[292] In November 2022, the Colorado PUC adopted rules to implement the Clean Heat Standard. In its decision, the Commission outlined six quantitative factors the PUC will consider when evaluating "lowest reasonable cost," including: "(1) fuel costs; (2) non-fuel direct investment associated with the clean heat plans; (3) gas infrastructure costs; (4) gas system operations costs; (5) a cost test that includes both the social cost of carbon and the social cost of methane; and (6) any other costs and benefits, as determined by the Commission" (CPUC Decision C22-0760 at 144).

## Appendix A – Legislation Pending before the Colorado General Assembly as of 4/27/2023

| Bill Number | Summary |
|---|---|
| HB 23-1074 | Requires the development of a workforce transitions study for Colorado that would explore skill transferability and training opportunities and offer policy recommendations to support workers in industries facing disruption, including the state's oil and gas industry. |
| HB 23-1161 | Updates appliance efficiency requirements for several technologies including commercial ovens, gas fireplaces, and residential windows and doors. The bill would also establish emissions standards for water and space heating appliances and direct the AQCC to set lower emissions standards by January 1, 2029. |
| HB 23-1210 | Adds certain carbon management projects as eligible projects under Colorado's Industrial and Manufacturing Operations Clean Air Grant Program. The bill defines carbon management as "any combination of" carbon removal, capture, storage, and utilization, but excludes agricultural, forestry, and enhanced oil and gas recovery projects. |
| HB 23-1216 | Directs the PUC to adopt new rules regarding positioning, inspection requirements, and maintenance liability and disclosure for gas meters and service lines and regulators by March 1, 2024.[293] |
| HB 23-1246 | Directs the State Board of Community Colleges and Occupational Education to administer an "in-demand short-term credentials program" which would provide financial assistance for eligible expenses for students enrolled in eligible programs, which include construction. The bill also requires the Office of Future Work to provide grants to registered apprenticeship programs that provide training in the buildings and construction fields. |
| HB 23-1252 | Would allow the CEO to award grants for retrofits to existing buildings to install geothermal systems. Under existing law, only new construction is eligible for the single-structure geothermal grant. The bill would also add thermal energy as an eligible resource under the Clean Heat Standard, authorize regulated gas utilities to seek PUC review of and approval for the use of thermal energy networks, and require that regulated gas utilities serving more than 500,000 customers in the state propose at least one thermal energy pilot program, consisting of one or more projects, for PUC review and approval by September 1, 2026. At least one project, under the proposed bill, must serve residential customers in a disproportionately impacted community, a mountain community served by the utility, or in a service area that the PUC has determined to be capacity constrained. |
| HB 23-1272 | Seeks to build upon the IRA by extending and creating several tax incentives. Among these:<br>• amends and creates tax credits for heat pump systems and thermal energy networks;<br>• creates a tax credit for owners of industrial facilities that conduct studies of or implement GHG emissions reduction improvements; and<br>• creates tax credits, including a production tax credit, for in-state geothermal energy projects undertaken by individuals, businesses, or local governments. |

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[293] Bishop, Matt. 2023. "Fiscal Note: HB23-1216." Colorado Legislative Council. March 14, 2023. https://leg.colorado.gov/sites/default/files/documents/2023A/bills/fn/2023a_hb1216_00.pdf

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| HB 23-1281 | Directs the PUC to develop a process for the review and approval of IOU owned clean hydrogen projects undertaken in collaboration with a state or federal agency. The bill would also allow IOUs to create a clean hydrogen tariff program and would create a tax credit for clean hydrogen use. |
| SB 23-016 | Makes several changes related to Colorado's energy policy. Among these:<br>• amends the powers and duties of the CEO to require that the Office "make progress toward eliminating [GHG] pollution from electricity generation, gas utilities, and transportation"; "support the implementation" of clean heat plans and beneficial electrification and support the deployment of such resources as energy efficiency and energy load management, clean hydrogen, geothermal energy, recovered methane, recovered heat, and other innovative technologies;<br>• includes wastewater thermal heat resources as eligible resources under the Clean Heat Standard;<br>• requires the AQCC to establish a fee per ton on GHG emissions;<br>• updates the state's GHG emissions reduction goals;<br>• authorizes, under certain conditions, Colorado Oil and Gas Conservation Commission (COGCC) regulation of Class VI injection wells for GHG sequestration;<br>• prohibits HOAs from disallowing heat pump systems; and<br>• adds recovered methane projects at livestock operations to the definitions of biomethane and recovered methane protocol under the Clean Heat Standard. |
| SB 23-285 | Would change the name of the COGCC to the Energy and Carbon Management Commission and expand the regulatory scope of the commission to include emerging technologies including deep geothermal resources and underground gas storage.[294] The bill also addresses property rights associated with geothermal resources and would direct the commission to study and issue reports on geothermal resources and regulation, hydrogen regulation and permitting, and pipeline siting and permitting. |
| SB 23-291 | Makes several changes to electric and gas utility regulation in Colorado. Among these:<br>• require that investor-owned gas utilities file a gas price risk management plan for PUC review, approval, amendment, or denial;<br>• require the PUC to adopt rules by January 1, 2025 that protect investor-owned gas utility customers from volatility in gas prices;<br>• require the PUC to open an investigatory docket into the extent to which development drives natural gas infrastructure costs for gas utilities serving more than 500,000 customers in the state;<br>• require each regulated gas utility, by December 31, 2023, to remove incentives for gas distribution extension lines;<br>• require the CEO to study the risks associated with stranded natural gas infrastructure and require the PUC to determine if any rule changes are warranted by the results of this study;<br>• prohibit penalties or fees for customers that voluntarily terminate gas service; and<br>• direct the PUC, by July 1, 2024, to determine if existing investor-owned electric utility tariffs, policies, and practices are barriers to beneficial electrification. |

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[294] Reynolds, Erin and Matt Bishop. 2023. "Fiscal Note: SB23-285." Colorado Legislative Council. April 21, 2023. https://leg.colorado.gov/sites/default/files/documents/2023A/bills/fn/2023a_sb285_r1.pdf